**Introduction:**

Several decades of research on infants has established that children are born with a universal capacity to perceive phonetic differences across all languages, but by 12 months of age, infant phoneme perception narrows such that native-language differences are recognized more accurately while non-native phoneme discrimination declines (Kuhl et al. 2006; Kuhl et al. 1992; Werker et al. 1981; Werker & Tees 1984). Moreover, researchers have demonstrated that speech perception skills in infancy is a reliable predictor of future language abilities. For example, Tsao et al. 2004 showed that individual variation in infants’ speech discrimination

skills at 6 months of age predicted their language abilities at three future points in time, 13

months, 16 months, and 24 months.

**﻿**

We used MEG to record the auditory evoked MMN, whose time course is taken as an electrophysiological index for early speech-comprehension processes (Pulvermuller F. 2006). MMN is a neuro-physiological index of the detection of a change in the acoustic input that can be elicited in the absence of focused attention ﻿(for a review, see Näätänen et al., 2007). It arises in the oddball paradigm, when listeners are confronted with series of stimuli, some of which are frequently presented (standards) and some infrequently (deviants). Relative to the response evoked by standards, around 200 ms after stimulus onset, deviants evoke a more pronounced response – negative in EEG. This is labelled Mismatch Negativity, MMN.

The rationale behind the oddball paradigm combines what is known about early infant language learning and categorical perception of speech sounds. It is well known that at birth infants are able to detect differences between speech sounds used in the world’s languages. But within the first year of life this capacity is altered by language experience resulting in a narrowing of phonetic perceptual ability facilitating native language learning (12–17). Along with this, we also know that information like speech sounds is typically perceived as discrete categories as opposed to gradual instances when there is a change in some variable along a continuum (18). In our paradigm we use categorical tokens of syllables /ba/ and /wa/ as deviants and an ambiguous syllable as standard, which is perceived by English speaking adults as either category prototype (i.e. /ba/ or /wa/) with equal probability. We reasoned that as young infants who have undergone limited perceptual narrowing by 2-months of age, would discern three distinct syllables presented as oddball stimuli that give rise to mismatch activity. In contrast, by 6-months of age infants are less likely to hear three distinct syllables, and as such show an attenuated MMN response due to the perceptual narrowing associated with their experience with English speech sounds. Meaning that as infants (speech) perceptual abilities mature the likelihood for perceiving the standard as a unique speech sound diminishes, and in turn diminishes the oddball effect by reducing the auditory memory trace established by the standard token. In the attached abstract, we presented preliminary MEG data for attenuated MMN activity as a potential electrophysiological marker for perceptual narrowing during early infant development. We argue that the attenuation in auditory MMN by 6-months of age corroborates the idea of perceptual narrowing, which facilitates later language learning.

**Materials & Methods  
*Subjects***

Fifty-two (22 males) typically developing (TD) English-learning infants were recruited for the study at two-months of age. At the time MEG recording at first visit children were on average 60±5.49 (M±STD) days old. The infants had no history of ear infections or other hearing difficulties, were born full term (between 39 and 42 weeks gestational age), had normal birth weights between 6 and 10 lbs., and typical head circumference 39±1.19 cm. Of the total number of infants recruited 40 (17 males) returned at six-months of age for MEG recording. At the time of t second visit children were on average 192±6.46 days old, and had typical head circumference of 44±1.77 cm. Ethical approval was obtained from the University of Washington Human Subjects Division. The parents or legal guardians of all participants provided informed written consent as per the principles of the Declaration of Helsinki.

***Stimuli***

The speech stimuli were the consonant–vowel (CV) syllables /ba/ and /wa/ (Figure), computer synthesized to be identical except for the duration of the initial formant transitions, the critical acoustic information differentiating the two syllables (Pisoni, Carrell & Gans, 1983). The stimuli contained five formants and consist of a 20-ms period of low frequency, low amplitude pre-voicing, 15-ms /ba/ or 45-ms /wa/ formant transitions, and a steady state vowel. The F1 transition started at 234 Hz and rose linearly to 769 Hz. The F2 transition started at 616 Hz and rose linearly to a steady state value of 1232 Hz. F3, F4, and F5 were constant for the duration of the steady state vowel and were set at 2862 Hz, 3600 Hz, and 3850 Hz. The stimuli were 325 ms in duration.

