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The Neural Basis of Phonetic Processing Seen Through the New Light of fNIRS

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INTRODUCTION

QUESTION

Does the network of brain areas dedicated to phonetic processing change over development?

Brain Areas for Phonetic Processing in Adults

Left-lateralized network of brain areas, including Broca's and Wernicke's Areas, involved in phonetic processing in adults[3,9,11] determined by

-Phonemic significance in native language[2,5]

-Fast temporal characteristics of speech stimuli[3]

Phonetic Processing Throughout Development

From birth, infants discriminate sounds along phonological dimensions, like voice-onset-time and place of articulation[4]; by 10-12 months, they narrow in on the phonetic inventory of the native language[1,7,10]

NEW

Functional Near Infrared Spectroscopy (fNIRS) is used as an innovative technology to study the development of brain networks underlying phonetic processing in infants

-fNIRS offers a significant advance over using previously available technologies with infants (PET, fMRI)

METHODS

Participants - all English monolinguals

Participants	AGE	Phonetic Perceptual Abilities
Adults	college age	English-specific
Young Infants	2-6 months	"Universal"
Old Infants	10-16 months	English-specific

Stimuli

Conditions	Stimuli	Difference between stimuli
Native (English)	voiceless aspirated [pa], [ta]	place of articulation (labial/coronal)
Non-Native (Zulu)	voiceless unaspirated [ca], [xa]	place of articulation (dental/lateral)
Control	non-linguisic tones	minor acoustic variations

All language stimuli were produced by female native speakers. Note: current IPA for Zulu clicks are [ǀa], [ǁa]. Zulu clicks can not be assimilated to any English phonetic category

All stimuli equated for duration, mean pitch, mean intensity using Praat

Block Design

English		Zulu		Tone
15s	15s	15s	15s	15s

Syllable/tone stimuli separated by ~1s inter-stimulus interval

Listening task. To maintain infants' interest, all participants viewed silent video of brightly colored, moving shapes during imaging data acquisition

NEUROIMAGING

Functional Near Infrared Spectroscopy (fNIRS)

•fNIRS measures changes in the brain's oxygen level density (BOLD), yielding separate measures of deoxygenated and oxygenated hemoglobin

•Good temporal (sampling rate=10 Hz) and spatial resolution, suitable for studies of higher cognition (~4cm depth)

•Tolerates movement better than fMRI

•Virtually silent, small (user friendly), and portable. Ideal for use with infants and children

a. Adult optode array

b. Adult MRI co-registration

c. Infant optode array

Adults

3x5 Optode Array (interoptode distance of 3cm) was positioned on participants' heads bilaterally using rigorous anatomical localization measures (see a above)

10-20 temporal coordinates (T3/T4) were identified and served as anchor points for the optode array

MRI Neuroanatomical Co-Registration was conducted by having participants (N = 6) wear a 3x5 array with vitamin-E capsules in MRI (see b above)

Infants

3x3 Optode Array (interoptode distance of 3cm) was positioned on participants' heads bilaterally using a terrycloth headband (see c above)

Data Acquisition and Analysis with fNIRS

•fNIRS signals were recorded using a *Hitachi ETG-4000* (Adult: 48 channels; Infants: 24 channels) with lasers factory set at 698nm and 830nm

•Data were analyzed and evaluated using a customized Matlab-based analysis package designed to solve the modified Beer-Lambert equation

•Analyses conducted on peak changes (from baseline) in oxygenated Hb

RESULTS

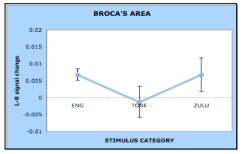
Adults (n=11)

BROCA'S AREA CHANNELS

•Strong and reliable hemispheric asymmetry for English: L>R, $t(10)=4.26$, $p<.001$

•Marginal hemispheric asymmetry for Zulu: L>R, $t(10)=1.45$, $p<.1$

•No hemispheric asymmetry for Tones: L=R, $t(10)=-.28$, *ns*



FRONTAL CONTROL CHANNELS

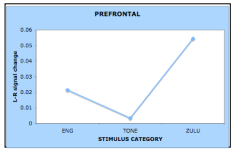
•No asymmetries for any stimulus type

COMPARISON OF BROCA'S and CONTROL CHANNELS

•Significantly greater asymmetry in Broca's than Control for English, but not for other two stimulus types

Infants (preliminary)

•Analyses for infants are ongoing. For illustrative purposes, we present the data for 2 infants in the older group (mean age=11.3 months) for all prefrontal channels



IMPLICATIONS

Does the network of brain areas dedicated to phonetic processing change over development?

YES!

•As predicted, English-speaking adults show reliable left lateralization for processing English syllables in Broca's Area, but no lateralization differences for Tones. English-speaking adults also show some left lateralization for processing Zulu click syllables

•Infant analyses are still ongoing. Recent studies using fNIRS find left lateralization for native language phonetic contrasts by 8 months[8]. Like adults, our infants show greater response for English in LH than RH, suggesting some LH dedication for phonetic processing of native language. Unlike adults, infants also show greater asymmetry for Zulu than for English, suggesting that phonetic processing develops and strengthen over time, and confirming previous findings of infants' heightened attention to novelty, including unfamiliar sights and novel languages[1]

NEW: fNIRS is indeed a promising technology that can shed new light on the neural basis of speech and language across the lifespan[6,8]

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