Effect of maturation on suprasegmental speech processing in full- and preterm infants: a mismatch negativity study

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Abstract
Infants born prematurely are at higher risk for later linguistic deficits present in delayed or atypical processing of phonetic and prosodic information. In order to be able to specify the nature of this atypical development, it is important to investigate the role of early experience in language perception. According to the concept of Gonzalez-Gomez and Nazzi (2012) there is a special intrauterine sensitivity to the prosodic features of languages that should have a special role in language acquisition. Therefore, we may also assume that pre- and full-term infants having months difference in intrauterine experience show different maturation patterns of processing prosodic and phonetic information present at word level. The aim of our study was to investigate the effect of these differences on word stress pattern vs. phoneme information processing.
Two age groups of infants (6 and 10 month-olds) were included in our study. 21 of 46 of the total of infants investigated were prematurely born with low birth weight.
We used the mismatch negativity (MMN) event related brain potential (ERP) component, a widely used electrophysiological correlate of acoustic change detection, for testing the assumed developmental changes of phoneme and word stress discrimination. In a passive oddball paradigm we used a word as standard, a pseudo-word as phoneme deviant, and an illegally uttered word as stress deviant.
Our results showed no differences in MMN responses in the phoneme deviant condition between the groups, meaning a relatively intact maturation of phoneme processing of preterm infants as compared to their contemporaries. However, the mismatch responses measured in the stress condition revealed significant between-group differences. These results strengthen the view that the total length of intrauterine experience influences the time of emergence of prosodic processing.

Keywords
maturation, preterm infants, speech perception, phoneme and stress discrimination, mismatch negativity

1. Introduction

The last decade of infant studies showed how well the early discrimination abilities of acoustic input could predict the mature linguistic skills during language acquisition (Benasich & Tallal, 2002; Kuhl & Rivera-Gaxiola, 2008). It seems that understanding verbal utterances needs a well-developed processing of crucial information present in the speech signal at pre-lexical level. The infants' ability to use phonetic and prosodic information is one of the many factors in service of detecting words in the speech flow.

Experiments testing infants' early speech processing abilities show that they are able to discriminate between different phoneme categories (Dehaene-Lambertz & Dehaene, 1994). This ability is based on the emerging categorical perception, which means that while setting category boundaries the acoustic variants of one category contribute to the same percept relying on invariant features (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). As Dehaene-Lambertz and Pena (2001) claim this automatic and fast *perceptual normalization process* which is simultaneous with the acoustic feature processing of speech stimuli is present from birth on.

As it is well known from the first behavioral studies on word stress processing, infants are sensitive to the prosodic cues present in spoken utterances as well. Nazzi, Bertoncini, and Mehler (1998) demonstrated that newborns can differentiate between two languages based on their rhythmic properties. According to the *native language* *acquisition hypothesis* this general ability, similarly to phoneme discrimination, becomes language specific due to experience with one's native language around the 5th month of age (Nazzi, Jusczyk, & Johnson, 2000).

Emphasizing the role of early prosodic processing the concept of *prosodic bootstrapping* published by Nazzi and Ramus (2003) claims that infants show an exquisite sensitivity to language-general rhythmic properties present at sentence level and this helps detecting language specific word forms already at the second half of the first year of life. Moreover, it seems that words stress information is one of those important prosodic cues that contribute to the identification of word boundaries. This information may have a special role in languages where word stress is highly regular (as in Hungarian), or have a high percentage of stress regular words formed by a large set of bisyllabic words of similar stress pattern (as in English), contributing to biased processing of the specific pattern (trochaic unit: stressed syllable followed by an unstressed one). As the experimental results of Jusczyk, Houston, and Newsome (1999) revealed more than a decade ago, American babies of 7.5 months showed an exquisite sensitivity to the predominant trochaic stress pattern in English called as *trochaic bias*. However, a decade later, results of a cross-linguistic study (Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009) revealed an earlier emergence of this bias in German infants as compared to French ones.

The first electrophysiological studies on infants' automatic detection of trochaic pattern revealed discriminative abilities below the age of 6 months as well. Weber, Hahne, Friedrich, and Friederici (2004) and Friedrich, Herold, and Friederici (2009) found that German infants of 5 months could well discriminate words of different stress patterns, showing a positive mismatch response to deviants with stress on the first syllable contrasted with standards with stress on the second syllable (Weber et al., 2004), as well as for deviants with stress on the second syllable contrasted with standards of first syllable stress (Friedrich et al., 2009).

Friederici, Friedrich, and Christophe (2007) demonstrated in a cross-linguistic study that in German and French infants a language-specific word stress pattern detection was present as early as the 4th month of age. These electrophysiological data supported the behavioral results of Nazzi, Iakimova, Bertoncini, Frédonie, and Alcantara (2006) and recently of Nazzi, Mersad, Sundara, Iakimova, and Polka (2013) who proposed that in case of European French-learning infants the rhythmic unit of French (the syllable) was used for segmenting continuous speech, a pattern assumed to have a similar role as the rhythmic unit of English (i.e. the trochaic stress unit) English infants rely on.