***Paradigm***

The task was a double oddball paradigm designed to elicit the MMN, with the standard stimulus occurring 60% of the time and deviant stimuli the remaining 40% of the time. Deviant stimuli consisted of CV tokens at the extremes of the VOT continuum separating /ba/ and /wa/. The standard stimulus was the perceptual mid-point of the VOT continuum separating deviant CVs. Oddball stimuli were pseudorandomly arranged where (i) deviants never occurred consecutively, and (ii) at least three successive standards deviant stimuli. Stimuli were

presented at 65 dB SL. The stimulus onset asynchrony was randomized at 1.0 ± 0.5s. Participants heard a total of 700 syllables. Only standards immediately preceding deviants were included in the analysis evoked responses.

***Data acquisition***

Infants were prepared for testing outside the MSR while a research assistant entertained them. A 3D position monitoring system (Polhemus, Colhester, VT) was used to record the locations of head position indicator (HPI) coils, cardinal (nasion, left/right preauricular) anatomical landmarks, and additional points (> 100) covering the scalp. We used an infant seat made for use in the MEG scanner to record brain activity in participants. The child's head was centered and positioned as high as possible relative to the MEG dewar, using foam cushions and padding to adjust position for recording. All infants were awake and alert during recordings. A female research assistant entertained the infant using silent toys, and we played a silent video in the background throughout the recording session. We recorded MEG signals with a 306-channel whole-scalp MEG system (VectorView™, Elekta Neuromag Oy, Helsinki, Finland) within an MSR at the Institute for Learning & Brain Sciences, University of Washington, Seattle. Neuromagnetic data was sampled at 1 kHz with a pass-band of .01 to 300 Hz. During MEG recordings signals from the HPI coils were used to continuously track the child’s head position relative to the MEG sensors.

***Data reduction and analysis***

MEG data signal processing was carried out using MNE-python (55, 56). To suppress signal artifacts from external sources the data were processed using temporal signal space separation (57). The continuous HPI data was used to compensate for subjects head movements using the initial head position as the target MEG coordinate frame. Signal space projection (58) was used to suppress the cardiac signal from the MEG data by estimating the spatial structure of the QRS complex from a maximally responsive gradiometer sensor for each subject. Single trials of neuromagnetic data were averaged to create ERF datasets for each oddball stimuli using 0.7s (0.1 s pre-stimulus) epochs. To adjust for DC offset in evoked data, the mean amplitude across sensors in the pre-stimulus interval was subtracted from sensor values in the post-stimulus period.

**Language measures**

Language skills were assessed using the MacArthur-Bates Communicative Development Inventories (CDIs), Words and Sentences assessment (1). The words and sentences form is designed to measure language production in children from 16 to 30 months of age. This form divides language production into two parts. Part 1 contains a 680-word vocabulary production checklist. Part 2 includes five sections designed to assess morphological and syntactic development. We used three of these sections in this study: vocabulary size, sentence complexity, and mean length of the longest three utterances (MLU). For each child included in the study the CDI survey was completed online by the parent or caregiver survey starting at 15 months of age, i.e., the earliest time point the words and sentences form can be administered, with follow-ups at three months intervals through 30 months of age. For each completed survey families received $10 for their effort. Out of the 10 participants with MEG in the study nine had completed CDI surveys at 15 months of age and eight provided measures of productive vocabulary at 27 and 30-time points. Here we report on productive vocabulary at 27 and 30 months, along with words understood approximately one month after MEG recording at 15 months.

**Results**

MEG data for 44 infants at two-months and 31 infants at six-months of age is included in this report.