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Research Report

Reduced stress pattern discrimination in 5-month-olds as a marker of risk for later language impairment: Neurophysiologial evidence

Christiane Weber, Anja Hahne, Manuela Friedrich, Angela D. Friederici*

Max Planck Institute for Human Cognitive and Brain Sciences, P.O. Box 500 355, 04103 Leipzig, Germany

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Abstract

The study at hand investigates prosodic abilities of infants as early predictors of Specific Language Impairment (SLI), which is commonly diagnosed at a later age. The study is based on the hypothesis that the prosodic abilities of infants at risk for SLI are less elaborated than those of controls due to less efficient processing of the relevant acoustic cues. One of the most critical prosodic cues for word segmentation is stress pattern. In German as well as in English, the most frequent stress pattern of bisyllabics is the trochee, in which stress is placed on the first syllable. Using a passive oddball design, German 5-month-olds were examined with respect to their ability to discriminate different stress patterns of bisyllabics. Infants were grouped retrospectively based on their production performance at the ages of 12 and 24 months. In contrast to matched controls, infants with very low word production displayed event-related brain potentials with a significantly reduced amplitude of the discrimination response, i.e. a Mismatch Negativity (MMN), to the trochaic stress pattern. This amplitude difference indicates impaired prosodic processing of word stress during early development and may thus be taken as an early marker of risk for SLI.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Infant; Event-related potential (ERP); Specific Language Impairment (SLI); Mismatch Negativity (MMN); Prosody; Lexicon

1. Introduction

The electrophysiological Mismatch Negativity (MMN) component has been successfully used to investigate auditory processing in adults and infants. It can be elicited in a passive oddball design by presenting subjects with a block of identical stimuli (standards) occasionally replaced by acoustically deviant stimuli (deviants). The MMN is interpreted to reflect the pre-cognitive detection of a deviance in the auditory input from information established in sensory auditory memory. Its morphology is considered to provide a neurophysiological correlate of discrimination accuracy ([19], for a review, see [37]). In adults, the MMN peak usually occurs at a latency of 100–200 ms after change onset with a fronto-central distribution. In infants, the mismatch response might occur as a negativity similar to the adult MMN [3,27,29]. Yet, a positive discrimination response starting around 300 ms after change onset is also frequently reported in very young subjects [7,10,28,39]. Some authors proposed the latter positivity to be a genuine infant discrimination response reflecting certain aspects of brain maturation [52]. Others suggested the positive deflection results from preponderant slow wave activity masking the genuine MMN in infants [35]. This hypothesis is supported by the fact that using a highpass filter during ERP analysis of infant data has a pronounced effect on the discernibility of the infant MMN [56]. Still, it seems very likely that functional aspects are associated with the slow wave positive discrimination response seen in infants. For example, it was proposed that the positivity might reflect a change in bottom–up categorization rather than a top–down change detection as assumed for the MMN ([11] but see also

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* Corresponding author. Fax: +49 3 41 99 40 113.
E-mail address: angelafr@cbs.mpg.de (A.D. Friederici).

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[32]). Thus, in contrast to the MMN, the significance of the positive infant discrimination response is still under investigation (for comprehensive discussions, see [11,35,52]).

Crucially, the amplitude of the MMN is sensitive to the accuracy of the discrimination process for auditory stimuli itself. Moreover, the component can be elicited irrespective of the attentional and/or motoric abilities of subjects. These factors make it a useful tool in investigating clinical populations of all age groups [37].

