



Sounds elicit relative left frontal alpha activity in 2-month-old infants



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ABSTRACT

As one kind of sounds, human voices are important for language acquisition and human–infant relations. Human voices have positive effects on infants, e.g., soothe infants and evoke an infant's smile. Increased left relative to right frontal alpha activity as assessed by the electroencephalogram (EEG) is considered to reflect approach-related emotions. In the present study, we recorded the EEG in thirty-eight 2-month-old infants during a baseline period while listening to sounds, i.e., human voices. Infants displayed increased relative left frontal alpha activity in response to sounds compared to the baseline condition. These results suggest that sounds can elicit relative left frontal activity in young infants, and that this approach-related emotion presents early in life.

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1. Introduction

Arguably the most important sound for infants is the human voice. It is not only important for language acquisition, but it is also critical for human relations, especially the parent–infant relationship. Infants prefer human voices, particularly high-pitched female voices, over other kinds of sounds (Ecklund-Flores and Turkewitz, 1996; Friedlander, 1970; Hutt et al., 1968). Through observing newborns' head-turning, Ecklund-Flores and Turkewitz (1996) reported that infants showed increased rightward orientation to the human voice, suggesting that infants are more interested in the human voice. Recently, using an eyeblink conditioning paradigm, Reeb-Sutherland et al. (2011) found that one-month-old infants displayed greater learning to a female voice compared to a pure tone, suggesting that human voices may facilitate learning during early infancy.

The sound of the human voice can soothe infants and make them happy. The human voice is one of the earliest stimuli to evoke an infant's smile. Wolff (1963) investigated smiling in newborn infants and found that a recognizable smile can be elicited in the first week of life and the broad, clear-cut smile can be elicited in the third week by the high-pitched human voice. Although behavioral observations in previous

studies show that human voices have positive effects on infants, the underlying brain mechanisms remain unclear.

Many studies have showed the frontal and temporal responses to speech sounds in young infants. Pena et al. (2003) examined cerebral hemodynamic responses to speech sounds in neonates using near-infrared spectroscopy (NIRS) and observed increased activations in neonates' left temporal areas when they were exposed to normal speech rather than to backward speech or silence. Using NIRS, Homae et al. (2011) measured brain activation in sleeping 3-month-old infants when speech sounds presented and during silence and proposed the functional brain networks, including the frontal and temporal regions, underlying speech processing in early infancy. In addition to studies examining infant brain responses to human voices relative to silence, some studies compared infant brain responses to mother's voices vs. stranger's voices. Using NIRS, Naoi et al. (2012) explored brain responses to infant-directed speech in infants with 4–13 months of age and observed larger activation in the frontal area for their own mother's voices than for stranger's voices. Using electrophysiology and source analysis, Beauchemin et al. (2011) compared newborn brain responses to mother's voices vs. stranger's voices and found that mother's voices elicited a distinctly left-dominant brain activation pattern at an early time and greater central activation at a later time. Dehaene-Lambertz et al. (2010) used fMRI to investigate how two-month-old infants react to speech vs. music, as well as to mother's voices vs. stranger's voices. They found that the left posterior temporal regions are more sensitive to speech than to music and mother's voices

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activated not only language areas (the left posterior temporal lobe), but also areas involved in emotional processing (amygdale and orbito-frontal cortex). These studies, at the neural level, suggest that human voices, especially the mother's voices, play a special role in early language acquisition.

