Clinical Neurophysiology 127 (2016) 1618–1628

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Oscillatory decoupling differentiates auditory encoding deficits in children with listening problems

Phillip M. Gilley [a,b,*], Mridula Sharma [c,d], Suzanne C. Purdy [e]

[a] The Neurodynamics Laboratory, The Institute of Cognitive Science, University of Colorado, Boulder, CO, USA
[b] The Marion Downs Center, Denver, CO, USA
[c] Audiology Section, Department of Linguistics, Macquarie University, Sydney, Australia
[d] Hearing Co-operative Research Center, Australia
[e] Discipline of Speech Science, School of Psychology, The University of Auckland, Auckland, New Zealand

ARTICLE INFO

Article history:
Accepted 10 November 2015
Available online 1 December 2015

Keywords:
Auditory processing
Auditory processing disorder
Auditory evoked potential
Child development
Neural oscillations
Oscillatory coupling

HIGHLIGHTS

- Oscillatory responses in the *theta*, *alpha*, *beta*, and *gamma* bands were suppressed when listening in background noise.
- Modulatory frequency shifts in the *theta* and *alpha* bands were different in children with listening problems.
- In addition, frequency shifts in the *beta* and *gamma* bands were different in children with listening problems and auditory processing disorders.

ABSTRACT

Objective: We sought to examine whether oscillatory EEG responses to a speech stimulus in both quiet and noise were different in children with listening problems than in children with normal hearing.
Methods: We employed a high-resolution spectral–temporal analysis of the cortical auditory evoked potential in response to a 150 ms speech sound /da/ in quiet and 3 dB SNR in 21 typically developing children (mean age = 10.7 years, standard deviation = 1.7) and 44 children with reported listening problems (LP) with absence of hearing loss (mean age = 10.3 years, standard deviation = 1.6). Children with LP were assessed for auditory processing disorder (APD) by which 24 children had APD, and 20 children did not. Peak latencies, magnitudes, and frequencies were compared between these groups.
Results: Children with LP had frequency shifts in the *theta*, and *alpha* bands ($p < 0.05$), and children with LP + APD had additional frequency ($p < 0.01$) and latency shifts ($p < 0.05$) in the upper *beta* and in the lower *gamma* bands.
Conclusions: These results provide evidence for differences in higher level modulatory processing in children with LP, and that APD is driven by differences in early auditory encoding.
Significance: These findings may better guide future research toward improving the differential diagnosis and treatment of listening problems in this population of children.
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1. Introduction

Neural oscillations underlie the dynamical interactions of multiple brain regions forming a functional network, and likely reflect a variety of mechanisms necessary for perception and action (Buzsáki and Draguhn, 2004; Giraud and Poeppel, 2012). The cortical auditory evoked potential (CAEP) is a powerful tool for examining interactions in the central auditory system as the characteristics of the CAEP waveforms are well defined (Picton et al., 1974). When processing an auditory sequence, neural oscillations are generated by the synchronous and rhythmic activity of neuronal populations engaged for auditory processing, giving rise to components of the CAEP. In this way, each oscillatory component reflects the properties of neural populations contributing to specific auditory encoding mechanisms. For example, higher frequency oscillations in the gamma (30–80 Hz) and beta (12–30 Hz) range

* Corresponding author at: The Marion Downs Center, 4280 Hale Parkway, Denver, CO 80220, USA.
E-mail address: gilley@colorado.edu (P.M. Gilley).

http://dx.doi.org/10.1016/j.clinph.2015.11.003
1388-2457/Published by Elsevier Ireland Ltd. on behalf of International Federation of Clinical Neurophysiology.

may reflect processes such as stimulus detection, feature selection, and temporal gating. Lower frequency oscillations in the alpha (8–12 Hz), and theta (4–8 Hz) range may reflect higher-order processes such as attention, stimulus tracking, and stimulus entrainment.

The time course of peak activity in each of these frequency bands also supports a spectral–temporal hierarchy such that higher frequency activity reflects early processing, and lower frequency activity reflects later higher-level modulatory processing (Lakatos et al., 2005; Kiebel et al., 2008). For instance, gamma activity from auditory cortex reflects early feature selection (Mesgarani and Chang, 2012) and is modulated by attention (Gilley and Sharma, 2010), suggesting an early selection process. Beta oscillations may reflect the sensory gating of temporal sequences as reflected by changes in power when processing repeated stimuli. Low beta generators (12–20 Hz) mediate the strength of sensory gating to stimulus pairs (Hong and Buchanan, 2008), and are sensitive to changes in the inter-stimulus interval between successive stimuli (Kisley and Cornwell, 2006). These beta modulations occur in the same time range (~25–150 ms) as changes in peak amplitudes and latencies of CAEP components to rapidly changing inter-stimulus intervals (Gilley et al., 2005), supporting sensory gating as an underlying mechanism. Other studies have shown changes in gamma and beta band power when stimuli are embedded in background noise (Kawase et al., 2012; Schepers et al., 2013), which may reflect the effects of noise on selective attention mechanisms driven by lower frequency components. For example, alpha activity may reflect the resource allocation for attention and memory retrieval (Senkowski et al., 2008; Gilley and Sharma, 2010; Klimesch, 2012), which in turn modulates the selectivity of early encoding mechanisms. There is also evidence that low frequency theta and delta oscillations reflect the tracking and entrainment of temporal sequences (Lakatos et al., 2005), such as those necessary for parsing connected speech (Giraud and Poeppel, 2012). Taken together, activity from each of these frequency bands reflects contributions from multiple underlying neural generators forming a functional network for auditory processing, and the characteristics of these generators can be exploited to better understand deficits in auditory processing.