The MMN has been successfully used to explore auditory processing of speech and non-speech stimuli in subjects at and not at risk for language problems. For example, electrophysiological evidence pointing to impaired discrimination abilities, i.e. reduced MMN amplitude for different speech contrasts, was shown for learning disabled children, children with language problems as well as for infants at risk for dyslexia [23,26,29,53]. In infants, the component is well established for (segmental) phonological processing of simple Consonant–Vowel (CV), complex VCV and CVCV stimuli [27–29]. These studies have investigated infant processing of phoneme duration, as temporal changes in the speech signal often provide important cues for phoneme recognition. Note that sensitivity to consonant duration increment and decrement embedded in complex speech sounds was reported for Finnish-learning newborns and 6-month-olds [27,29]. Yet, when Finnish newborns were presented with consonant duration decrement exceeding 160 ms, no MMN was observed [27]. A similar effect was reported when German 2-month-olds were presented with decrement of vowel duration [11].

In German, vowel duration is an important aspect of phonological processing on the segmental level. Similar to Finnish, vowel length contrasts cue semantic changes in the German language. Yet, in German, vowel length is also a crucial aspect of suprasegmental phonology, namely, syllable stress [54]. Suprasegmental information in stress timed languages like German or English, in turn, is considered to be important for segmenting the incoming speech stream. The adult language system was demonstrated to be sensitive to the systematical suprasegmental information contained in bisyllabics. Note that in English as well as in German the most frequent stress pattern in bisyllabics is the trochee, i.e. about 90% of CVCV items bare stress on the initial syllable [4,5,58]. In fact, English adults are very likely to consider a strong syllable as the onset of a new lexical word [4,6]. Thus, sensitivity to the most frequent native language stress pattern might also serve as a cue for word segmentation in infants learning English or German (‘prosodic bootstrapping’) [55]. In fact, results of previous behavioral research in 6- to 9-month-old German and English learning infants suggest a stable preference for the canonical native language prosodic pattern of two syllable content words, i.e. the trochee [20]. Moreover, infants in the older age group actually use stress pattern of bisyllabics for word segmentation [21]. This finding is generally referred to as the ‘trochaic bias’ [34]. In order to explore the development of the trochaic bias in German infants younger than 6 months, an MMN study was conducted [56]. In this study, German learning infants were presented with trochaic (stress on the first syllable) as well as with iambic (stress on the second syllable) bisyllabics. Irrespective of gender, it was demonstrated that the trochaic bias is already present at the age of 5 months, i.e. infants discriminated a trochaic item presented among iambic items but not vice versa.

On a mere perceptual level, it might be argued that aspects of saliency and position might account for this result. In general, onsets of auditory stimuli constitute particularly salient transients and are, furthermore, behaviorally relevant. In fact, first position syllables and first position complex tones have a certain processing advantage in terms of latency and amplitude of the MMN in adults [45]. Thus, a trochaic item starting with a long vowel syllable is more salient than an iambic one starting with a short vowel and can therefore be discriminated more easily by 5-month-old German infants (cf. [11,27]). Yet, the enhancement of the MMN for the trochaic item in German 5-month-olds might also relate to the existence of language-specific long term memory traces for the canonical stress pattern of the target language. In order to further clarify this question, a cross-linguistic study should be conducted. Furthermore, the question is still open as to whether infants at risk for Specific Language Impairment (SLI), i.e. infants who display low word production scores later in life, also display a trochaic bias at the age of 5 months.

According to the International Classification of Diseases [22], the diagnostic criteria for Specific Language Disorders (SLI) are specified as follows: language skills are below the 2 standard deviations cut-off point and they are at least one standard deviation below nonverbal IQ. Furthermore, there are no neurological, sensory or physical impairments that directly affect the use of spoken language nor is there a pervasive developmental disorder. Typically, males are more vulnerable than females [22,24,49].

With respect to the etiology of SLI, evidence in favor of a strong genetic component has been gathered [31,51]. However, behavioral measures can also indicate the at risk status for language problems in children. In fact, a strong correlation with onset of language production (‘late talkers’) and SLI has already been reported in several longitudinal behavioral studies [16,42–44,46,50,57]. It was demonstrated that about 70% of ‘late talkers’, i.e. children who produced less than 50 words at age 2 years, exhibit persisting phonological and syntactic deficits at 4 years of age. As pre-schoolers, late talkers show reduced MLU (Mean Length of Utterance) when compared to normal controls. An influential hypothesis concerning the correlation between word knowledge and language development states that language development in late talkers cannot be triggered due to reduced word knowledge at the critical developmental timepoint, i.e. around 2 years of age [2,30].