The electroencephalogram (EEG) has been extensively used to investigate infants' brain electrical activity during emotion expression and regulation. Frontal brain asymmetries as assessed by the EEG have been noted to be associated with the perception and generation of emotion (Fox, 1991). Greater relative left vs. right frontal alpha activity has been associated with positive, approach-related emotions, and greater relative right vs. left frontal alpha activity has been associated with negative, withdrawal-related emotions (Davidson, 1992; Davidson and Fox, 1982; Fox, 1991). For instance, when 10-month-old infants were presented with film clips of happy and sad facial expressions, they showed greater relative left frontal alpha activity in response to the happy expression than to the sad expression (Davidson and Fox, 1982). In a study of 10-month-old infants' responses to maternal separation, Davidson and Fox (1989) reported that infants who cried upon maternal separation displayed greater resting right frontal alpha activation than infants who did not cry. Moreover, Fox and Davidson (1986) found that even newborn infants exhibited differences in the asymmetry of frontal electrical activity in response to positive vs. negative affective stimuli. In their study, infants as young as 2–3 days showed greater relative left frontal alpha activity in response to a sucrose solution placed on their tongues, while showing more right frontal activity in response to neutrally flavored solution (distilled water).

In the present study, we report electrical brain responses to sound (i.e., human voices) in 2-month-old infants. We focused on the 6–9 Hz frequency band of the EEG, because it is believed to reflect infant alpha activity and has been used extensively in studies of EEG and infant emotion development (Bell and Fox, 1994; Davidson and Fox, 1989; Dawson et al., 1992, 1997). EEG asymmetry reflects the power in one hemisphere relative to the power in the contralateral hemisphere (calculated as right minus left EEG power). Because increased alpha power is believed to correspond to decreased functional activity in underlying cortex, i.e., alpha power is inversely related to cortical activity, positive scores reflect greater activation on the left compared with the right frontal cortex, and negative scores reflect greater relative right activation (Shagass, 1972). In the present study, we expected to observe greater relative left frontal EEG asymmetry when infants listened to human voices. This study extends previous work using behavioral observation by providing evidence on how the infant brain responds to human voices.

2. Methods

2.1. Participants

EEG recordings were obtained from 49 healthy 2-month-old infants. A subset of the data of the current sample was reported in another paper examining event-related potentials (ERPs) to mother vs. stranger's voices (Mai et al., 2012). In the present study, ten participants were excluded from analyses (failed hearing test, $n = 1$; low iron status at birth, $n = 4$; less than 30-s artifact-free EEG for each condition, $n = 5$; or less artifact-free EEG segments with sounds for the voice condition, $n = 1$). Infants with iron deficiency were excluded, since studies of early iron deficiency found social-emotional differences and/or ERP differences between infants with and without iron deficiency (Burden et al., 2007; deRegnier et al., 2007; Lozoff et al., 1998; Siddappa et al., 2004). The final sample for analysis consisted of 38 infants, 14 male, 24 female, between 57 and 63 days old (Mean = 59.7 days, SD = 1.8 days). All infants were born full-term (37–42 week gestation) and with normal birth weight (>2500 g). The assessments were conducted in the Children's Hospital of Zhejiang University in China. The study was approved by the Institutional Review Board of the University of

Michigan and the Children's Hospital of Zhejiang University. All parents gave signed informed consent.

2.2. Procedures

The procedures in the present study are similar to those reported in another paper (Mai et al., 2012). In that paper, however, the focus was on ERPs elicited by mother vs. stranger voices. In the present study, we focused on the spectral power of EEG in infants during baseline period and when listening to human voices.

2.2.1. EEG recording

The EEG recording was made in an electrically shielded quiet room. The infant was seated in the mother's lap and tested in a behavioral state of quiet alert. The mother was instructed to remain as still as possible and maintain a neutral expression if the infant looked at her during EEG recording.

The EEG was recorded with a 60-electrode HydroCel Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR). The EEG signal was amplified using a 0.1–100 Hz bandpass and digitized at 500 Hz. Impedances were maintained below 50 k Ω throughout recording. Recording in every electrode was vertex-referenced. The raw data were stored for later analysis. After the placement of EEG electrodes on the infant's scalp, the electrical brain activity was measured during a baseline condition and a condition in which the human voice stimuli were presented.

2.2.2. Baseline EEG

The baseline EEG was recorded for 2 min during which the infant was kept relaxed and alert by observing a bubble cascade. The purpose of the bubble cascade was to keep the infant quiet and minimize movement artifacts. Immediately after baseline, the recording of EEG continued as the auditory stimuli were presented.

