Power and phase synchronization underlie a left processing advantage in 7-month-old infants with active auditory experience

Silvia Ortiz-Mantilla[1], Teresa Realpe-Bonilla[1], Cynthia Roesler[1], Naseem Choudhury[1,2], April A. Benasich[1]

[1]Center for Molecular & Behavioral Neuroscience, Rutgers University, Newark, NJ, USA, [2]Ramapo College of New Jersey, Mahwah, NJ, USA

Introduction

During the first months of life infants construct language specific maps within the auditory cortex. Interactive acoustic experience using temporally modulated non-speech stimuli has been shown to impact the efficiency of infants' acoustic processing. Significant effects of acoustic experience were documented for the accuracy and speed of discrimination of key pre-linguistic acoustic cues; this effect generalized to enhanced processing of novel non-speech stimuli (Benasich et al., 2014). However, analogous effects of such acoustic experience and the role of the underlying oscillatory mechanisms have not been examined within the speech domain.

In adults, oscillatory activity in the theta range is hypothesized to resolve syllabic information, whereas gamma activity may assist in resolving segmental information (Poeppel et al., 2008). In infants, low frequency theta oscillations support syllable (Ortiz-Mantilla et al., 2013) and tone processing (Musacchia et al., 2013) and a burst in gamma power signals preference for native prosody (Peña et al., 2010) and native phonemes (Ortiz-Mantilla et al., 2013).

In this study we explore neural mechanisms (i.e. changes in the pattern and the topography of oscillatory activity) that appear to underlie generalization effects seen during syllable processing in 7-month infants who had passive or active non-speech acoustic experience as compared to naïve controls with no such experience.

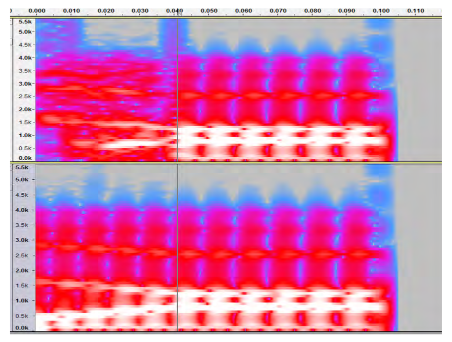
Methods

Participants: 49 7-month-old infants
- Active experience group (AEx): 18 (8 females)
- Passive experience group (PEx): 17 (8 females)
- Naïve control group (NC): 14 (7 females)

Interactive Acoustic Experience:
Once a week for 6 weeks, infants between 4 and 7 months were exposed to paired complex tones, band-pass noise and simple sweeps.
- AEx: Go/no-go operant conditioning protocol
- PEx: Passive experience protocol

ERP: Computer generated CV syllables with a VOT contrast followed by a 60 ms steady-state vowel were presented in a passive oddball paradigm. Total: 566 standards /100 deviants. dEEG/ERP was recorded with 128-channel EGI net.

- Deviant (DEV): /ta/ (VOT = 40 ms)
- Standard (STD): /da/ (VOT = 0 ms)



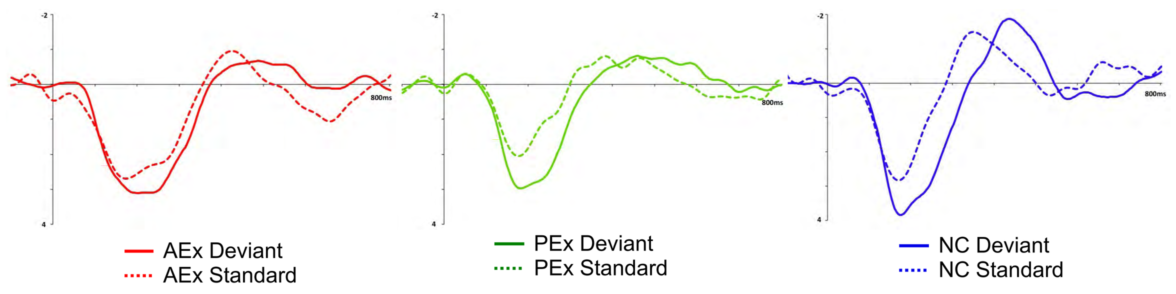
Source Localization: ERP generators were located using age-appropriate infant templates (Ortiz-Mantilla et al., 2012).