Importantly, evidence for a lack of specific prosodic knowledge on the word level has also been collected in German pre-schoolers with SLI [38].

In SLI, motor abilities as well as attentional capacities are often both reduced [18]. Hence, differences with respect to motor and attentional behavior might interfere with results obtained in behavioral paradigms. The MMN paradigm was therefore used in this study [37].

In the following experiments, discrimination abilities for different bisyllabic stress patterns will be retrospectively investigated in 5-month-olds who displayed low word production scores later in life and are, therefore, classified as at risk for SLI. It is hypothesized that, due to less efficient processing of relevant prosodic cues in the language input, stress pattern discrimination in German 5-month-olds with low word production scores at the ages of 12 and 24 months is less elaborate than in normal controls [38]. Thus, infants at risk for SLI should display a reduced amplitude of the MMN when compared to normal controls [37].

2. Materials and methods

2.1. Participants

The present experiments are part of the German Language Development Study (GlaD, http://www.glad-stuy.de) at the Lindenhof Children's Hospital, Charité, Medical Faculty of the Humboldt University, Berlin. The main goal of the study is to determine possible processing differences for speech stimuli in infants at and not at risk for SLI. All families participating in the study followed institutional informed consent procedures. The studies were performed with German 20 weeks old full-term infants (GA: 37 to 41 + 6; APGAR 1′ > 6, APGAR 5′ > 8, APGAR 10′ > 9; birth weight females: >2460 g, birth weight males: >2570 g). All infants were born into monolingual German families. They passed a peripheral hearing screening with evoked otoacoustic emissions (OAE). The infants had no history of neurological problems [12,40]. All subjects completed both experimental runs and spent most of the experimental time not in quiet sleep stage. The experimental standards were approved by the ethics committee of the Charité, Humboldt University Berlin. Parents gave the written consent for their children's participation in the study.

2.1.1. Infants at risk for SLI

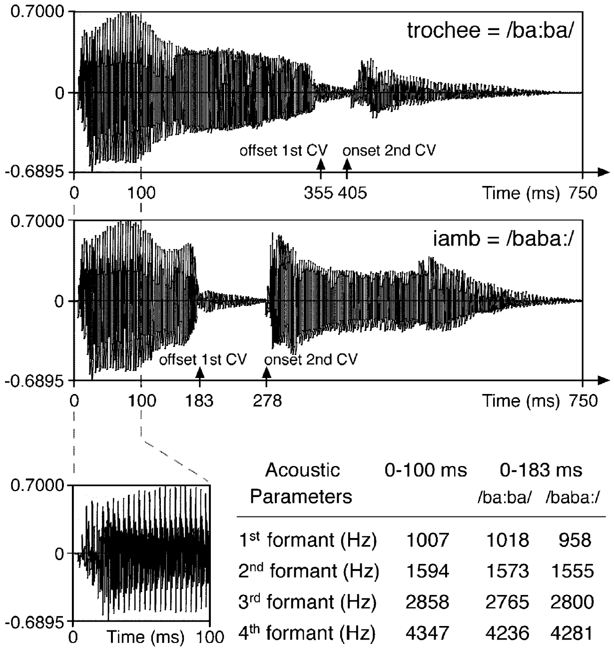
A total of 9 infants (8 male, 1 female) were recruited for the study. All of them demonstrated low word production scores at the age of 12 and 24 months as determined by the standardized parental questionnaires 'Elternfragebogen I and II' (ELFRA I and II, [15]). These tests are very similar to the 'MacArthur Communicative Development Inventories' [9] and the 'Language Development Survey' [41], that is, they measure speech production in toddlers. In the study, children are considered to be at risk for SLI when they produce less than 6 out of 164 language-related items at age 12 months (ELFRA I) and when they produce less than 50 out of 260 words at age 24 months (ELFRA II). They did not have a family history of language problems in their nuclear family according to results obtained in language tests performed on their siblings and/or their parents [8,13,14,17].