2.2.3. Infant listening to human voices

In addition to observing the bubble cascade during this period, infants were also presented with natural human voice stimuli, spoken either by the mother or a stranger, through two loudspeakers. The stranger's voice varied for each infant and was the voice of the mother whose infant was previously tested. The voice stimulus consisted of the Chinese word "baobao", meaning "baby", spoken in neutral prosody, digitized and edited to 750 ms. The infant was presented with auditory stimuli of the mother's and stranger's voices with equal probability. A total of 200 trials were presented, randomly ordered with the constraint that the same stimulus was not repeated for more than two consecutive trials. The interstimulus interval (ISI) was varied randomly from 2250 to 3250 ms. The sounds were presented through two loudspeakers placed 65 cm away from each side of the infant's head. Stimulus intensity at the infant's head was 65 dB. The duration of the recording for this paradigm was around 12 min. For comparability to the 2-minute baseline EEG condition, we analyzed the first two minutes of the data during voice presentation.

2.3. EEG data reduction and processing

These 4 min of EEG data (2 min for baseline and 2 min for listening-voice conditions) were first processed offline using Net Station 4.3 (Eugene, OR). Data were band-pass filtered at 1–47 Hz, and then divided into smaller 1-sec segments. To minimize the possible interference of city electric-field (50 Hz in China), we set the low-pass filter at 47 Hz. We did not exclude the ISI period from analysis of the 2-minute listening-voice condition, because we examine the EEG spectral power in a continuous period in which the voices were presented. In addition, the EEG to mother's and stranger's voices were combined in the analyses because 1) this study focused on differences in infant EEG responses to the human voice compared to baseline, and 2) the voices were presented in random order instead of two separate blocks, making it

impossible to separate the EEG spectral power. The segmented data were in turn hand-edited for ocular and motion artifacts. Segments in which eye-blinks or eye-movements were clearly visible in the EEG data were excluded as were segments during which substantial drift was visually evident across the entire electrode array. Data from individual electrodes were marked bad if there was artifact resulting from poor contact or movement, again by visual inspection. The entire segment was excluded if more than nine electrodes were marked bad or if an eye blink, eye movement, or other significant artifact occurred. Of the remaining segments, individual electrodes containing artifact were replaced using spherical spline interpolation. The mean number of electrodes replaced with interpolation was 2.9 (SD = 1.2) for the baseline condition and 3.0 (SD = 1.7) for the voice condition. The electrode number of interpolations did not differ for the two condition ($t(37) = -0.734, p = 0.467$). At least 30-sec of artifact-free EEG (i.e., 30 good segments) for each condition was required to be included in the analyses. In addition, for the voice condition, the ratio of sound/silence before the artifact rejection was about 0.21. Thus, artifact-free EEG segment-with-sound/segment-without-sound ratio below 0.21 would be excluded in the analysis. There was no difference between the two conditions in the number of artifact-free EEG segments included in the analysis (Mean = 80.6, SD = 20.8 for the baseline condition, Mean = 81.6, SD = 25.6 for the listening-voice condition, $t(37) = -.199, p = .844$). In addition, there was no difference between the mother's and stranger's voices in the number of artifact-free EEG segments (Mean = 22.1, SD = 8.6 for the mother's voice, Mean = 21.7, SD = 9.3 for the stranger's voice, $t(37) = .562, p = .578$), indicating that there was a relatively 50–50 ratio of the mother's and stranger's voices for the voices-condition. The data were re-referenced against the average of all channels.