The primary focus of our present study was to shed light on the maturational and developmental factors of word stress processing as compared to phonetic information. Our question was when and how infants are able to use phoneme and stress information in order to discriminate different forms of the same word.

The secondary focus of this study was to compare the linguistic capabilities of premature and full term infants in order to better understand the importance of intra- versus extra-uterine development and to shed light on the origin of common preschool language deficits of premature infants.

A recent study revealed an interesting phenomenon with respect to the possible role of early experience. As Gonzalez-Gomez and Nazzi (2012) suggest *the intrauterine experience favors processing prosody* over the other attributes of speech. As the two authors argue the uterus works as a low pass filter resulting in attenuated higher frequencies and allowing fetuses to process prosodic information (Griffiths, Brown, Gerhardt, Abrams, & Morris, 1994). Gonzalez-Gomez and Nazzi (2012) argue that even the in-utero vowel discrimination could be explained by suggesting that fetuses react to the stimuli on the basis of prosodic properties (cf. Lecanuet, Graniere-Deferre, Jacquet, and DeCasper (2000) who claim that differences in the structure of formants of the vowels make some syllables louder than the others causing the perceptual differences). Mampe, Friederici, Christophe, and Wermke (2009) found different cry patterns in case of French and German newborns according to their native-language prosody, which also demonstrate the special intrauterine sensitivity to prosodic features of languages.

For testing the role of intrauterine experiences on early perceptual abilities Gonzalez-Gomez and Nazzi (2012) tested if healthy preterm infants showed developmental lag in discrimination of consonant sequences. Their results revealed that preterm infants behaved according to their chronological age. These results are in concordance with the results of Pena, Werker, and Dehaene-Lambertz (2012) who didn't find differences in phoneme discrimination between preterm and full-term infants. This result was also confirmed by Mahmoudzadeh et al. (2013) who, by using NIRS (near infrared spectroscopy), found further evidence of the advanced maturity of the phoneme-sensitive cortical network at birth. As the authors argued maturation only, and not the duration of post-term experience determined the phoneme discrimination abilities.

Although maturational differences were found between preterm and full-term infants for phoneme discrimination, these differences seemed to diminish by the first half of the first year of life. Key, Lambert, Aschner, and Maitre (2012) revealed that the first 4 months of extra-uterine life represent the most sensitive period considering maturational differences in vowel and consonant discrimination. However, it has been found that in case of prosodic information preterm infants are not merely unable to profit from the experience of the longer extra-uterine life, but systematically show developmental lag (Pena, Pittaluga, & Mehler, 2010). Their results revealed, that 6 month-old preterm infants were at the level of 3 months during the discrimination of their mother tongue from a rhythmically similar language. According to the hypothesis of Gonzalez-Gomez and Nazzi (2012) this difference is caused by the shortened intrauterine time preventing from a sufficient exposition to the filtered prosodic information processed by a cortical network assumed to be different from that of phonetic information functioning according to the maturational age.

It seems to be relevant that for studying the impact of maturation on the development of these two kinds of basic processes influencing the later language skills and learning abilities, the possible effect of experience would be compared by investigating pre- and full-term babies at different months of the first year of life.

This is of broader interest for many reasons. Studies on cognitive skills of children born preterm demonstrate a high frequency of learning difficulties including speech and language processing deficits (Grunau, Oberlander, Whitfield, Fitzgerald, & Lee, 2001; Jennische & Sedin, 2001; Rickards, Kelly, Doyle, & Callanan, 2001). These deficits are hypothetically connected to problems of primary auditory attention and perception (Davis et al., 2001). Gomot, Bruneau, Laurent, Barthelemy, and Saliba (2007) found deficient auditory processing in prematurely born infants even at the age of nine. Mikkola et al. (2007) conducted a longitudinal study where they could follow the altered acoustic processing up to the 5th year of age. Jansson-Verkasalo et al. (2010) found qualitatively different ERP response pattern in case of 4 year-olds born with very low birth weight. A more recent study of Ramon-Casas, Bosch, Iriondo, and Krauel (2013) showed diminished lexical processing speed at the age of two.

Based on all the suggestions of these studies one may assume that a better specification of the nature of early maturational differences would allow us to develop more effective intervention programs to be used from the early months of life on.

In order to test the assumed correlation between different intrauterine experiences as well as phonetic and prosodic information processing abilities, we tested preterm and full-term born infants in two conditions: in a phonetic and in a word stress discrimination task by measuring the Mismatch Negativity (MMN) event-related brain potential (ERP) component. The MMN is a negative going auditory ERP component of fronto-central voltage maximum, appearing 100-250 ms after the onset of change in any feature of the incoming acoustic events (for review see Näätänen (2001).

The vast majority of studies use the passive oddball paradigm where deviant stimuli are expected to elicit the Mismatch Negativity ERP component. The MMN paradigm is seen as ideal for infant studies as it measures pre-attentive change detection mechanisms, present even in newborns, and are sensitive to various kinds of deviances (cf. Ceponiene et al. (2002); Dehaene-Lambertz and Baillet (1998); Kujala et al. (2004); Kushnerenko, Ceponiene, Balan, Fellman, and Näätänen (2002); Pihko et al. (1999); Sambeth, Huotilainen, Kushnerenko, Fellman, and Pihko (2006).