2.1.2. Control group

A total of 9 infants (1 male, 8 female) were recruited for the control group. They were part of a larger sample without familial risk for SLI which was investigated earlier with the same paradigm [56]. The control infants of the subsample showed normal word production skills according to the same standardized parental questionnaires performed at the ages of 12 and 24 months [13,14].

2.2. Stimuli and procedure

Two CVCV pseudowords differing in stress pattern were used (cf. Fig. 1). They were produced in infant-directed speech by a young mother who is a native speaker of German. In order to control for the onset of the acoustic differences present in natural speech, the first 100 ms of the trochaic item (ba:ba/, offset 1st syllable: 355 ms, onset 2nd syllable: 405 ms, total duration: 750 ms) was replaced by the first 100 ms of the iambic pseudoword (/baba:/, offset 1st syllable: 183 ms, onset 2nd syllable: 278 ms, total duration: 750 ms). This was done after recording and digitalization (44.1 kHz, 16 bit sampling rate). Both stimuli were judged to sound like natural sounds by three independent German monolingual adults.



Acoustic Parameters	0-100 ms	0-183 ms /ba:ba/	0-183 ms /baba:/
1st formant (Hz)	1007	1018	958
2nd formant (Hz)	1594	1573	1555
3rd formant (Hz)	2858	2765	2800
4th formant (Hz)	4347	4236	4281

Fig. 1. Illustration of the two stimuli. Physical differences begin at 100 ms.

Stimuli were presented in a passive oddball paradigm (standard: $P = 5/6$ deviant: $P = 1/6$). Two experimental runs were performed:

> Condition trochee: the iambic pseudoword functioned as the standard and was occasionally replaced by the trochaic deviant item;
> Condition iamb: the trochaic CVCV pseudoword took the standard position, whereas the iambic pseudoword was presented as the deviant item.

During each experimental run, 600 trials were presented using a fixed ISI (offset to onset) of 855 ms. The order of the two runs was counterbalanced across the subjects. Stimuli were presented via loudspeaker with an intensity of 64 dBSPL. Two blocks lasting approximately 12 min each were presented to the infants. Infants were seated in a safety seat or on their parent's lap. The experiment was completely painless and took approximately 1.5 h, including preparation and pauses.

2.3. EEG recording

The EEG was recorded with Ag–AgCL electrodes attached to frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites using an electrode cap (Falk–Minow). The scalp sites were located according to the International 10–20 electrode system. Vertical electrooculograms were recorded from infra- and supraorbital electrodes located at the right eye, horizontal electrooculograms were recorded from lateral electrodes located at both eyes. The recordings were automatically referenced to Cz by the PORTI-32/MREFA amplifier (Twente Medical Systems) and digitalized on-line at a rate of 250 Hz. Both mastoids were actively recorded. Impedances were below 10 kΩ. Further analyses were processed offline. Because infants of the age group in question generally display a high proportion of slow wave activity, a bandpass 1–15 Hz filter was used [56]. Data were algebraically re-referenced to the average of both mastoids.