Artifact-free EEG data were then processed in Matlab 7.6 (The Mathworks Inc, Natick, MA). Power spectral density was produced by applying the Matlab command 'pwelch'. It divided the continuous time-domain signal into segments using a 1-second Hanning window with 50% overlap to calculate the amplitude at each frequency. Averaged power spectral density was calculated for frontal and temporal scalp areas of both the left and right hemispheres: left frontal—electrodes 9, 11, 12, 13, and 14 (encompassing F3 in the 10–20 System); right frontal—electrodes 2, 3, 57, 59, and 60 (encompassing F4); left temporal—electrodes 24, 25, 27, 30; right temporal—44, 45, 48, 52 (see Fig. 1). Spectral power at 6–9 Hz (actually 5.5–9.5 Hz) was computed

and then natural log-transformed to normalize the distribution. The EEG alpha asymmetry score ($\ln[\text{right}] - \ln[\text{left}]$) for two scalp areas was calculated. EEG alpha asymmetry scores were submitted to a repeated-measure analysis of variance (ANOVA) with Condition (baseline, voice) and Scalp area (frontal, temporal) as two within-subject factors.

3. Results

We found main effects of Condition ($F(1,37) = 6.402, p = 0.016$) and Scalp area ($F(1,37) = 4.420, p = 0.042$), indicating that alpha asymmetry scores were different among the scalp areas and between the voice and baseline conditions. In further comparing the alpha asymmetry scores in baseline and voice conditions for each scalp area, we found the difference between voice and baseline conditions at the frontal area ($p = 0.012$) but not at the temporal area ($p > 0.1$), indicating the larger frontal alpha asymmetry in the voice condition.

Relative left frontal alpha asymmetry may be a function of left frontal activation or it may be a function of hypoactivation of the right frontal region or both. To disentangle the separate contributions of the left and right hemispheres to frontal asymmetries between conditions, absolute EEG alpha power at frontal areas were submitted to a repeated-measure ANOVA with Condition (baseline, voice) and Hemisphere (left, right) as within subject factors. This analysis yielded a significant Hemisphere main effect ($F(1,37) = 12.717, p = .001$) and a significant Condition \times Hemisphere interaction ($F(1,37) = 7.042, p = .012$). Pairwise comparisons revealed that the EEG alpha power was smaller for the left than the right hemisphere in the voice condition ($p = .0002$). Although the EEG alpha power also was lower in the left than the right hemisphere for the baseline condition ($p = .029$), this hemispherical difference was smaller than found in the voice condition (Fig. 1b). Reduced EEG alpha power indicates increased brain activation (Shagass, 1972). Therefore, these results suggest that human voices elicited greater relative left frontal brain activity compared to the baseline condition.

4. Discussion

The present study examined the alpha band EEG asymmetry in 2-month-old infants in response to sounds, i.e., human voices. We found that infants exhibited increased relative left frontal brain activity in response to human voices compared to the baseline condition in