Most of the MMN studies focusing on prosodic information use a single feature, mostly the duration of sounds. Leppänen et al. (2002) tested the detection of stress information while changing the duration of consonants. Friederici and her colleagues (Friederici et al. (2007), Friedrich et al. (2009) and Weber et al. (2004) investigated the infants' early sensitivity to stress information by varying the duration of vowels. In contrast, our approach was to use acoustically rich stress information, including several specific cues related to syllabic stress, such as intensity, F0, and rise time.

Our goal was to study the use of phoneme and stress information in infancy at the word level. Therefore, the prosodic cues used in our experiment were as complex as in spoken utterances, so that the stimuli used were highly similar to the typical stress pattern of the Hungarian language (changing intensity, F0, and rise time). We presented a meaningful word (and its two modified counterparts) to the participants by using digitized natural speech produced by a native speaker. The stress manipulated stimulus was an illegally stressed form of the normal word. To test the use of phonetic information we changed the first phoneme of the word thus creating a pseudo-word. For our experiment, another important task was to decide on the age when early enough and reliable behavioral and brain correlates of stress pattern detection can be expected. According to the literature reviewed above we decided for testing infants of 6 and 10 months of age.

Our hypothesis was that both maturation and duration of exposure to the language in acquisition would affect the phoneme and word stress discrimination so that the MMN would show age differences (6 vs. 10 month-olds) for both of the processes investigated. However, if prenatal experience favored prosody over other features and phonemic processing functioned according to the cortical network's extra-uterine maturation, we wouldn't find differences in phoneme discrimination according to the status of infants (preterm vs. full-term), and preterm infants would show a lack or delay only in detecting stress information deviating from the regular pattern.

2. Methods

2.1. Participants

Ninety-eight infants were recruited to participate in the experiment. Fifty-two of them were excluded either because they did not match the strict selection criteria aimed to promote group homogeneity concerning age, birth weight, and Gestation Age (GA) characteristics (n=12), or because of a low percentage of the artifact-free trials in the electrophysiological data due to infants' disturbed behavior such as crying, and/or frequent and excessive head and body movements (n=40). Statistical analyses were made on data of the remaining forty-six infants (23 boys and 23 girls).

All preterm infants were recruited by using the database of the Follow up Center for Developmental Neurology, I. Department of Obstetrics and Gynecology, Semmelweis University, Budapest, Hungary. Inclusion criteria for premature infants were normal cerebral ultrasound and hearing-testing (oto-acoustic emissions). The definition of preterm birth was used in the study, for infants born below 37 weeks of gestation and at 1000-2000 g of birth weight. All infants with cerebral malformations and perinatal cerebral problems, such as asphyxia, intraventricular heamorrhage, periventricular leukomalacia were excluded. According to the ethical requirements set by the Ethical Board responsible for permission we conducted the experiment at the clinic applying a portable EEG/ERP recording system (BrainAmp from BrainProducts GmbH) after having the parents' written informed consent.

With the principle of focusing on maturation the preterm infants' age was not corrected to the expected date of delivery. Although this method do not conform the generally accepted clinical suggestion (see Allen and Alexander (1990); Ouden, Rijken, Brand, Verloovevanhorick, and Ruys (1991); Restiffe and Gherpelli (2006) our reasons were the following: i) definition of gestational age, and consequently the value of correction is debated (see Lems, Hopkins, and Samsom (1993); Siegel (1983); Urquia, Moineddin, and Frank (2012); ii) testing speech perception in relation to the duration of experience with the mother tongue seemed to be more important than the definition of developmental lag; iii) as the developmental dynamics are different in the pre- and postnatal periods, it is not easy to define the exact developmental lag in case of individual infants (cf. Kosińska (2006) who suggests that using chronological age is acceptable and sometimes more reasonable when we try to emphasize the role of duration of intrauterine developmental differences, and the influence of gestational age in development).

In our opinion, gestational age and not corrected ages at 6 and 10 months has the advantage of reflecting purely similar extrauterine maturation for preterm and full-term groups. It also provides us the opportunity to compare our results with studies reflecting on later linguistic problems of preterm infants, such as dyslexia, dyscalculia. There is evidence from MR studies that the preterm brain at corrected age on term is different from the term infants' brain (Inder, Warfield, Wang, Huppi, & Volpe, 2005). Premature brain shows smaller volume, less cortical folding and less grey matter when compared to full-term controlls. Therefore we decided that trying to correct weight for the two groups would not reflect truly the brain maturation.

The full-term infants were selected with help of pediatricians from the Health Care Centre (Vezér utca, Budapest, Hungary).

The full-term infants were selected during the routine follow up screening at a local health centre by a pediatritcian. Inclusion criteria included gestational age above 38 weeks of gestation, no perinatal problems, no chronic diseases and normal hearing test. Parents were fully informed and consented before the experiment. The circumstances and conditions of the EEG recordings were similar to those of preterm infants.

