

Auditory Evoked Magnetic Fields to Speech Stimuli in Newborns – Effect of Sleep Stages

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ABSTRACT

The aim of the study was to examine whether a newborn can detect changes in a speech stimulus consisting of a fricative followed by a vowel /su/. In addition, we studied the possible effect of the two sleep stages (active and quiet sleep) on the evoked magnetic responses. In young children (6 years), the same stimulus evokes a prominent deflection, consisting of two peaks. The first one (P1m) is evoked by the beginning of the fricative consonant and has a latency of about 145 ms. The second peak (P2m), with a latency of 340 ms, is evoked by the switch to the vowel. In newborns ($n = 10$), the waveform resembled that of the older children but latencies of the corresponding peaks were longer, 190 and 435 ms, correspondingly. The results suggest that already the newborn brain detects the change inside the auditory speech stimulus, namely the fricative sound changing into a vowel. However, the immaturity of the brain is reflected in the prolonged latencies. In addition, the responses were higher in amplitude in quiet sleep than in active sleep ($F(1,9) = 36,5; p < 0,0002$). This is in line with the enhanced somatosensory magnetic fields to tactile stimulation in quiet compared to active sleep in newborns.

KEY WORDS

Auditory evoked magnetic fields, Magnetoencephalography (MEG), Newborn, Sleep stages, Speech sound

INTRODUCTION

The capabilities of a newborn to discriminate changes in a stream of auditory information have been studied extensively with event-related potentials (ERP). While a typical obligatory ERP to tone and speech stimuli in newborns consists of a major positive response at about 200–300 ms, a sudden deviation in a stimulus stream has been reported to elicit a deflection, a so called mismatch response, either with a negative or positive polarity at about the same or somewhat later latency (for a recent review and discussion, see [Leppänen, 2004]). Recently, there have also been attempts to use magnetoencephalography (MEG) for studying auditory change detection in newborns [Huotilainen, 2003] [Kujala, 2004] [Cheour, 2004]. The present study examined if the newborn brain detects, in addition to a change in a stimulus stream, a change within a speech stimulus, as has been shown for 6-year-old children [Pihko, 2005].

METHODS

The subjects were 18 healthy newborns from the Helsinki University Central Hospital maternity ward, measured while 1–4 days old. In 10 full-term babies (5 females) the measurements were successfully carried out both in active and quiet sleep stages and therefore only data from those subjects are included. The 1 minute Apgar scores were 9, except in two cases 8. The study was approved by the Ethical Committee of Helsinki and Uusimaa. One of the parents of each baby signed an informed consent form.

Stimuli were syllables /su/ (standard 76 %), /so/ (deviant 12 %) and /sy/ (deviant 12%) presented in an oddball paradigm. The phoneme duration was 219 ms for the fricative /s/ and 152 ms for the following vowel with an overall duration of 371 ms. (For details about the preparation of the stimuli see Pihko, 2005). In the following, only responses to the standard /su/ syllables are statistically analyzed. Stimuli were presented with an inter-stimulus interval (ISI) of 1 s (from the beginning of one to the beginning of the next stimulus). Stimuli were delivered to the left, contralateral ear through a plastic tube and a soft earpiece.

MEG was recorded with a helmet-shaped device with 306 channels (of which 204 were gradiometers and 102 magnetometers; Elekta Neuromag Oy, Helsinki, Finland). The measuring helmet was in a supine position and the baby was lying with the right hemisphere downwards over the 'occipital' part of the helmet. Data were collected with a bandpass filter of 0,1–200 Hz using a sampling rate of 600 Hz.

Sleep stages were monitored via three EEG electrodes (F4, P4 and Cz) and two electro-oculograms, one on the upper corner of the left and the other on the lower corner of the right eye. In addition, behavior of the baby (*e.g.*, breathing pattern) during the measurement was monitored and coded on-line to the data file.

The data were averaged off-line according to the sleep stages. For statistical analysis, vector sums of the responses on the gradiometer channels were calculated with a low-pass filter of 40 Hz. From the vector sums, two amplitude averages were chosen individually, one 50 ms-long corresponding to the first, P1m peak, and a second, 100 ms-long corresponding to the second, P2m peak. For each subject, an average of vector sums from three channels with the maximal responses was used for ANOVA.