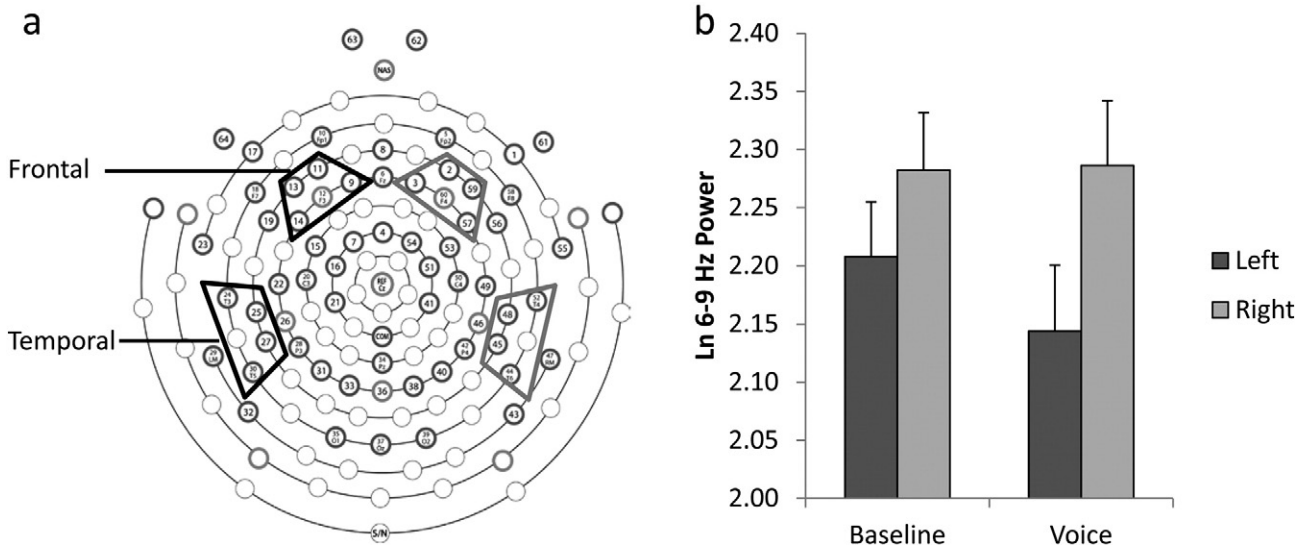


Fig. 1. (a) The map of the 60-channel HydroCel Geodesic Sensor Net. Electrode groupings used for the analysis of EEG at frontal and temporal scalp areas are denoted with parallelograms. (b) Mean frontal left and right hemisphere electrical activity at 6–9 Hz, expressed as natural log EEG power, recorded during baseline and voice conditions. Note that reduced power indicates increased cortical activity.

which only bubble cascades were presented. Our results extend previous behavioral observations by suggesting that human voices might be able to elicit brain electrical activity corresponding to approach-related emotions in infants.

Voice-specific processing has been found in the superior temporal cortex of human adults and infants (Belin et al., 2000; Charest et al., 2009; Grossmann et al., 2010; Rogier et al., 2010). For example, Grossmann et al. (2010) using NIRS it was found that 7-month-old infants showed increased hemodynamic responses in the superior temporal cortex to the human voice. Some studies further observed increased hemodynamic responses to normal speech in left temporal areas of neonates and 3-month-old infants (Dehaene-Lambertz et al., 2002; Pena et al., 2003). We did not find the lateralized-temporal brain activity in response to human voices in two-month-old infants. The possible explanation is that the alpha activity might not be related to the voice-specific processing.

Several studies have found that young infants show the lateralized-frontal brain activity in response to language stimuli. Using functional magnetic resonance imaging, Dehaene-Lambertz et al. (2002) found that in addition to activation in the left superior temporal and angular gyri, the right prefrontal cortex was active in awake 3-month-old infants processing normal speech. A recent study investigated the neural bases of the memory of word sounds in newborns by using NIRS (Benavides-Varela et al., 2012). They reported characteristic neural responses in the right frontal areas of newborns during the recognition of speech sequence. These studies suggest that cortical areas related to speech processing are already active in very young infants, even at birth. It is interesting that we also observed asymmetrical frontal brain activity in response to human voices by using EEG in our study. However, inconsistent with previous studies, we found relative left frontal activity instead of right frontal activity, indicating that the asymmetrical frontal brain activity observed in our study might reflect other processing rather than speech processing. Behavioral studies show that infants display a positive bias to human voices (Ecklund-Flores and Turkewitz, 1996; Hutt et al., 1968; Wolff, 1963). In addition, relative left frontal alpha activity has been associated with positive, approach-related emotions (Bell and Fox, 1994; Davidson, 1992; Davidson and Fox, 1982). Therefore, the relative left frontal activity elicited in 2-month-old infants by human voices in our study might be related to approach-related emotions, which indicates that brain systems related to emotion processing might emerge also at a very early age.