We created 4 groups of infants based on age, and the term of birth. We had two age groups: 6-month-old infants (n=20), 10-month-old infants (n=26). Consequently we had 21 preterm and 25 full-term infants. Combining these two characteristics we created four groups of participants: ten 6-month old preterm infants, ten 6-month old full-term infants, eleven10-month old preterm infants, and fifteen 10-month old full-term infants. The range of birth weight and GA of the groups were the following: i) 6 month-old preterm: 980-2100 g & 28-36 GA; ii) 6 month-old full-term: 2970-389 g & 38-42 GA; iii) 10 month-old preterm: 950-1920 g & 28-33 GA; iv) 10 month-old full term: 2330-3850 g & 38-42 GA. For details of main descriptive statistics see Table 1.

Table1. Descriptive data of the four group of subjects.

	N	Mean age in month (SE)	Mean birth weight in gram (SE)	Mean GA in week (SE)
6PT	10	6.2 (.29)	1632 (212.27)	31.8 (1.009)
6FT	10	6.05 (.28)	3373 (113.99)	39.6 (0.371)
10PT	11	10.09 (.21)	1288.18 (112.89)	30.64 (.54)
10FT	15	10.73 (.61)	3312.67 (111.46)	39.2 (.341)

Note: PT: preterm; FT: full-term; SE: standard error

In the following we present the result of statistical analyses we performed in order to verify the validity of our grouping method. The one-sample t-test calculated on the descriptive data revealed that the birth weight of the two preterm groups did not differ significantly from 1500 grams ($t(20) = -.4$ $p = .693$) but the two full-term group's did ($t(24)=23.081$ $p < .001$). Corresponding to the GA criteria the preterm group was significantly below 37 weeks, and the full-term was significantly above (preterm groups: $t(20)=-10.393$ $p < .001$; full-term group: $t(24)=9.407$ $p < .001$) The one-way ANOVA tests revealed significant differences between the preterm and full-term groups based on birth weight and GA characteristics (birth weight: $F(1)=180.649$ $p < .001$; GA: $F(1)=198.32$ $p < .001$). These differences were present if we separate the four groups: ANOVAs for the GA differences between preterm and full-term groups showed that the GA was significantly different (6 month-olds $F(1)=52.65$ $p<0.001$; 10 month-olds $F(1)=196.15$ $p<0.001$.) There was also a significant difference between the full-term and preterm groups regarding the birth weight (ANOVAs for the birth-weight differences between preterm and full-term groups: 6 month-olds $F(1)=52.21$ $p<0.001$; 10 month-olds $F(1)=155.65$ $p<0.001$.)

2.2. Stimuli and experimental conditions

We used a passive oddball paradigm with a standard Hungarian word `banán` (`banana` in English) and two deviants: a voiceless phoneme deviant (`panán`, which is meaningless in Hungarian), and a stress deviant where the stress was on the second syllable, instead of the first which is a normal stress pattern in Hungarian (`ban:án`) (for all details see Honbolygó, Csépe, and Ragó (2004). The acoustical properties of stimuli were the following: the maximal amplitudes of the first and second syllables were 77 vs. 74 dB in the case of the standard, and 72 vs. 76 dB in the case of the stress deviant. The maximal f0's were 210 vs. 183 Hz in the case of the standard, and 177 vs. 180 Hz in the case of the stress deviant.

The experimental stimuli uttered by a native female speaker and were recorded and digitized by means of a personal computer with a sampling rate of 44100 Hz. The stimuli were presented in random order; the probability of the deviant stimuli was 25%, and the stimulus onset asymmetry (SOA) varied randomly between 730 and 830 ms. The two deviants were presented in separate series (150 standard and 50 deviant stimuli; the order of two series was counterbalanced).

During the experiment babies sat on their parents lap, in a silent room. We used different toys as distractor stimuli, in order to prevent the babies paying attention to the acoustic stimuli. The experimental stimuli were presented via two loudspeakers placed in equal distance (40 cm) from the infants' head on the left and on the right side. The volume was the same for all participants.

2.3. Data collection and measurement

The electroencephalogram was recorded from 16 scalp locations: F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, O2, T3, T4, M1, M2. The reference electrode was at point Fpz, and the ground was between Fz and Fpz on the midline.

The offline data analysis was performed by using the BrainVision Analyzer software (BrainProducts GmbH). The original EEG was algebraically re-referenced to the average activity of the two mastoid electrodes. A band-pass filter of 0.3 – 20 Hz, 12 dB/octave was used. The raw EEG data was segmented into epochs of 800 ms, time-locked to the onset of the stimulus (-100 ms before onset to 700 ms after onset). Next, we applied an automatic artifact rejection method where amplitudes above ±120μV were discarded. Participants whose recordings were below 20 artifact-free epochs were excluded from further analysis (see above). Then the segmented data was base-line corrected from -100 ms to the onset of the stimuli and finally, the remaining epochs were averaged. To ensure that averages were based on an equal number of epochs, we calculated averages to the standard stimuli by selecting those epochs presented before the two kinds of deviants respectively.

Based on the result of adult data in the similar experiment and the grand averages in the present experiment two time-windows of 100 ms were selected between 250-350 ms, and at 450-550 ms at the frontal electrode sites (F3, Fz, F4) in the phoneme deviant condition. In the stress deviant condition two time-windows of 100 ms was selected between 200-300 ms and 500-600 ms at the same electrode sites.

