Neural Representation of Transposed Melody in Infants at 6 Months of Age

Sarah Tew,[a] Takako Fujioka,[a,b] Chao He,[a] and Laurel Trainor[a,b]

[a]*Department of Psychology, McMaster University, Hamilton, Ontario, Canada*

[b]*Rotman Research Institute, Baycrest, University of Toronto, Toronto, Canada*

We examined adults' and 6-month-old infants' event-related potentials in response to occasional changes (deviants) in a 4-note melody presented at different pitch levels from trial to trial. In both groups, responses to standard and deviant stimuli differed significantly; however, adults produced a typical mismatch negativity (MMN), whereas 6-month-old infants exhibited a slow positive wave. We conclude that 6-month-old infants, like adults, encode melodic information in terms of relative pitch distances, but that the underlying cortical activity differs significantly from that of adults.

Key words: **melody; development; infant; EEG; relative pitch**

Introduction

The ability to discriminate changes in pitch patterns is fundamental for musical perception as well as for understanding spoken language, yet little is known about how melodies are encoded in auditory cortex in infancy. The exaggerated pitch contours of infant-directed speech elucidate the formant resonances of vowels,[1] enable infants to process emotional meaning,[2] and provide cues to lexical and grammatical boundaries.[3,4]

Infants as young as 2 months can recognize familiar melodies.[5] By 6 months infants can remember melodies for days[6–8] and recognize melodies even when they are transposed higher or lower in pitch,[9–12] indicating that they process the relative pitch distances between tones.

The present paper compares melodic encoding in auditory cortex in infants and adults using electroencephalography (EEG). In adults, an occasional change to one dimension of a repeating sound (a deviant) elicits a negative deflection in the event-related potential (ERP) between about 130 and 250 ms after the onset of the deviant sound, termed a mismatch negativity or MMN.[13,14] At the scalp, the MMN is frontally negative with a posterior polarity reversal consistent with primary generators in auditory cortex.[15] In adults, MMN responses are also elicited by occasional changes in a melody, even when the melody is presented in transposition to different pitch levels from trial to trial.[16,17]

The infant MMN response to pitch changes in an isolated tone assumes an adult-like morphology by 3 months of age.[18–19] The ERP responses of younger infants are dominated by slow waves, and a change in pitch results in an increase in a frontally positive slow wave.[18–21] In the present paper, we examine the maturation of relative pitch codes in auditory cortex by presenting a 4-note melody in transposition to a different key on every trial.

Method

Participants

EEG was recorded in 5 nonmusician adults (21–29 years; 4 F, 1 M; mean age = 24.4 years) and 17 healthy, full-term infants between

Address for correspondence: Laurel J. Trainor, Department of Psychology, Neuroscience & Behaviour, McMaster University, 1280 Main Street West, Hamilton, Ontario, Canada L8S 4K1. Voice: 905-525-9140 ext. 23007; fax: 905-529-6225. LJT@mcmaster.ca

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Figure 1. Stimulus: 600 trials of a 4-note melody were presented, transposed to one of 20 different starting notes between G3 and D5, such that successive transpositions were to related keys (up or down by a Perfect 5th, 7/12 octave, or Perfect 4th, 5/12 octave). On deviant trials (20% of trials, separated by at least two standard trials) the fourth note was raised by a semitone.

6.1 and 6.9 months (10 F, 7 M; mean age = 6.3 months) with no known hearing deficits. Four additional infants were excluded for excessive movement and two because of equipment failure.

Stimuli

Eighty percent of the 600 trials were standard and 20% were deviant melodies in random order (Fig. 1). On deviant trials, the last note of the melody was raised by a semitone. Melodies were presented in 20 different transpositions, with successive melodies in related keys. Tones were synthesized in acoustic grand piano timbre (Creative Tech, Dulles, VA) at a 44,100 Hz sampling rate. Sound intensites were normalized using Adobe Audition (San Jose, CA) and played at 70 dB(A) using E-prime 1.2 from a Dell OptiPlex280 computer (Austin, TX) over a custom-designed speaker (WestSun Jason Sound JS1P63; Toronto, ON) one meter in front of the subject.

Apparatus and Procedure

EEG was recorded using 128 channel (124 for infants) HydroCel GSN nets (Electrical Geodesics, Eugene, OR) referenced to Cz with background noise level less than 29 dB(A). Adults watched a silent movie; infants watched a silent movie and puppet show on their caregiver's lap.

Data Analyses

The data were filtered between 0.5 and 20 Hz, segmented into 900-ms epochs, including a base line of 100 ms prior to stimulus onset. For adults, trials containing EEG voltage greater than ± 100 μV at any electrode were rejected. The average numbers of accepted standard and deviant trials across subjects were 267 (SD = 31.02) and 91 (SD = 11.34), respectively. For infants, rejection and averaging were performed at each electrode such that only the electrodes that exceeded ± 100 μV were rejected and unaffected electrodes were preserved (see He *et al.*[18] for details). The total number of accepted trials across all electrodes varied, with the average numbers of accepted standards and deviants being 287 (SD = 51) and 94 (SD = 17), respectively.

Standards and deviants were averaged and re-referenced using an average reference; standards immediately following deviants were omitted. Difference waves were obtained by subtracting the average response to the standard from the average response to the deviant stimuli.