Infants also prefer music to noise and vocal music to instrumental music (Standley and Madsen, 1990). However, Hernandez-Reif et al. (2006) found that newborns showed greater relative right frontal EEG asymmetry to both vocal and instrumental music, suggesting a withdrawal response. This inconsistency between our study and their study might be interpreted as follows. It is possible that only a mother's voice could elicit greater relative left frontal brain activity, because infants are able to recognize their mother's voice and prefer their mother's voices over any other human voice after birth (Beauchemin et al., 2011; Decasper and Fifer, 1980; deRegnier et al., 2000; Fifer and Moon, 1994). In the present study, infants were presented with both their mother's voice and another female voice in random order. We thus could not separate whether only mother's voice, or both, evoked increased relative left frontal brain activity. Future direct comparisons between the frontal EEG asymmetry elicited by mother and stranger voices will be critical for dissecting emotion processing of different voices in the human infant brain.

In addition, although the human voice is the most powerful sound for infants, it is possible that sounds other than human voices could evoke greater relative left frontal activity. Thus, lacking a control condition ("other-sounds condition") is one of the main limitations of the present study. Furthermore, 2-month-old infants already have experiences with the word "baby" which used as the stimuli in the present study. The familiarity with the word "baby" might also evoke this brain activity. Therefore, given the richness of the stimuli used and the

lack of controls in the present study, it is difficult to determine the actual explanation. Future studies specifically comparing human voices to other sounds are needed to confirm or refute these possibilities. Including behavioral assessment in future studies would help to confirm the relations between left frontal alpha activity and approach-related emotions elicited by human voices.

In addition to the asymmetric frontal response in association with emotions, many functional neuroimaging studies in adults indicate that the predominant left frontal activation might be association with the process of encoding verbal or nonverbal information (Fletcher et al., 1998; Kelley et al., 1998; Nyberg et al., 1996; Tulving et al., 1994). Since we used the verbal stimulus in the present study and infants listened to a repetition of the same stimulus throughout the 2 min, it is possible that the asymmetric frontal response we observed here might be related to encoding processes.

To our knowledge, this is the first study demonstrating that sounds (i.e., human voices) can elicit greater relative left frontal alpha activity in young infants. This finding might be related to the positive effects of human voices on infants observed through their behaviors in previous studies (Ecklund-Flores and Turkewitz, 1996; Reeb-Sutherland et al., 2011; Wolff, 1963). The brain activity and corresponding emotional response may facilitate language acquisition and the human–infant relationship. This study establishes a scientific basis for encouraging parents to talk to their prelinguistic infants. In addition, these findings might have important implications for neurodevelopmental disorders. For example, one of the characteristics of autism is difficulties in social and emotional functioning. Children with autism display poor orienting to the human voice (Klin, 1991). They also show less positive emotion than typically developing children (Zwaigenbaum et al., 2005). Assessing brain responses to human voices in very young infants might provide a means of identifying autism in early infancy before behavioral symptoms appear.

Conflict of interest

The authors declare no conflicts of interest.

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References

- Beauchemin, M., Gonzalez-Frankenberger, B., Tremblay, J., Vannasing, P., Martinez-Montes, E., Belin, P., Beland, R., Francoeur, D., Carceller, A.M., Wallois, F., Lassonde, M., 2011. Mother and stranger: an electrophysiological study of voice processing in newborns. *Cereb. Cortex* 21, 1705–1711.
- Belin, P., Zatorre, R.J., Lafaille, P., Ahad, P., Pike, B., 2000. Voice-selective areas in human auditory cortex. *Nature* 403, 309–312.
- Bell, M.A., Fox, N.A., 1994. Brain development over the first year of life: relations between EEG frequency and coherence and cognitive and affective behaviors. In: Dawson, G., Fischer, K. (Eds.), *Human behavior and the developing brain*. Guilford Press, New York, pp. 314–345.
- Benavides-Varela, S., Hochmann, J.-R., Macagno, F., Nespor, M., Mehler, J., 2012. Newborn's brain activity signals the origin of word memories. *Proc. Natl. Acad. Sci.* 109, 17908–17913.
- Burden, M.J., Westerlund, A.J., Armony-Sivan, R., Nelson, C.A., Jacobson, S.W., Lozoff, B., Angelilli, M.L., Jacobson, J.L., 2007. An event-related potential study of attention and recognition memory in infants with iron deficiency anemia. *Pediatrics* 120, E336–E345.
- Charest, I., Pernet, C.R., Rousselet, G.A., Quinones, I., Latinus, M., Fillion-Bilodeau, S., Chartrand, J.P., Belin, P., 2009. Electrophysiological evidence for an early processing of human voices. *BMC Neurosci.* 10.
- Davidson, R.J., 1992. Emotion and affective style: hemispheric substrates. *Psychol. Sci.* 3, 39–43.