Single-trial Temporal-Spectral Analysis: Conducted in source space with a 2-dipole montage using a complex demodulation method in the 2-90 Hz frequency range, over -300 to 1020 ms, with 1 Hz wide frequency bins and time resolution of 50 ms.

Results

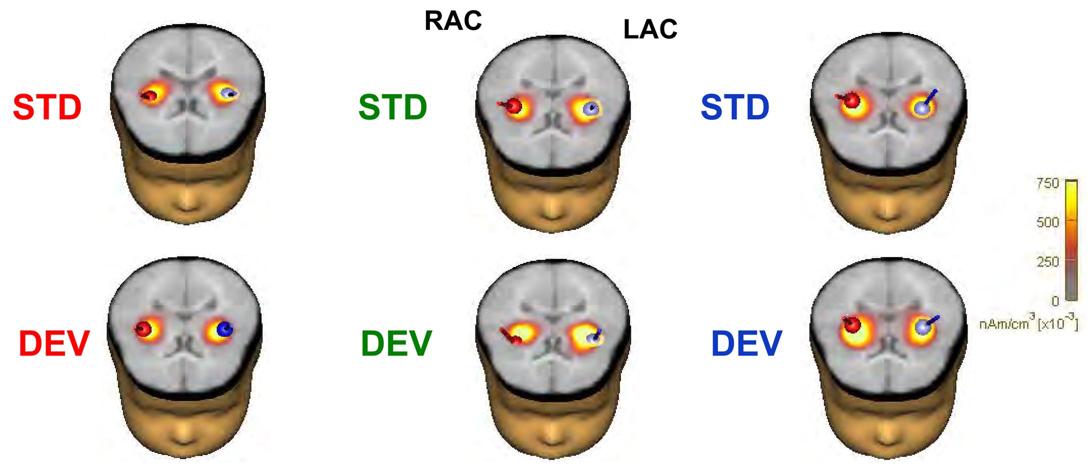
Event-related potentials: Grand average ERPs

Frontal midline (Fz) channel

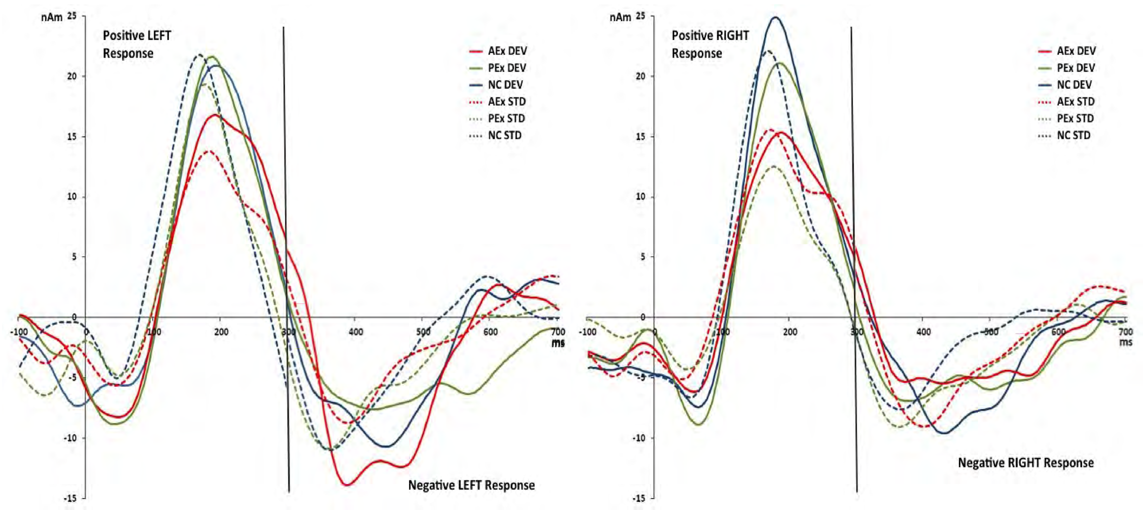


Results

Source Localization of ERP Generators



Converging location of ERP generators, shown by distributed CLARA and discrete dipole solutions, for standard **(STD)** and deviant **(DEV)** for **AEx**, **PEx** and **NC** group responses at left (LAC) and right (RAC) auditory cortices explaining ~97% of the ERP variance at 7-months.



