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Reduced sensory oscillatory activity during rapid auditory processing as a correlate of language-learning impairment

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A B S T R A C T

Successful language acquisition has been hypothesized to involve the ability to integrate rapidly presented, brief acoustic cues in sensory cortex. A body of work has suggested that this ability is compromised in language-learning impairment (LLI). The present research aimed to examine sensory integration during rapid auditory processing by means of electrophysiological measures of oscillatory brain activity using data from a larger longitudinal study. Twenty-nine children with LLI and control participants with typical language development ($n = 18$) listened to tone doublets presented at a temporal interval that is essential for accurate speech processing (70-ms interstimulus interval). The children performed a deviant (pitch change of second tone) detection task, or listened passively. The electroencephalogram was recorded from 64 electrodes. Data were source-projected to the auditory cortices and submitted to wavelet analysis, resulting in time-frequency representations of electrocortical activity. Results show significantly reduced amplitude and phase-locking of early (45–75 ms) oscillations in the gamma-band range (29–52 Hz), specifically in the LLI group, for the second stimulus of the tone doublet. This suggests altered temporal organization of sensory oscillatory activity in LLI when processing rapid sequences.

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1. Introduction

The auditory analysis of spoken language is an important aspect of language comprehension and communication. Research investigating the spatiotemporal properties of speech highlights the fact that crucial linguistic information within the auditory signal is coded by brief, rapid and successive spectrotemporal events, emerging as a result of consonantal articulation, in particular stop consonants. For instance, critical information for differentiating the stop consonant syllables [ba] and [pa] is conveyed by the voice onset time (VOT), which denotes the brief gap between the release burst by the articulators and the onset of laryngeal pulsing, or voicing: VOT for [ba] is shorter than for [pa], in American English about less than 25 ms, as compared to greater than 40 ms, respectively. Acoustic cues essential for the perception of other stop consonant-contrasts (e.g., [ba] versus [da]) are present in the trajectory of rapid frequency changes that precede the onset of the stationary spectral pattern characterizing the vowel. Such formant transitions typically occur within 40 ms (Borden & Harris, 1980; Kewley-Port, 1982; Phillips, 1999). As a consequence, some authors have argued that auditory processing of language requires exquisite temporal resolution, at high spectral accuracy over extended time periods (e.g., Hickok & Poeppel, 2007; Johnson, Nicol, Zecker, & Kraus, 2007; Telkemeyer et al., 2009; Zatorre, Belin, & Penhune, 2002). In particular, fast changes in the amplitude and frequency composition related to speech require rapid analysis on the level of bottom-up (sensory) processing, and then need to be identified and isolated from competing simultaneous sounds (e.g., environmental noise). This complex task is achieved in the healthy human auditory cortex with ease and in a seemingly effortless fashion. In this special issue on the neurocognitive precursors of difficulties in reading and arithmetic, we examine the electrophysiological correlates of such rapid sensory processing in children with and without language impairments. Specifically, the current report is concerned with sensory cortical oscillations evoked by fast-rate auditory events.

1.1. Rapid auditory processing

A well-known theoretical account that emphasizes the potential role of auditory temporal sensitivity in language development was initially proposed in Tallal and Piercy (1973a). Because the present research focuses on the sensory dynamics during auditory processing, this framework is presented below in some detail. It is important to note however that many other cognitive and physiological mechanisms affect language processing and thus have been shown to be involved in atypical language development (for reviews see Heim & Keil, 2004; Leonard, 1998; Peterson, McGrath, Smith, & Pennington, 2007). Here, we refer to the integration of two or more brief, successive acoustic cues that are rapidly presented to the central nervous system as rapid auditory processing (RAP). It was in the seventies of the last century, when Tallal and Piercy (1973a, 1973b, 1974, 1975) considered whether deficient RAP skills might constitute a basic impairment in developmental language disorders. The authors studied 6 to 9 year-old children diagnosed with specific language impairment (SLI), a condition characterized by a significant limitation in receptive and/or expressive language skills in the context of otherwise typical cognitive development. Even though the SLI children had normal hearing and sequencing abilities, difficulties arose specifically in those tasks that required discriminating and sequencing two rapidly occurring tones (within a temporal gap of less than 150 ms) or single tones having a short duration (75 or 125 ms). In contrast, age-mates with typical language development performed at above-chance levels, when two successive 75-ms tones were presented with a gap as brief as 8 ms (Tallal & Piercy, 1973a, 1973b). The auditory rate deficit in the “tens of milliseconds range” (Tallal, Miller, & Fitch, 1993) led the authors to focus on the phoneme level of speech given that specific acoustic cues occur within this time frame (see above). As expected, SLI children had problems differentiating the stop consonant–vowel syllables [ba] and [da], having formant transition durations of 43 ms. They succeeded, however, when this time period was artificially lengthened to 95 ms, stretched beyond the natural speed of speech (Tallal & Piercy, 1974, 1975).

Subsequent replication of the results across laboratories, tasks, and stimulus variations strengthened the hypothesis of a fundamental RAP dysfunction in SLI (for reviews and contradictory findings, see Heim & Benasich, 2006; Rosen, 2003; Tallal & Gaab, 2006). Tallal (2004) proposed that during sensitive periods of development, slower spectrotemporal processing in the auditory cortex may