For analyzing data we performed 2x3x2x2 mixed ANOVAs (the first two repeated within subject factor were standard vs. deviant conditions and 3 electrode sites; the last two between subject factors were 6-, vs. 10 month-old, and preterm vs. full term) separately for the three conditions (phoneme deviant first and second response, stress deviant responses). Because of a possible violation of the sphericity assumption we used the Greenhouse-Geisser (G-G) adjusted univariate tests where it was necessary.

3. Results

Grand-average ERP waves computed separately for the 4 groups were obtained by averaging the individual waveforms of all the participants (see Figure1 for phoneme deviant condition and Figure2 for stress deviant condition). In case of phoneme deviant we can see the two latency ranges where the deviant curve differs from the standard one. This twofold difference is partly similar to our previous results (Honbolygó et al., 2004), where we found two negativities. The first was located at 300 ms and a second one at 400 ms. In case of stress deviant, based on adults' data we could expect two latency ranges where ERP's to the standard and deviant stimuli could differ. Our first impression was that the first mismatch response (the so called S- located at 334 ms in adults) was absent on the infants' ERPs, nevertheless we analyzed responses in the corresponding time window (200-300 ms). At the second time window there was a huge positive deflection at some of the groups near 500 ms (most probably the counterpart of S+ that was the biggest at 632 ms in adults).

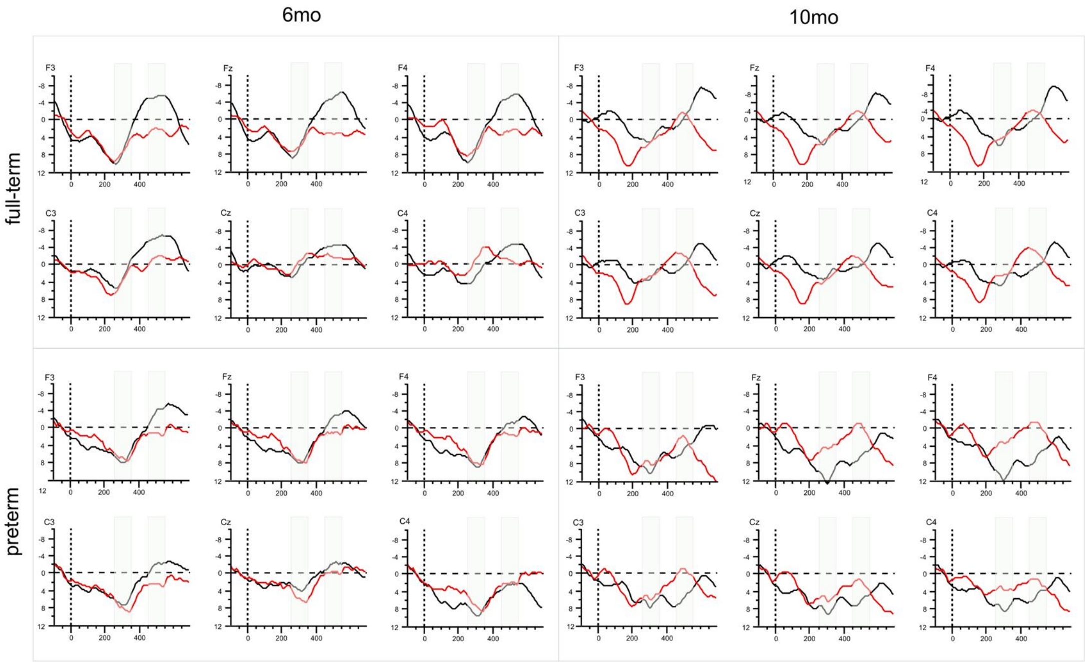

Figure1. Phoneme deviant condition. A standard and deviant grand average curves computed in the four groups at the three frontal and the three central electrode sites. Black is for the standard and red lines show the phoneme deviant responses. Negativity is upward here and on the following figures. The grey areas highlight the two time windows where significant mismatch negativity responses were found (250-350 ms & 450-550 ms).