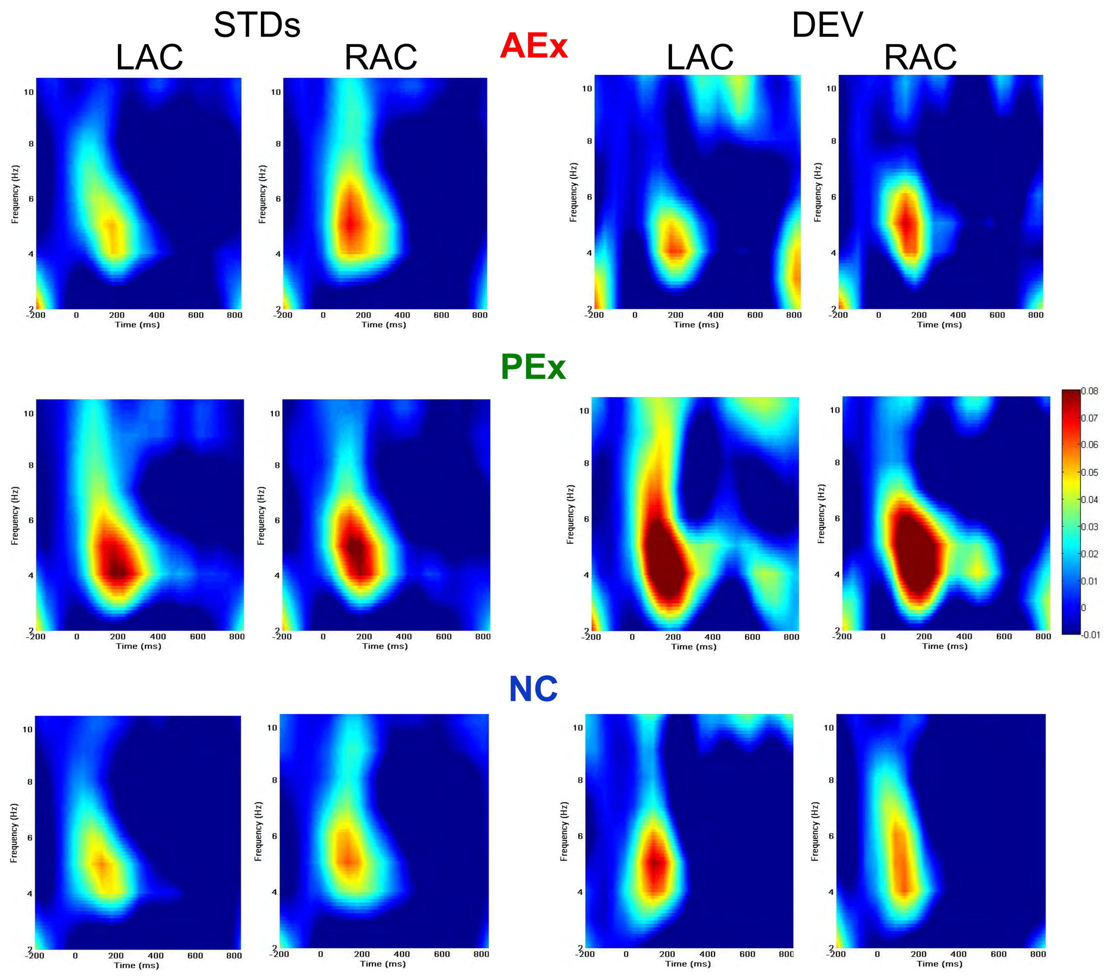
Amplitude of Positive Response: 2 X 2 X 3 (source [LAC, RAC] X stimulus [STD, DEV] X group [AEx, PEx, NC]) ANOVA showed: Significant 3-way interaction ($F_{(2,43)}$ = 3.61, *p* = .036):

- In the **AEx** group, the DEV is larger in the LAC than the RAC as compared to the NC and PEx groups
- In the **NC** group, the DEV is larger in the RAC than the LAC as compared to the PEx and AEx groups
- In the **PEx** group, the DEV is larger than the STD in the RAC as compared to the NC and AEx groups