RESULTS

Figure 1 shows responses of one newborn (upper traces) and of one 6-year-old child (lower traces) to /su/ as a standard (continuous line) and /sy/ as a deviant (dashed line). The data from the 6-year-old was measured with the same paradigm and stimuli, but the child was awake and the ISI was 700 ms. In most newborns, a clear response to standards could be elicited in quiet sleep. The response consisted of a wider deflection, which in many cases showed separate peaks corresponding to the P1m and P2m of the response waveform of older children. In Figure 1, upper trace, the two peaks are clearly seen in the

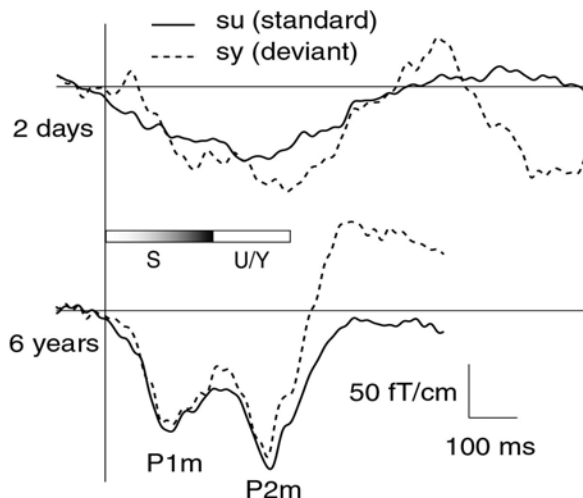


Figure 1. Auditory evoked responses to standard /su/ and deviant /sy/ of one newborn (upper traces) and a 6-year-old child (lower traces).

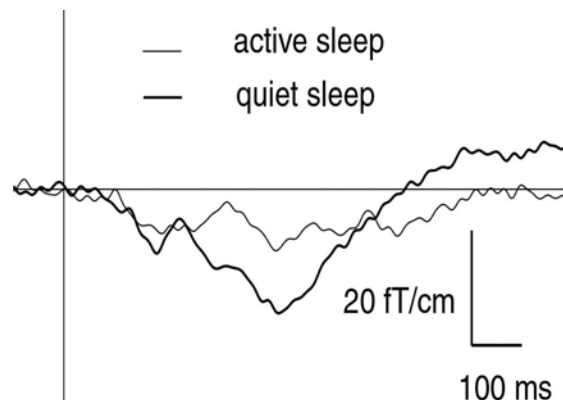


Figure 2. Grand average magnetic responses of newborns ($n = 10$) to the syllable /su/ in active (gray line) and quiet (black line) sleep stages.

response to the deviant. Also after P1m and P2m, the waveform of the deviant response remarkably follows that of the older child with a deflection of opposite direction corresponding to a mismatch response. The average latency of the responses tended to be longer in newborns (190 and 435 ms) than in children (145 and 350 ms).

In active sleep, the responses to standards were generally smaller and not always distinguishable from the baseline activity. Figure 2 shows, on one gradiometer channel, grand average responses from the ten subjects measured over a contralateral location. 2-way ANOVA resulted in a main effect of the sleep stage [$F(1,9) = 36,5; p < 0,0002$], and a main effect of the peak [$F(1,9) = 7,7; p < 0,022$] with bigger responses in quiet than in active sleep and bigger responses during the second than during the first peak. In addition, there was an interaction of peak and sleep stage (Sleep stage 2 x Peak 2) [$F(1,9) = 6,4; p < 0,033$] indicating that the P2m was more enhanced than the P1m in quiet sleep.

DISCUSSION

Magnetic fields evoked by a speech sound in newborns in the present study are in agreement with a positive deflection measured in numerous evoked potential studies on fullterm newborns (see *e.g.* [Leppänen, 2004]). This response is usually a broad deflection peaking around 200–300 ms. In our study, however, two distinct peaks were observed suggesting a contribution from the change within the stimulus. The two-peaked structure can be seen *e.g.* in responses evoked by /kaa/ and /ka/ stimuli in the study by Leppänen, [1999], but with a shorter latency for the 2nd peak (300–350 ms), presumably because of a shorter duration for the voiceless /k/ consonant.

The present study thus suggests that already a newborn reacts to different features within an auditory speech stimulus, namely those involved in a transition from a fricative to a vowel. In adults, onset of a word beginning with a fricative elicits a N100m response, followed by a N100m' triggered by the switch to a vowel [Kaukoranta, 1987]. In 6-year-old children the response to syllables /su/ and /sy/ consists of P1m and P2m, two deflections with opposite field distribution to those in adults (Fig. 1 and [Pihko, 2005]), which is in agreement with developmental changes of auditory responses reported in EEG and MEG studies in children [Paetau, 1995] [Ponton, 2000]. A similar sequence of N100m-N100m' can be evoked by a stimulus in which a noise burst is followed by a square-wave [Mäkelä, 1988]. The evoked magnetic responses to this mimicked fricative-vowel combination are diminished in dyslexic subjects [Renvall, 2002], adding thus a special interest to this stimulus combination in studies of young infants at-risk *e.g.* for dyslexia.