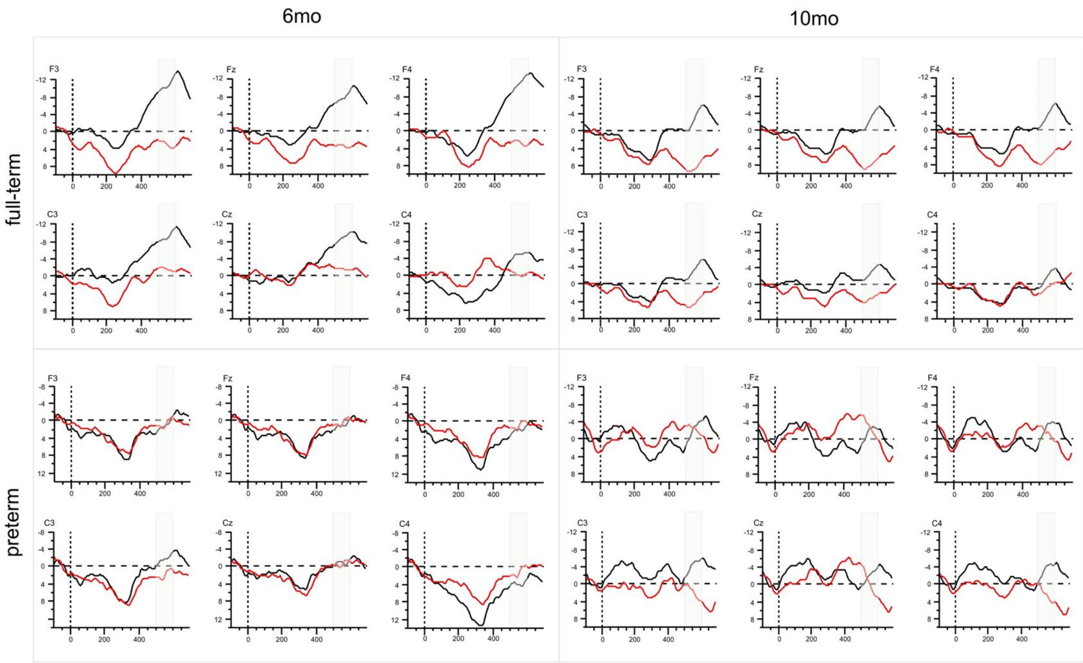

Figure2. Stress deviant condition. A standard and deviant grand average curves computed in the four groups at the three frontal and the three central electrode sites. Black is for the standard and red lines show the stress deviant responses. The grey area highlights the time window where significant positive mismatch responses were found (500-600 ms).

3.1. Phoneme deviant condition

In the phoneme deviant condition, based on adults' data and grand average curves we expected two peaks to occur: one at an early period and another later. The repeated-measures ANOVA revealed significant differences between the ERP's of standard and phoneme deviant in both time-windows. Figure3 shows the difference waves for all infants, and the younger vs. the older groups at Fz electrode site.

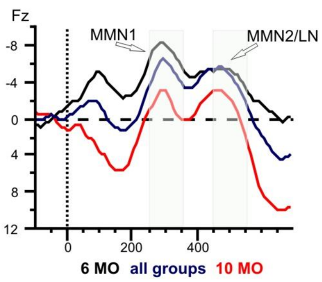

Figure3. Grand average difference waves to the phoneme deviant of all infants, and the two age groups on Fz. In both areas highlighted by the grey significant mismatch responses were found. (all groups: blue; 6month-olds: black; 10 month-olds: red; the two time windows of MMN and MMN2/LN responses are 250-350 ms and 450-550 ms).

3.1.1. First time window (250-350 ms)

In the first time window we found a significant main effect of condition (*F*(1,42)=11.834 *p*< *.002*, *r*= *.46*). The cause of this effect was the negative deviation in the deviant condition as compared to the standard condition.
Additionally, we found a significant main effect of status (*F*(1,42)=4.929 *p*< *.05*). As the mean amplitudes used by the statistical analysis could be misleading in the interpretation, we calculated the difference amplitudes of the mismatch responses in all groups (deviant minus standard on the individual EEG data). Then another mixed design ANOVA was calculated for the MMN differences at the three electrode sites with two grouping variables (age and clinical status). Here we didn't find any main effect of the grouping variables (age: *p*= *.081*; clinical status: *p*= *.955*).

3.1.2. Second time window (500-550 ms)

The phoneme deviant elicited another component occurring in the second time window and this component showed a significant main effect of condition (*F*(1,42) = 5.558 *p*< *.002*, *r*= *.34*), confirming the presence of this late mismatch negativity response. Furthermore, we found a significant main effect of age (*F*(1,42)=18.061 *p*< *.001*) and clinical status (*F*(1,42)=8.225 *p*< *.002*).
In order to clarify this effect we calculated the degree of mismatch responses in all channels in the original EEG data by subtracting standard from deviant responses.
Comparing the MMNs with a mixed ANOVA where the within-subject variable was the frontal site with three electrodes (F3, Fz, F4) and the two grouping variables were the age and clinical status, no significant difference was found in the amplitude of MMNs between the groups for age (*p*= *.499*) or for clinical status *(p*= *.823*).
Summarizing the results obtained in the phoneme deviant condition, it can be stated that no age or clinical status related differences occurred in the first time window. The two MMN components were present to the phoneme deviant in all the four groups.

3.2. Stress deviant condition

As it was mentioned above, in adults a characteristic ERP waveform of two consecutive MMNs was found. The first MMN occurred as synchronized to the unstressed syllable (peak amplitude at 334 ms) and it was interpreted as a response to the absence of stress (S-) on the first syllable of the deviant word. The second MMN response was elicited by the additional stress (S+) present as extra or salient cue on the second syllable of the word and occurred at 632 ms (cf. Honbolygó et al. (2004).
Figure4 shows the grand average ERP differences of the infants investigated in the present study at the Fz electrode site. At first inspection we cannot find the adults' S-response. However, as the full-term groups' individual difference waves were different as compared to the group average, the first time window was also used in the analysis. Based on the grand average difference waves it seems evident that the infants detected extra stress (S+) present on the second syllable and this gave rise to a mismatch response (MMR, not necessarily negative going) synchronized to the salient acoustic feature.