2.4. Data analysis

For each condition, electrode and participant epochs of 1200 ms were averaged separately. A 50 ms pre-stimulus baseline was used. Trials exceeding a standard deviation of 80 μV within a sliding window of 200 ms in any channel were rejected automatically. Mean individual averages included 74.4 accepted deviant trials in the low production group and 71.4 in the normal production group. Statistical analysis of the negative Mismatch response was carried out for the same 80 ms time window as reported earlier for the larger sample, i.e. at 275–355 ms after stimulus onset [56]. For this latency window, three-way analysis of variance (ANOVA) for repeated measures was conducted with the factors DISCRIMINATION (deviant trochee vs. standard trochee; deviant iamb vs. standard iamb), REGION (anterior: F3/F4; central: C3/C4; posterior: P3/P4) and HEMISPHERE (F3/F4; C3/C4; P3/P4) in each group. Cross comparisons (deviant trochee vs. standard trochee; deviant iamb vs. standard iamb) were used in order to exclude any influence of the physical differences between both stimuli. In order to compare amplitude differences of the relevant negativity, one-way ANOVAs with the factor RISK were performed for the maxima of the negative peak of the difference wave at 250–370 ms after stimulus onset for all subjects at fronto-central sites (F3/F4/C3/C4). Correlations between word production and MMN amplitude peaks at fronto-central sites were examined using the Pearson coefficient. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following, uncorrected degrees of freedom and corrected probabilities are reported.

3. Results

3.1. Infants with low word production scores at age 12 and 24 months

In Fig. 2, grand-average ERPs for the trochaic stimulus (left) and the iambic pseudoword (right) are presented using cross comparisons.

3.1.1. Trochaic stress pattern

For the trochaic deviant item, a negative deflection at the MMN latency, i.e. at around 300 ms after stimulus onset, appears to be observable (Fig. 2, left). Statistical analysis did not reveal any significant effect for this deflection.

3.1.2. Iambic stress pattern

The iambic stress pattern did not elicit a negative deflection in the relevant MMN latency range, i.e. around 300 ms after stimulus onset (Fig. 2, right). Hence, no discrimination-related electrophysiological response to the iambic stress pattern was observed in 5-month-olds at risk for SLI.

3.2. Control group: infants with normal word production scores at age 12 and 24 months

Fig. 3 displays grand-average ERPs for the trochaic (left) and the iambic (right) stimulus using cross-comparisons.

3.2.1. Trochaic stress pattern

When the deviant stimulus was the trochaic pseudoword (Fig. 3, left), visual inspection suggested a negative deflection mainly at fronto-central sites starting around 240 ms, i.e. at about 140 ms after change onset. Statistical analyses revealed a significant main effect for DISCRIMINATION at 275–355 ms [$F(1,8) = 15.28$, $P < 0.01$]. In addition, a significant main effect for REGION was