The ISI in the study with children was 700 ms while for the newborns it was 1 s. Longer ISI and analysis window were used to be able to record the later response. Longer latencies and less pronounced deflections of the newborns' responses reflect the relative immaturity of their brain.

Responses measured in quiet sleep were significantly larger than responses in active sleep. The typical full-term infant's sleep is characterized by two major stages – active and quiet sleep, with typical changes in EEG. The effect of sleep stages on auditory ERPs of newborns [Ellingson, 1974], and of few-month-old infants [Duclaux, 1991] [Friedrich, 2004] have been shown earlier though there are studies reporting no effects [Cheour, 2002] [Martynova, 2003]. Since these studies differ in many ways, like in age groups, stimulus types, and ISI, it is difficult to pinpoint the possible factors contributing to the different results. The sleep stage effect is clear for late somatosensory magnetic evoked fields in newborns [Pihko, 2004]. Given the pronounced sleep stage effect on the amplitudes of evoked magnetic fields, monitoring them is especially important in possible future experiments when clinical or at-risk groups will be studied and compared to control subjects.

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REFERENCES

- Cheour M, Ceponiene R, Leppänen P, Alho K, Kujala T, Renlund M, et al. The auditory sensory memory trace decays rapidly in newborns. *Scand J Psychol* 2002;43:33–9.
- Cheour M, Imada T, Taulu S, Ahonen A, Salonen J, Kuhl P. Magnetoencephalography is feasible for infant assessment of auditory discrimination. *Exp Neurol* 2004;190:S44–51.
- Duclaux R, Challamel MJ, Collet L, Rouillet-Solignac I, Revol M. Hemispheric asymmetry of late auditory evoked response induced by pitch changes in infants: influence of sleep stages. *Brain Res* 1991;566:152–8.
- Ellingson RJ, Danay T, Nelson B, Lathrop GH. Variability of auditory evoked potentials in human newborns. *Electroencephalogr Clin Neurophysiol* 1974;36:155–62.
- Friedrich M, Weber D, Friederici AD. Electrophysiological evidence for delayed mismatch response in infants at-risk for specific language impairment. *Psychophysiol* 2004;41:772–82.
- Huotilainen M, Kujala A, Hotakainen M, Shestakova A, Kushnerenko E, Parkkonen L, et al. Auditory magnetic responses of healthy newborns. *NeuroReport* 2003;13:1871–5.
- Kaukoranta E, Hari R, Lounasmaa OV. Responses of the human auditory cortex to vowel onset after fricative consonants. *Exp Brain Res* 1987;69:19–23.
- Kujala A, Huotilainen M, Hotakainen M, Lennes M, Parkkonen L, Fellman V et al. Speech sound discrimination in neonates as measured with MEG. *NeuroReport* 2004;15:2089–92.
- Leppänen PHT, Pihko E, Eklund KM, Lyytinen H. Cortical responses of infants with and without a genetic risk for dyslexia: II. Group effects. *NeuroReport* 1999;10:969–73.
- Leppänen PHT, Guttorm TK, Pihko E, Takkinen S, Eklund KM, Lyytinen H. Maturational effects on newborn ERPs measured in the mismatch negativity paradigm. *Exp Neurol* 2004;190:S91–101.
- Martynova O, Kirjavainen J, Cheour M. Mismatch negativity and late discriminative negativity in sleeping human newborns. *Neurosci Lett* 2003;340:75–8.
- Mäkelä J, Hari R, Leinonen L. Magnetic responses of the human auditory cortex to noise/square wave transitions. *Electroencephalogr Clin Neurophysiol* 1988;69:423–30.
- Paetau R, Ahonen A, Salonen O, Sams M. Auditory evoked magnetic fields to tones and pseudowords in healthy children and adults. *J Clin Neurophysiol* 1995;12:177–85.
- Pihko E, Kujala T, Mickos A, Antell H, Alku P, Byring R, et al. Magnetic fields evoked by speech sounds in preschool children. *Clin Neurophysiol* 2005;116:112–9.
- Pihko E, Lauronen L, Wikström H, Taulu S, Nurminen J, Kivitie-Kallio S, et al. Somatosensory evoked potentials and magnetic fields elicited by tactile stimulation of the hand during active and quiet sleep in newborns. *Clin Neurophysiol* 2004;115:448–55.

Ponton CW, Eggermont JJ, Kwong B, Don M. Maturation of human central auditory system activity: evidence from multi-channel evoked potentials. *Clin Neurophysiol* 2000;111:220–36.

Renvall H, Hari R. Auditory cortical responses to speech-like stimuli in dyslexic adults. *J Cogn Neurosci* 2002;14:757–68.