Results

The difference wave showed a right lateralized MMN in adults, but a less lateralized frontal positive slow wave (reversed polarity at occipital regions) between 200 and 500 ms in infants. For adults, the electrodes were divided into nine groups, each containing 7–8 electrodes centered at F3, F4, Fz, C3, C4, Cz, P3, P4, and Pz. Adults' responses to deviants were significantly different from standards at the time of the MMN by *t*-tests (Fig. 2).

For infants, eight electrode groups were used, each containing 8–10 sites centered around F3,

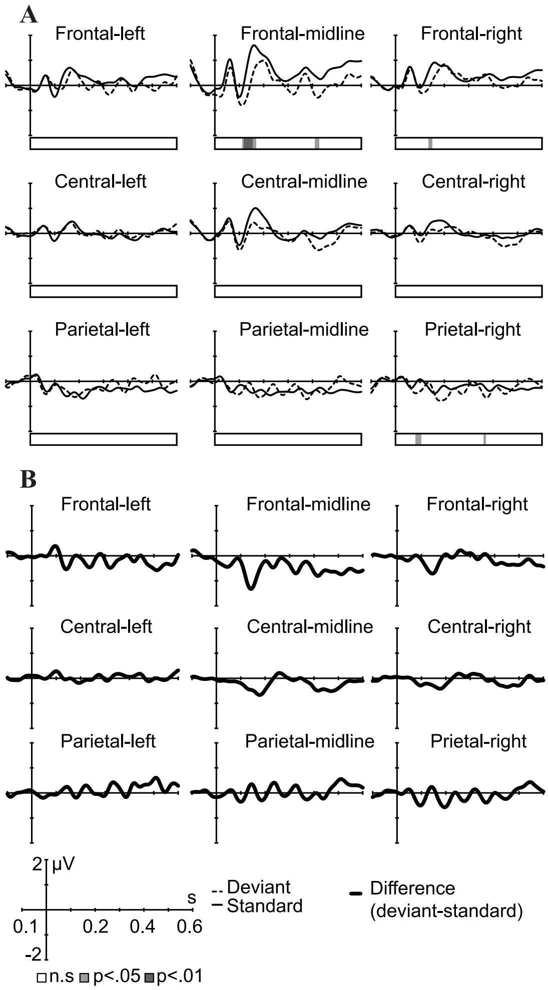

Figure 2. Adult grand average ERP responses ($n = 5$) for (**A**) the standard and deviant waveforms and (**B**) the difference waves (deviant–standard). Time zero represents the onset of the 4th melody note. Eight to 10 electrode sites were averaged for each waveform. Bars in (**A**) represent times when standard and deviant waveforms differ significantly.

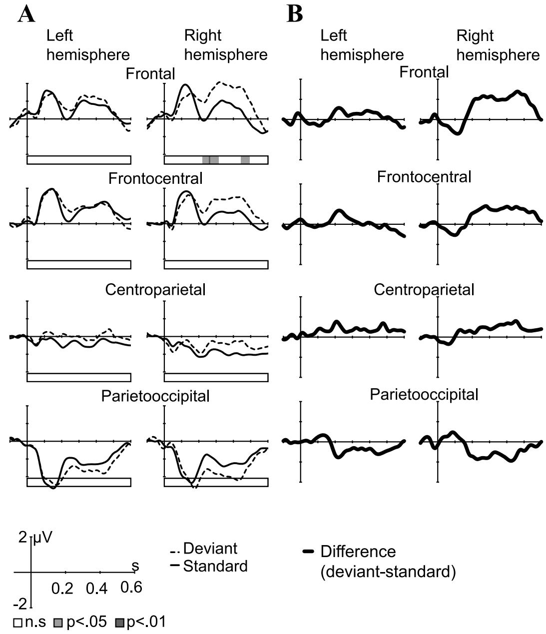

Figure 3. Infant grand average ERP responses ($n = 17$) for (**A**) standard and deviant trials and (**B**) the difference waves at left and right frontal, central, occipital and parietal regions. Eight to 10 electrode sites were averaged for each waveform. Time zero represents the onset of the 4th melody note. Bars in (**A**) represent times when standard and deviant waveforms differ significantly.

F4, C3, C4, P3, P4, O3, and O4. Responses to deviants were significantly different from responses to standards by *t*-tests (Fig. 3). However, there was no significant negativity.

Conclusions

Both infants and adults showed cortical responses to a change in relative pitch in a short melodic pattern. However, adults showed a right, frontally negative MMN similar to that of previous studies,[16,17] whereas 6-month-olds showed an extended right frontally positive response. A similar slow positive wave has been reported previously in younger infants for simple pitch changes.[18,19] The present results indicate that this immature response persists for longer in the case of more complex melody processing. The results corroborate previous behavioral studies showing relative pitch representation in infants,[9–12] but show that this representation differs substantially from that of adults.

Pitch representation in the auditory pathway is not achieved until auditory cortex, and processing relative pitch involves further interactions with parietal and frontal areas.[22,23] These connections may remain immature at 6 months. Future research should address whether processing melodies in infants and adults involves different brain areas, or the same areas using different processing mechanisms.

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Conflicts of Interest

The authors declare no conflicts of interest.

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