Temporal Spectral Evolution (TSE)

Measures changes in amplitude of frequency bands as a function of time relative to stimulus presentation

TSE THETA

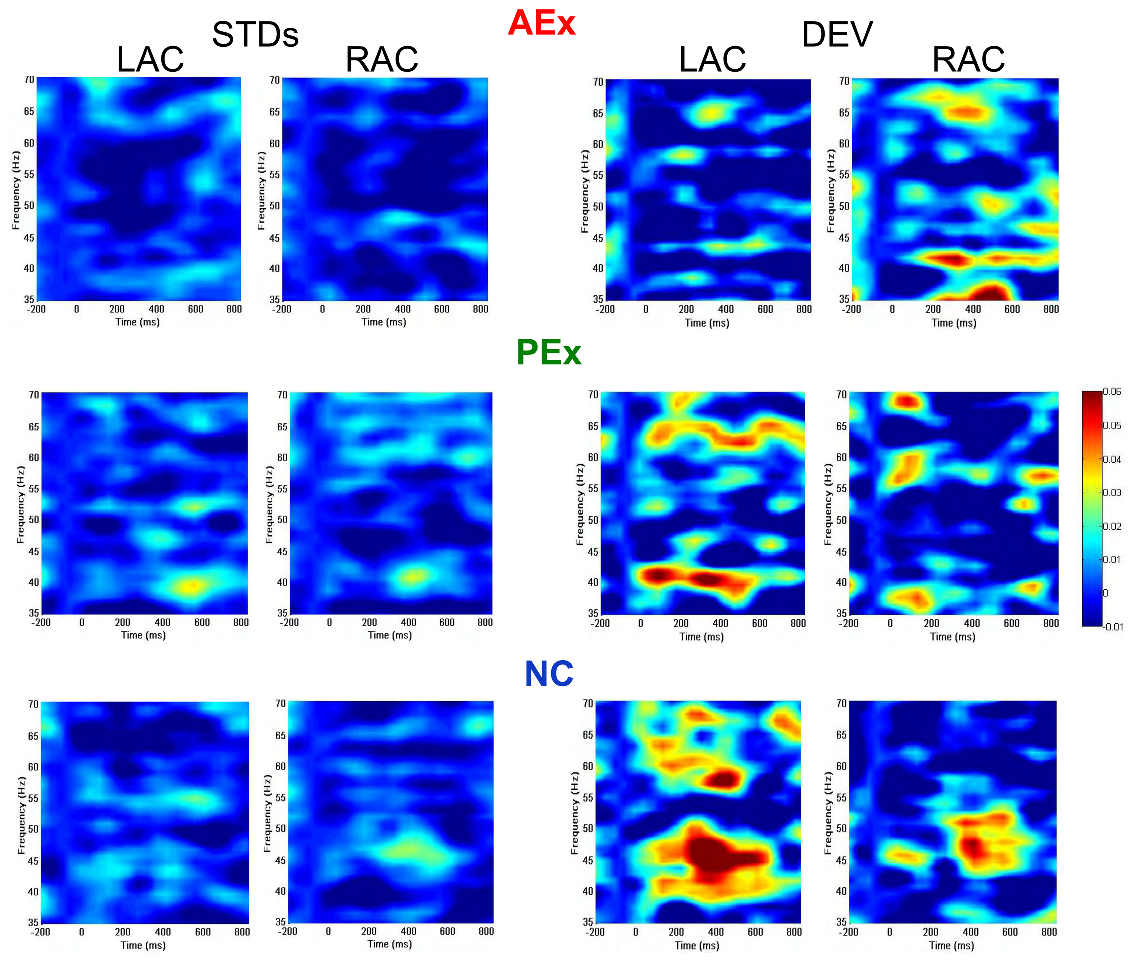


2 X 3 (source [LAC, RAC] X group [AEx, PEx, NC]) ANOVA on the mean of the theta cluster (0-250 ms, 3-7 Hz) showed:

- ALL STDs (syllable representation): no group difference
- DEV: Main effect of source ($F_{(2,42)}$ = 9.21, *p* = .004): LAC > RAC