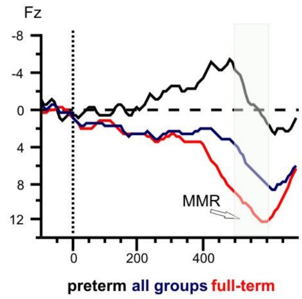

Figure4. Grand average difference waves to the stress deviant of all infants, and the full-term vs. preterm groups on Fz. The second mismatch response at the time window highlighted by the grey area was verified by the statistical analysis. (all groups: blue; preterm: black; full-term: red; the time window of MMR is 500-600 ms).

3.2.1. First time window (200-300 ms)

In spite of the first mismatch response of the grand averages missing in the first time window a mixed design 2x3x2x2 ANOVA described above was performed. The results confirmed the lack of ERP components in this time range as we did not find a significant main effect of condition ($p= .179$). None of the between-subject variables had any main effects (age: $p= .396$; clinical status: $p= .098$). The results are the same if we separate infants according to their group category, so even the older full-term groups' mismatch responses did not differ from zero.

3.2.2. Second time window (500-600 ms)

In the second ERP time window a significant main effect of condition ($F(1,42)=11.333$ $p< .003$, $r= .46$) was found. Furthermore, we have found a significant interaction of the clinical status and condition ($F(1,42)=13.963$ $p< .002$, $r= .49$). Moreover, there was a significant interaction between age and clinical status ($F(1,42)=4.693$ $p< .05$).

In order to have a better interpretation of the age effect we conducted a mixed ANOVA for the mismatch differences obtained by subtracting individual ERPs to the standard from that of the deviant. The within-subject variable was the frontal site consisting of three electrodes (F3, Fz, F4), and the grouping variables were the age and clinical status. Here a significant main effect of status was found ($F(1,42)=13.963$ $p< .002$, $r= .49$). Preterm infants had smaller positive mismatch responses than those of the full-term group. We didn't find main effect of age ($p= .339$).

Summarizing the results we can argue that in case of natural speech stimuli and complex stress cues, the detection of suprasegmental speech cues is based on detecting the presence of the salient acoustic change. Infants didn't detect the absence of the stress as adults did in our previous experiment. We found a positive MMR in the second time window. Here we did found differences between the preterm and full-term groups as the former had significantly smaller MMR than the latter. As the difference between age groups was not significant we can conclude that infants at the age of 6 months are able to detect stress information.

4. Discussion

In the present study we applied a passive acoustic odd-ball paradigm designed for measuring the MMN component. Here we used a meaningful word as standard stimulus, and two deviants: a pseudo-word by changing the first consonant of the standard as a phoneme deviant, and a stress deviant by moving the stress from the first to the second syllable violating the highly regular Hungarian stress rule. In order to test the role of intrauterine experience in prosodic processing we compared full-term and healthy preterm infants at two ages, 6 months and 10 months.
Our first hypothesis was that the two age groups would show an adult-like detection of the phoneme contrast used and partially developed word stress detection because of the two cortical networks' differences in maturation. Moreover, our second assumption based on the hypothesis on intrauterine experience favoring prosody over other linguistic features (Gonzalez-Gomez & Nazzi, 2012), so that we expected differences between preterm and full-term infants only in case of stress discrimination.
In case of phoneme detection we registered significant MMN responses in the first time window (250-350 ms), but we didn't find differences between the four groups. This result is in correspondence with the findings of Mahmoudzadeh et al. (2013) who claim that "the human brain, at the very onset of the establishment of a cortical circuit for auditory perception, already discriminates subtle differences in speech syllables" (p.4848). We did also find significant MMN responses in the second time window (450-550 ms) in case of processing the phoneme deviant. However, naming and interpreting this component is not obvious or evident. This is mainly due to the fact that this late component either reflects a process that may correspond to a late feature analysis giving rise to the adults' MMN (found in the Honbolygó et al. (2004) study at 384 ms), or correlates with a different type of processing reflected by the late discriminative negativity (the so called LDN or LNl). The second negativity elicited mainly by speech sound contrasts in a passive oddball paradigm is usually found at 450-500 ms. Alho, Woods, and Algazi (1994) found a shift, and not a component-like wave called as 'sustained negativity' following the genuine mismatch negativity response elicited by the deviant tones. They interpreted this second negativity as an ERP correlate of the sensitization period reflecting an automatic preparation to the possible subsequent changes taking place. In the developmental literature there are more frequent references to this component, though the authors label it differently. Kraus et al. (1993) called it NM4, others as late MMN (Korpilahti, Lang, & Aaltonen, 1995), and Ceponiene, Cheour, and Näätänen (1998) named this component as LDN (late difference negativity). The later authors proposed that this difference detection in children shown by the LDN could be related to a further processing of the detected change. In these cases the LDN showed scalp distribution and amplitude characteristics similar to those of the MMN component.
The third main result of our study was that no indication of a mismatch response could be found in the early time window (between 200-300 ms) of the ERPs elicited by the stress deviant, contrary to what we found in adult participants (Honbolygó et al., 2004). However, this finding confirms our hypothesis on the origin of the first MMN elicited by the lack of stress in the canonic position that is the first syllable. We suggest that there are two forms of responses to the missing stress cue eliciting the MMN response; one as a result of matching with a short-trace (like in the Friederici et al. (2007) study using the violated stress pattern as standard) and one as a result of matching to a long-term representation serving as template for comparing the incoming pattern. Our infant data provide a strong argument for this interpretation as it demonstrates the sensitivity to the salient stress cue and the absence of a well-