- Davidson, R.J., Fox, N.A., 1982. Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science* 218, 1235–1237.
- Davidson, R.J., Fox, N.A., 1989. Frontal brain asymmetry predicts infants' response to maternal separation. *J. Abnorm. Psychol.* 98, 127–131.
- Dawson, G., Klinger, L.G., Panagiotides, H., Hill, D., Spieker, S., 1992. Frontal lobe activity and affective behavior of infants of mothers with depressive symptoms. *Child Dev.* 63, 725–737.
- Dawson, G., Panagiotides, H., Klinger, L.G., Spieker, S., 1997. Infants of depressed and non-depressed mothers exhibit differences in frontal brain electrical activity during the expression of negative emotions. *Dev. Psychol.* 33, 650–656.
- Decasper, A.J., Fifer, W.P., 1980. Of human bonding: newborns prefer their mothers' voices. *Science* 208, 1174–1176.
- Dehaene-Lambertz, G., Dehaene, S., Hertz-Pannier, L., 2002. Functional neuroimaging of speech perception in infants. *Science* 298, 2013–2015.
- Dehaene-Lambertz, G., Montavont, A., Jobert, A., Alliro, L., Dubois, J., Hertz-Pannier, L., Dehaene, S., 2010. Language or music, mother or Mozart? Structural and environmental influences on infants' language networks. *Brain Lang.* 114, 53–65.
- deRegnier, R.A., Nelson, C.A., Thomas, K.M., Wewerka, S., Georgieff, M.K., 2000. Neurophysiologic evaluation of auditory recognition memory in healthy newborn infants and infants of diabetic mothers. *J. Pediatr.* 137, 777–784.
- deRegnier, R.A., Long, J.D., Georgieff, M.K., Nelson, C.A., 2007. Using event-related potentials to study perinatal nutrition and brain development in infants of diabetic mothers. *Dev. Neuropsychol.* 31, 379–396.
- Ecklund-Flores, L., Turkewitz, G., 1996. Asymmetric headturning to speech and nonspeech in human newborns. *Dev. Psychobiol.* 29, 205–217.
- Fifer, W.P., Moon, C.M., 1994. The role of mother's voice in the organization of brain function in the newborn. *Acta Paediatr. Suppl.* 397, 86–93.
- Fletcher, P., Shallice, T., Dolan, R., 1998. The functional roles of prefrontal cortex in episodic memory. I. Encoding. *Brain* 121, 1239–1248.
- Fox, N.A., 1991. If it's not left, it's right: electroencephalograph asymmetry and the development of emotion. *Am. Psychol.* 46, 863–872.
- Fox, N.A., Davidson, R.J., 1986. Taste-elicited changes in facial signs of emotion and the asymmetry of brain electrical activity in human newborns. *Neuropsychologia* 24, 417–422.
- Friedlander, B.Z., 1970. Receptive language development in infancy: issues and problems. *Merrill-Palmer Q. Behav. Dev.* 16, 7–51.
- Grossmann, T., Oberecker, R., Koch, S.P., Friederici, A.D., 2010. The developmental origins of voice processing in the human brain. *Neuron* 65, 852–858.
- Hernandez-Reif, M., Diego, M., Field, T., 2006. Instrumental and vocal music effects on EEG and EKG in neonates of depressed and non-depressed mothers. *Infant Behav. Dev.* 29, 518–525.
- Homae, F., Watanabe, H., Nakano, T., Taga, G., 2011. Large-scale brain networks underlying language acquisition in early infancy. *Front. Psychol.* 2.