Results

TSE GAMMA



2 X 3 (source [LAC, RAC] X group [AEx, PEx, NC]) ANOVA on the mean of the low gamma cluster (0-500 ms, 39-65 Hz) showed:

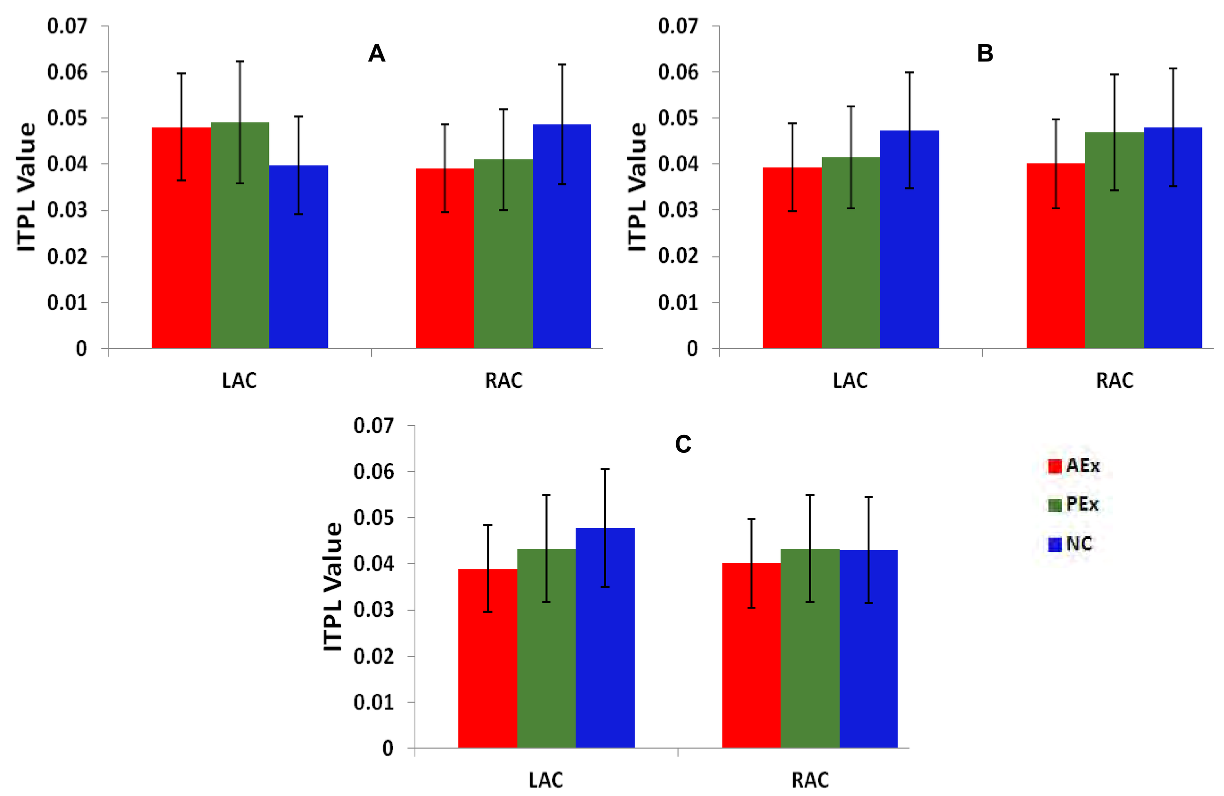
- ALL STDs (syllable representation): no group difference
- DEV: Source by group interaction ($F_{(2,42)}$ = 3.37, *p* = .034)

  For **AEx**, LAC power **<** RAC power.
  For **PEx** & **NC**, LAC power **>** RAC power.

Inter-trial Phase Locking (ITPL): GAMMA

Measures how consistently the phase at different frequency bands locks to stimulus presentation across trials.

