Journal of Neurolinguistics 38 (2016) 14–25

Contents lists available at ScienceDirect

Journal of Neurolinguistics

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

Research paper

Electrophysiological auditory response to acoustically modified syllables in preterm and full-term infants

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A R T I C L E I N F O

Article history:
Received 15 April 2015
Received in revised form 22 October 2015
Accepted 23 October 2015
Available online 9 November 2015

Keywords:
Preterm infants
Language acquisition
Auditory habituation
Acoustically modified syllable
Time–frequency analysis

A B S T R A C T

This study explored the effect of extending the duration of the syllable formant transition on auditory habituation in full-term and preterm infants at 12 months, as measured by decreases in amplitude for syllable repetition using EEG time–frequency analyses. EEG recordings for four repetitions of the syllable (/ta/) under two different conditions (non-modified and modified) were collected for one group of 13 full-term and two groups of preterm infants differing in language production performance; 15 infants had high scores (HS), and 14 had low scores (LS). Full-term and HS preterm infants showed significant decreases in amplitude for syllable repetition in both conditions. LS preterm infants showed a decrease only in the modified syllable condition, suggesting a facilitation effect of modified syllables in the LS preterm group.

1. Introduction

Preterm infants have a higher risk of developing cognitive disorders than healthy, full-term infants (e.g., Ortiz-Mantilla, Choudhury, Leevers, & Benasich, 2008), and these cognitive disorders often manifest as language development problems (Kurtzberg, Hilpert, Kreuzer, & Vaughan, 1984; Sansavini et al., 2011). Studies using indirect measures of processing speed, such as paired comparison and habituation, show that preterm infants process visual (e.g., Rose, Feldman, Jankowski, & Caro, 2002) and auditory information (e.g., Peña, Pittaluga, & Farkas, 2010; Ramon-Casas, Bosch, Iriondo, & Krauel, 2013) more slowly than full-term infants.

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http://dx.doi.org/10.1016/j.jneuroling.2015.10.002
0911-6044/

Harmony et al. (2009) suggested impaired auditory cortical processing in infants at risk for cerebral damage with normal hearing. These authors found differences in oscillatory brain activity during the processing of linguistic (syllables) and non-linguistic stimuli (tones) between full term and at-risk infants at 6 weeks of age. A further study conducted by Avecilla-Ramírez et al. (2011) suggested that altered cortical sound processing in at-risk infants is related to impaired language acquisition in subsequent child development.

In particular, Avecilla-Ramírez et al. (2011) showed that the time–frequency EEG measures of 6-week-old infants during the processing of repeated syllables and tones could discriminate between infants with different risk levels for language development who later, at 14 months of age, scored high or low on a standard language inventory. The researchers suggested that an alteration in the low scoring infants' sensory memory could affect the habituation effect.

The habituation process has been studied as an indirect measure of processing speed. In fact, a significant relationship has been found between habituation, auditory temporal processing, and recognition memory, suggesting that these measures of information processing are based on a similar mechanism: processing speed (Benasich & Tallal, 1996). In particular, the researchers found that 6-month-old full-term infants who could process rapidly (lower auditory temporal processing thresholds) also habituated more efficiently (fewer trials to reach habituation and steeper habituation slopes) and discriminated better (higher scores for novel image recognition memory).

Processing speed plays an important role in speech temporal perception for phoneme representation (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Pisoni, 1973). The auditory signal unfolds over time; therefore, the process of decoding input sounds to link them to meaningful objects requires integrating sensory information over time at multiple scales (Poeppel, 2003). In speech perception, this temporal integration must occur in at least two distinct time scales that are related to syllable-level (approximately 200 ms or 5 Hz) or phonemic level (approximately 25 ms or 40 Hz) information (Doelling, Arnal, Ghitza, & Poeppel, 2014). This multi-time resolution analysis and integration could be performed in the auditory cortex using neuronal oscillations to parse the stimulus into meaningful chunks that are appropriate for subsequent decoding, enhancing perception and intelligibility (Doelling et al., 2014; Ghitza, 2011). Similar results have been shown in studies of the oscillatory brain activity in healthy full-term infants.

Ortiz-Mantilla, Hämäläinen, Musacchia, and Benasich (2013) reported amplitude increases at 4–6 Hz (theta) and phase synchronization at 2–4 Hz (delta/theta) in 6-month-old full-term infants during syllable processing. Bosseler et al. (2013) also showed amplitude increases over baseline in theta in 6-month- and 12-month-old full-term infants. Zhang et al. (2011) investigated neural coding of formant-exaggerated speech in 6–12-month-old full-term infants and reported increases in the EEG amplitude in delta, at the frontal-central-parietal electrode, and in the theta band, at the frontal-central electrode, in response to vowels pronounced using formant-exaggerated speech, which is known as motherese, compared to speech addressed to adults.

Limitations in decoding temporal cues to discriminate phonemes can be detected in infants (Trehub & Henderson, 1996); they are predictive of later language difficulties (Benasich & Tallal, 2002; Choudhury & Benasich, 2011) and are associated with poor language learning at school age (Merzenich, Jenkins, Jonson, Schreiner, Mille, Tallal, et al., 1996; Tallal, Miller, Bedi, Byma, Wang, Nagarajan, et al., 1996). One approach for ameliorating such impairment in school-aged children is to use acoustically modified syllables to lengthen the transition and enhance the contrast between phonemes, implementing a digital signal processing algorithm to modify the fast amplitude envelope modulations of the speech signal (Nagarajan, Wang, Merzenich, Shreiner, Johnston, Jenkins, et al., 1998).

The amplitude envelope of the speech signal provides information about syllables (syllabic rhythm) or serves as the basis for entrainment between speakers and listeners (Giraud & Poeppel, 2012). One hypothesis is that the delta–theta brain oscillations are realigned with the critical bands of the envelope of the speech signal, which is the crucial property that carries the temporal and syllabic information about the signal (Doelling et al., 2014).

The use of modified speech as a therapeutic treatment to improve the discrimination of phonemes in school-aged children with limited processing speed has generated a vigorous debate in the academic community. Some studies supporting the procedure are the work of Heim, Friedman, Keil, and Benasich (2010) and Choudhury and Benasich (2011). Among those studies with contrasting results are Studdert-Kennedy and Mody (1995) and Strong, Torgerson, Torgerson, and Hulme (2011).

As preterm birth is a risk for impaired cognitive development and preterm infants often perform poorly in tasks thought to depend on processing speed (e.g., Escobar, Littenberg, & Petitti, 1991), modified speech that prolongs the duration of the syllable formant transition could facilitate speech processing in preterm infants at risk for language development problems.

The purpose of this study is to examine whether exposure to acoustically modified syllables that prolong the duration of the syllable formant transition facilitates perceptual processing of syllables in preterm infants. The facilitation effect was measured by examining auditory habituation through the time–frequency analysis of the EEG recordings during the processing of repeated syllables from three groups of 12-month-old-infants: full term, preterm with high language production scores and preterm with low language production scores. For preterm infants, the corrected age was considered. The auditory habituation task is particularly suitable for our purpose because it is a measure that is present from the first months of life (González-Frankerberger et al., 2008; Ramon-Casas et al. 2013; Rose et al., 2002) and is an indirect measure of processing speed. We hypothesized that the extension of the syllable formant transitions would facilitate auditory habituation in preterm infants who are at risk for language development problems.