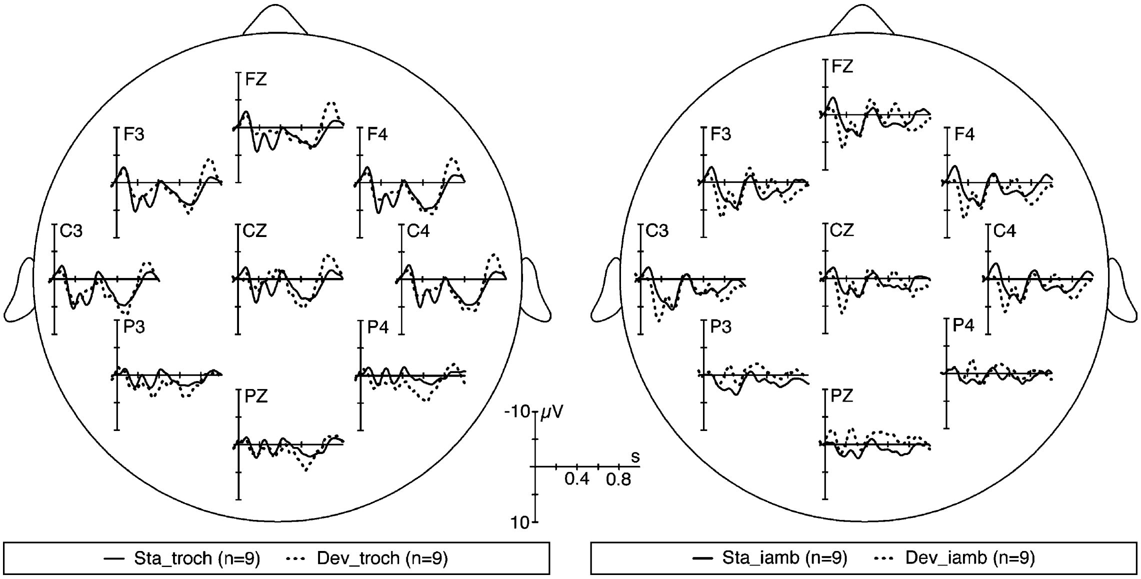


Fig. 2. Grand-average ERPs for the trochee condition (left) and the iamb condition (right) in German 5-month-olds at risk for SLI (n = 9).

observed [$F(2,16) = 4.78$, $P < 0.05$]. Furthermore, a significant interaction REGION × DISCRIMINATION was revealed [$F(2,16) = 7.65$, $P < 0.05$]. Thus, similar to previous results obtained in 5-month-olds not at risk for SLI, a negative discrimination response at the MMN latency was elicited, mainly at fronto-central sites [56]. No hemispheric differences were observed.

3.2.2. Iambic stress pattern

When the iambic pseudoword functioned as the deviant item, no negative deflection was seen within a relevant MMN latency range. Again, similar to results obtained in a larger sample of 5-month-olds, no discrimination-related response was induced by the iambic stress pattern [56].

3.3. Differences between both groups

Fig. 4 shows the grand-average difference waves for the trochaic deviant item obtained in infants with low word production (dotted line) as well as in infants with normal word production (solid line). Again, cross comparisons were used in order to exclude any influence of the physical differences between both stimuli.

Visual inspection suggested a large amplitude difference between both groups at the negative MMR latency, i.e. at 175–255 ms after change onset. In infants at risk for SLI, only a small negative deflection was observable. Statistically significant differences in peak amplitudes between groups were revealed at C3 [$F(1,17) = 4.91$, $P < 0.05$] and

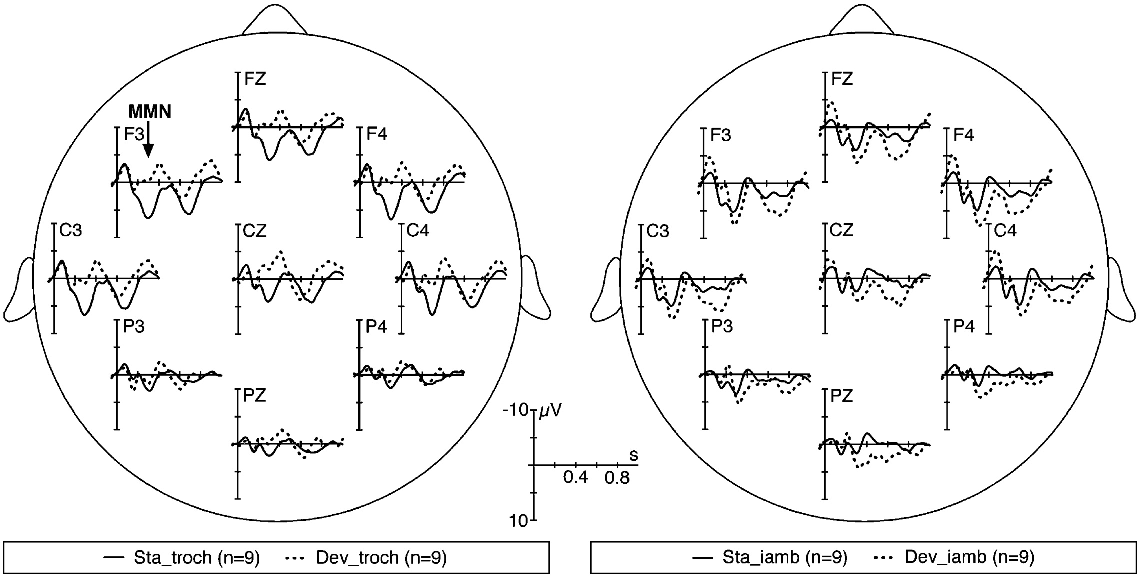


Fig. 3. Grand-average ERPs for the trochee condition (left) and the iamb condition (right) in German 5-month-olds not at risk for SLI (n = 9).