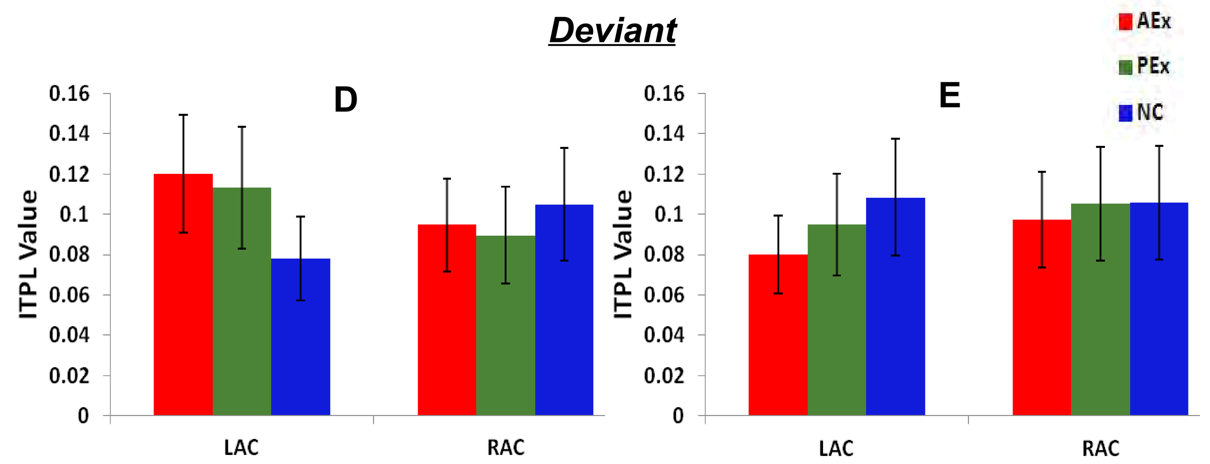
All STDs: Syllable representation



Frequency Band	Frequency Range (Hz)	Time Range (ms)	2X3 ANOVA Statistic	ANOVA Interpretation
Early high Gamma (A) >60 Hz	73 - 81	0 - 200	$F_{(2,42)}$ =10.46 *p* = .000	Source by Group interaction: **AEx** & **PEx**: LAC > RAC **NC**: LAC < RAC
Early low Gamma (B) <60 Hz	42 - 52	0 - 250	$F_{(2,42)}$ = 10.04 *p* = .000	Group effect: **AEx** < **PEx** & **NC**
Late Gamma (C)	58 - 64	200 - 600	$F_{(2,42)}$ = 3.81 *p* = .030	Group effect: **AEx** < **NC**

Results

Deviant



Frequency Band	Frequency Range (Hz)	Time Range (ms)	2X3 ANOVA Statistic	ANOVA Interpretation
Early low Gamma (D)	39 - 41	100 - 250	$F_{(2,42)}$ = 4.60 *p* = .016	Source by Group interaction: **AEx** & **PEx**: LAC>RAC **NC**: LAC < RAC
Late low Gamma (E)	47 - 52	200 - 400	$F_{(2,42)}$ = 3.86 *p* = .029	Group effect: **AEx** < **NC**

Conclusions

Results from this study show that **specific temporal, spatial and spectral oscillatory patterns were modulated as a function of early acoustic experience** as infants' processed a syllable contrast.

- **Generalization:** Effects of early acoustic experience with non-speech stimuli that contained temporal and spectral cues important for speech processing, **generalized to speech and conferred a left hemisphere advantage** for the processing of a syllabic contrast varying in VOT.
- **Effects of acoustic experience**: Across typical development, oscillatory activity at lower frequencies gradually shifts to more precise oscillatory activity in higher frequency bands. In this study, **early acoustic experience not only supported faster speech processing in the left hemisphere but also appeared to accelerate the maturational trajectory,** particularly when the acoustic experience involved interactive training. **The acoustic experience also appears to facilitate syllable representation** over an important period when infants are establishing their phonetic maps.
- **Theta oscillations resolving syllabic information:** increase in theta power during infants' deviant processing was seen in auditory cortices, particularly on the left, known for its specialization for speech. But the **acoustic experience did not modulate theta oscillations.**
- **Gamma functional specificity**: High (>60 Hz) and low (<60 Hz) gamma oscillations may reflect distinct processes implying functional specialization. High gamma is more discretely localized and faster than low gamma, increases during cognitive processing and has been observed in temporal areas critical for discrimination of the complex acoustic features of speech. **Infants with auditory experience, responded to syllables by activating early high gamma on the left while NC processed speech in low gamma and later on the right.** These results suggest that acoustic experience facilitated segmental processing and therefore, **phonetic mapping** while the NC group continued to process the speech stimuli via acoustic discrimination.

References

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Acknowledgments

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