Children with reported listening problems in absence of a hearing loss (LP) often perform poorly on tests of auditory processing skills such as listening in noise (Cameron and Dillon, 2007; Dhamani et al., 2013) and processing spectral and/or temporal sequences (McArthur and Bishop, 2001; Sharma et al., 2009). It is often difficult to determine whether poor auditory performance reflects an auditory processing disorder (APD) or some other impairment that affects auditory encoding (Cacace and McFarland, 2005). For example, up to 65% of children with APD may have coincident language and reading impairments (Sharma et al., 2009) and up to 50% may have coincident attention deficit disorders (Riccio et al., 1994), which complicates the differentiation of auditory specific deficits. A key issue is whether auditory deficits are the result of an impoverished signal from impaired encoding mechanisms (e.g., low-level feature encoding), or whether poor performance on psychoacoustic tasks reflects deficits in higher-order modulatory mechanisms (e.g., allocation of attention resources).

Given that the oscillatory frequencies of the underlying CAEP responses may reflect different levels of auditory processing, we examined whether changes in these frequency bands could provide information about auditory processing in children with LP and/or APD. To this end, a series of time–frequency transforms (continuous wavelet transform, CWT) were applied to the scalp recorded EEG data typically used when computing the CAEP. The results of these transforms reveal an event related spectral perturbation (ERSP), which reflects relative changes in oscillatory frequency over time. We hypothesized that children with LP and APD would have lower gamma magnitudes when listening in noise, which would reflect energetic masking in the early stages of auditory processing. Further, we hypothesized that children with LP would demonstrate higher alpha magnitudes, which would suggest differences in allocation of attention resources for auditory processing. To better understand how these different components contribute to auditory processing differences, we also performed a statistical clustering of the ERSP peak data in order to identify those variables that best explain the differences between these groups of children and to help guide future research.

2. Methods

2.1. Participants

Sixty-five children aged 7–12 years participated in the study. Twenty-one children (11 females) participating in the study with no concerns were referred to as normal hearing controls (NHC, mean age 10.4 years; s.d. 1.6) and were recruited by advertisements and word-of-mouth. Forty-four children with reported listening problems (LP) also participated in the study (mean age 10.3 years; s.d. 1.6). LP group participated in the study from a number of different referrals such as Audiology and Speech Pathology clinics, teachers and itinerant teachers. Sample sizes were restricted by available clinical cases of LP children, and by availability of age-matched controls. All children were studying in English medium schools and were recruited from near and around Auckland, New Zealand. No ethnicity and cultural information was collected. All children were tested on ASHA recommended auditory processing test battery and CAEPs, and gave written (parent/guardian) and verbal consent. This research was approved by the University of Auckland Human Participants Ethics Committee.

2.2. Procedure

Peripheral hearing was tested using pure tone, speech, and immittance audiometry, and transient click-evoked otoacoustic emissions (OAE). All participants had pure tone thresholds of 15 dB HL or better at octave frequencies from 250 to 8000 Hz, Type A tympanograms (Jerger, 1970), ipsilateral 1000-Hz acoustic reflex thresholds less than 100 dB HL (Silman and Gelfand, 1981), left and right ear CVC phoneme scores of 90% or better for speech presented in quiet (Boothroyd and Nittrouer, 1988), and OAE strength within the normal range based on the pass/refer criteria in the TEOAE protocols of the Scout Sport System (Bio-logic Systems Corp®). If all measures of peripheral hearing were normal, participants proceeded to the tests for reading accuracy, test for nonverbal intelligence and auditory processing test battery. All participating children had nonverbal intelligence score of 80 or higher on the Test of Nonverbal Intelligence (TONI-3). The tasks' procedural details are described briefly in Table 1 and in another publication (Sharma et al., 2009).

2.3. Auditory processing assessment

The auditory processing assessment was comprised of the Frequency Pattern Test (FPT), Dichotic Digits Test (DDT), Random Gap Detection Test (RGDT), Masking Level Difference (MLD), and compressed and reverberant speech scores. All children in the NHC group performed within the expected age appropriate norms (Kelly, 2007). Based on the auditory processing assessment, children with listening problems were then separated into two groups. If the performance on any auditory processing test was two