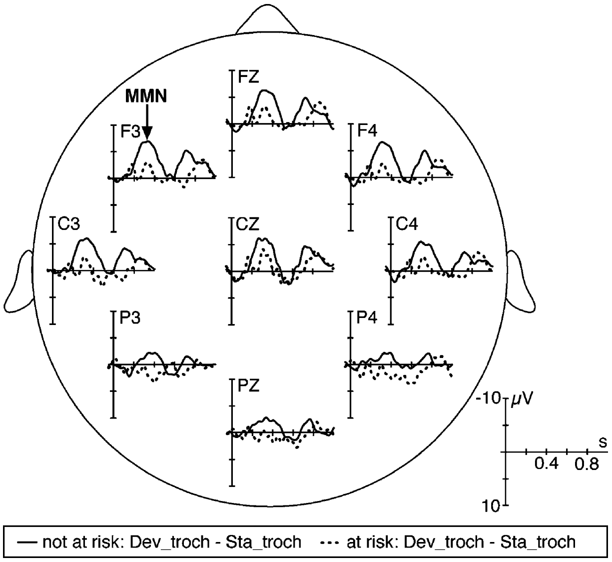


Fig. 4. Grand-average difference waves (deviant trochee minus standard trochee) for the trochaic pseudoword obtained in German 5-month-olds at risk for SLI (n = 9, dotted line) and in matched infants not at risk for SLI (n = 9, solid line).

at F3 [$F(1,17) = 4.51$, $P = 0.05$]. Thus, the amplitude of the negative discrimination response in German 5-month-olds at risk for SLI was significantly reduced as compared to matched controls. Pearson correlation revealed a significant negative correlation between the 5-month-olds' MMN amplitude at C3 and word production at the age of 12 months [−.446, $P = 0.03$]. A statistical trend was seen when the interaction between word production at the age of 24 months and the 5-month-olds' MMN amplitude at C3 was examined [−.368, $P = 0.06$]. Thus, the smaller the MMN amplitude at the age of 5 months, the lower the word production at 12 and 24 months of age proved to be.

4. Discussion

In the present study, the ability to discriminate between trochaic and iambic pseudowords was retrospectively evaluated in German 5-month-olds. It was hypothesized that less elaborate prosodic bootstrapping capacities in infants at risk for language problems, in this case, infants with low word production scores at age 12 and 24 months, lead to less efficient discrimination abilities for the relevant stress pattern. In fact, infants in this age group use stress pattern in bisyllabics to segment lexical entities [21,25]. Electrophysiological responses evoked with a mismatch paradigm in a previous study demonstrated the trochaic bias in German 5-month-olds [56].

In the present study, infants with normal word production scores demonstrated a discrimination-related negativity for the trochaic stimulus, but not for the iambic item. Its fronto-central distribution as well as its latency correspond to a typical Mismatch Negativity. These results are in line with those obtained earlier in a larger sample (cf. [56]). Hence, German 5-month-olds with normal word production scores at 12 and 24 months of age display an electrophysiological discrimination response when presented occasional trochaic stimuli embedded among iambic standards, but not vice versa.