functioning long-term representation of the predominant native stress pattern. The MMN to the non-stressed syllable is still missing at the age of 10 months, and since the standards correspond to the regular stress pattern in Hungarian neither a short-term trace nor a long-term representation of the native language's regularity provide a sufficient basis for detecting the lack of stress on the first syllable of the stress deviant.

Moreover, the salient acoustic cue on the second syllable elicited a late positive MMR at the time window of 500-600 ms resembling the MMN found in adults in the Honbolygó et al. (2004) study. In our present study we found this component in both age groups and this means that infants are able to use the prosodic, the syllabic stress, information from the early months on as suggested by Gonzalez-Gomez and Nazzi (2012)

The fact that we found a positive ERP component, called MMR (mismatch response) in infants instead of a negative one as in adults has many precedents in the developmental electrophysiological literature. Leppänen, Eklund, and Lyytinen (1997) found MMN only in the half of the newborns to pitch change of sine-tones, but all of the infants showed the mismatch response (positive deflection at 250-350 ms). In another study Leppänen, Pihko, Eklund, and Lyytinen (1999) tested the detection of changes in vowel duration and found mismatch responses only. They interpreted these responses as the functional counterparts of adults' MMN responses. The presence of positive MMR is widely accepted in the recent literature, although the nature of processes behind and the conditions elicited in are not fully clear. As Kushnerenko et al. (2002) based on their longitudinal study suggest the positive mismatch responses are in fact P3a type responses correlating with the infants' involuntary orientation to the deviation therefore calling it difference positivity. These authors also connect this kind of response to the higher distractibility characteristic for premature (in this case those of preterm infants) processing. Another possible interpretation of the MMR comes from Pihko et al. (1999) who see this variability of positive-negative differences in 6 month-olds as a sign of maturational changes during development. A further explanation is used by Trainor et al. (2003) who emphasize the impact of background neural processes in different cortical layers on the surface recorded responses. The different background is denoted by different wave morphology of the positive and negative responses. While the MMN is usually a fast component, the positive MMR responses are slower with a longer deflection. Rivera-Gaxiola, Silva-Pereyra, and Kuhl (2005) emphasize the meaning of polarity changes further by seeing it as an indication of different processing mechanisms (e.g. different generators or listening strategies or maturity) determining the differences in speech perception processes. Furthermore, in their recent study, Mueller, Friederici, and Mannel (2012) divide infants by the polarity of their mismatch response and as a result of matching the electrophysiological responses to behavioral results, argue that the positive MMR is a correlate of immature stimulus comparison.

In an early study Näätänen, Simpson, and Loveless (1982) called the slightly differing deviants as 'proximates.' They got a more prolonged MMN to this kind of stimuli, which they attributed to subjective uncertainty. But as this connection is neither explained in detail nor confirmed we have to accept that the polarity change is the natural characteristics of the ERP responses of infants elicited by change detection.

Our most important result is the absence of change detection difference between pre- and full-term groups in the phoneme deviant condition, and a parallel to this its presence in the stress deviant condition. We suggest that our result provides further evidence on the different impact of intrauterine experience on the maturation of speech sound and prosodic information processing suggested by (Gonzalez-Gomez & Nazzi, 2012).

However, further explanations are also possible for the developmental lag of processing syllabic stress shown by preterm infants. Pena et al. (2010) measuring induced gamma band power argue for example for a maturational fallback in the prosodic processing. Gimenez et al. (2008) argue for causal relationship between the maturational lag and the microstructural deviations of white matter even in preterm infants without organic deficits.

In summary, our results show that the intrauterine period has to be taken into account when specifying the exact nature of maturation of early speech processing. As in uterus fetuses have access to reduced and low pass filtered acoustic stimuli, prosodic information as well as prosody-based phonemic cues will form the base of the postnatal speech processing and the foundations of early abilities.

The interconnection between early lexical knowledge and processing metrical information remains open. We do not know how infants use complex stress information in case of familiar words. Another question is whether the regular stress pattern of the native language is sufficient for provoking word-like processing.

The maturational difference we found in the processing word level prosody suggests a beneficial approach to develop training programs for prematurely born infants that focus on the processing of prosodic information, and for that aim we argue for the importance of investigating the prosody representation beyond the first year of age. The importance of perception of rhythmic properties of language in later development of phonological representation in dyslexics was also shown by Leong and Goswami (2013). However, for developing an effective training program we should take into account: i) language specific differences in rhythm ii) the preterm infant' sensitivity to other stress components such as duration, intensity and frequency iii) and other comorbidity factors that might play role in later language development.

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