- Hutt, S.J., Hutt, C., Lenard, H.G., Vonbernu, H., Muntjewe, W.J., 1968. Auditory responsivity in the human neonate. *Nature* 218, 888–890.
- Kelley, W.M., Miezin, F.M., McDermott, K.B., Buckner, R.L., Raichle, M.E., Cohen, N.J., Ollinger, J.M., Akbudak, E., Conturo, T.E., Snyder, A.Z., 1998. Hemispheric specialization in human dorsal frontal cortex and medial temporal lobe for verbal and nonverbal memory encoding. *Neuron* 20, 927–936.
- Klin, A., 1991. Young autistic children's listening preferences in regard to speech: a possible characterization of the symptom of social withdrawal. *J. Autism Dev. Disord.* 21, 29–42.
- Lozoff, B., Klein, N.K., Nelson, E.C., McClish, D.K., Manuel, M., Chacon, M.E., 1998. Behavior of infants with iron deficiency anemia. *Child Dev.* 69, 24–36.
- Mai, X., Xu, L., Li, M., Shao, J., Zhang, Z., deRegnier, R., Nelson, C.A., Lozoff, B., 2012. Auditory recognition memory in 2-month-old infants as assessed by event-related potentials. *Dev. Neuropsychol.* 37, 400–414.
- Naoi, N., Minagawa-Kawai, Y., Kobayashi, A., Takeuchi, K., Nakamura, K., Yamamoto, J., Shozo, K., 2012. Cerebral responses to infant-directed speech and the effect of talker familiarity. *NeuroImage* 59, 1735–1744.
- Nyberg, L., Cabeza, R., Tulving, E., 1996. PET studies of encoding and retrieval: the HERA model. *Psychon. Bull. Rev.* 3, 135–148.
- Pena, M., Maki, A., Kovacic, D., Dehaene-Lambertz, G., Koizumi, H., Bouquet, F., Mehler, J., 2003. Sounds and silence: an optical topography study of language recognition at birth. *Proc. Natl. Acad. Sci. U. S. A.* 100, 11702–11705.
- Reeb-Sutherland, B.C., Fifer, W.P., Byrd, D.L., Hammock, E.A.D., Levitt, P., Fox, N.A., 2011. One-month-old human infants learn about the social world while they sleep. *Dev. Sci.* 14, 1134–1141.
- Rogier, O., Roux, S., Belin, P., Bonnet-Brilhaut, F., Bruneau, N., 2010. An electrophysiological correlate of voice processing in 4- to 5-year-old children. *Int. J. Psychophysiol.* 75, 44–47.
- Shagass, C., 1972. Electrical activity of the brain. In: Greenfield, N.S., Sternbach, R.A. (Eds.), *Handbook of Psychophysiology*. Holt, Rinehart and Winston, New York, pp. 263–328.
- Siddappa, A.M., Georgieff, M.K., Wewerka, S., Worwa, C., Nelson, C.A., DeRegnier, R.A., 2004. Iron deficiency alters auditory recognition memory in newborn infants of diabetic mothers. *Pediatr. Res.* 55, 1034–1041.
- Standley, J.M., Madsen, C.K., 1990. Comparison of infant preferences and responses to auditory stimuli: music, mother, and other female voice. *J. Music. Ther.* 27, 54–97.
- Tulving, E., Kapur, S., Craik, F., Moscovitch, M., Houle, S., 1994. Hemispheric encoding/retrieval asymmetry in episodic memory: positron emission tomography findings. *Proc. Natl. Acad. Sci.* 91, 2016–2020.
- Wolff, P.H., 1963. Observations on the early development of smiling. In: Foss, B.M. (Ed.), *Determinants of Infant Behavior*. Wiley, New York, pp. 113–138.
- Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., Szatmari, P., 2005. Behavioral manifestations of autism in the first year of life. *Int. J. Dev. Neurosci.* 23, 143–152.