Yet, in German 5-month-olds with low word production scores at age 12 and 24 months, no discrimination-related negativity was observed in response to either stress pattern. Further analysis of the MMN revealed a significantly reduced amplitude in response to the trochaic stimulus at left temporal sites when compared to normal controls. Hence, these results might point to a less effective processing of complex durational information in speech stimuli at left temporal sites in infants at risk for SLI. Moreover, the reduced temporal processing abilities of these infants seem related to prosodic bootstrapping capacities such as word segmentation. Note that in the German language the most critical feature of syllable stress is its increase in duration [54]. Reduced sensitivity to the temporal aspects of speech stimuli has already been demonstrated in infants with language problems like SLI and/or dyslexia. Using a mismatch paradigm, German 2-month-olds with a familial risk for SLI demonstrated a reduced ability to discriminate lengthened vowels within CV items when compared to infants not at risk [11]. Leppänen and colleagues [29] provided evidence for the impaired discrimination of durational differences contained within complex VCV stimuli in infants at risk for language problems. In this case, MMN amplitude differences between both groups were also largest at left temporal sites. Considerable debate remains over whether time-related speech and non-speech perception is handled by the same neural mechanisms. Whereas some authors found similar processing deficits for tone and speech stimuli varying in temporal information in children with SLI, others demonstrated specific language-related deficits in those subjects [1,47,48,53]. In the existing MMN studies, for the most part conducted with older children, pure tone stimuli were generally used as comparison stimuli. Yet, in order to investigate speech and non-speech auditory processing, future research should control for the complexity of speech stimuli and, therefore, use complex rather than pure tones as comparison stimuli [45].

Another way to account for the differences in MMN amplitude relates to impaired auditory memory function observed in infants at risk for language problems [29]. According to this view, a language-specific memory trace for the frequent trochaic stress pattern might exist in 5-month-olds not at risk for SLI. Due to the latter memory impairment, this trace might be missing in 5-month-olds at risk for SLI. In fact, the dependence of MMN amplitude on memory for language-specific phonemes was demonstrated for adults as well as for infants [3,36]. In both groups, an enhanced MMN amplitude for native language speech sounds as compared to non-native language phonemes was observed. This finding was interpreted as resulting from long term memory traces for native language items. Yet, in the infant study on language-specific enhancement of MMN amplitude, a language-specific influence on the phoneme-elicited MMN amplitude was only observable at the age of 12 months. Still, according to behavioral data, segmental information is less effectively processed than prosodic information during the first half year of life [33,34]. Behavioral data furthermore suggest increased sensitivity for suprasegmental information as compared to segmental information at the age of 7.5 months [25]. Therefore, long term memory traces for the ambient language's most frequent stress pattern might well already be in place at the age of 5 months, enhancing MMN amplitude. However, they might not be equally well established at this age in infants at risk for language problems leading to less efficient prosodic bootstrapping capacities in terms of word segmentation.

Taken together, results obtained in this study suggest that 5-month-old German infants with less elaborate discrimination abilities for the trochaic stress pattern also demonstrate poorer word production scores at the age of 12 and 24 months. Once again, the Mismatch Negativity paradigm proved to be a useful tool for investigating auditory processing in clinical populations on a group level. However, methods for evaluating single subject data in the infant population must be improved in order for MMN to serve as a diagnostic tool.

5. Conclusion

The aim of this study was to investigate whether German 5-month-olds at risk for SLI (classified retrospectively at the ages of 12 and 24 months) display less ability to discriminate between different bisyllabic stress patterns when compared to normal controls. According to the prosodic bootstrapping hypothesis, elaborate stress pattern processing capacities are crucial to word segmentation abilities in German as well as in English learning infants. In fact, it was demonstrated that German 5-month-olds classified as at risk for SLI cannot discriminate their ambient language's most frequent stress pattern, the trochee, as efficiently as normal controls. Thus, the initial hypothesis suggesting a reduced ability of infants at risk for SLI to detect relevant prosodic cues in speech input during early infancy was confirmed. Whether these results indicate a role for temporal auditory processing deficits and/or less elaborate memory functioning in the reduction of the linguistic capacities of at risk children, or rather point to a specific linguistic deficit in SLI, remains to be determined. The present findings, however, clearly suggest that the reduced MMN amplitude can be considered an early marker of risk for SLI.

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