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**Rhythm is Gonna Get you**

**Electrophysiological Markers of Rhythmic Processing  
in Infants with and without Risk for Specific Language  
Impairment (SLI)**

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Christiane Weber, M.A.  
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Dekanin:  
Prof. Dr. Ria de Bleser

Gutachter:  
Prof. Dr. Angela D. Friederici  
Prof. Dr. Jürgen Weissenborn

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## Chapter 1

### Introduction

One of the crucial problems for the language learning child is how to segment the incoming speech stream. The influential „prosodic bootstrapping“ account holds that prosodic information, such as intonational phrase boundaries and syllable stress, is used to guide early segmentation processes (Jusczyk, 1997; Wanner & Gleitman, 1982).

In stress-timed languages like English or German, the stress pattern of two syllable content words is a very regular prosodic feature: about 90% of these words have stress on the first syllable, indicating a strong/weak or trochaic stress pattern (Cutler & Carter, 1987; Wiese, 1996). Cutler and colleagues suggested that this characteristic rhythmic structure of English could form the basis of an effective segmentation procedure due to the systematic relationship between rhythmic patterns and word boundary location in English: a strong syllable in spontaneous English conversation is very likely to be the onset of a new lexical word (Cutler & Norris, 1988).

Given its rhythmic organization, the same also holds for German (Wiese, 1996). Consequently, word segmentation strategies based on the most frequent native-language prosodic pattern of bisyllabics have been proposed to be useful for English- and German-learning infants (Echols, Crowhurst & Childers, 1997; Cutler, 1994). Note that, in German, word stress is systematically related to durational differences with respect to vowel length in bisyllabics, i.e. the most reliable acoustic parameter for word stress is that the stressed syllable usually displays longer vowel duration than the unstressed one (Dogil, 1995; Jessen, Marasek, Schneider & Clahßen, 1995; van der Hulst, 1999). Therefore, in German, processing of different stress patterns in bisyllabics involves processing of complex durational patterns with respect to vowel length.

Using behavioral paradigms, evidence in favour of the prosodic bootstrapping hypothesis with regard to word segmentation has been gathered. It was demonstrated that American infants' sensitivity to trochaic (stress on the first syllable) content words increases between six and nine months of age (for a review, see Jusczyk, 1997). In addition, it was shown that six months old German infants listened significantly longer to trochaic than to iambic items when presented with two syllable pseudowords varying in stress pattern but not in phonetic content (Hoehle, 2002).

Children exposing Speech and Language Impairment (SLI), however, demonstrate reduced prosodic bootstrapping capacity. Penner and coworkers (Penner, Wyman &

Fikkert, 1998) argue that due to the reduced language learning ability of SLI children, they are not as adept as others in detecting the relevant cues in the input data which are, however, needed to trigger further prosodic development. Yet, it is not clear whether the linguistic bootstrapping deficit in terms of prosodic development is related to a basic auditory language processing problem. In the context of stress pattern processing in German which is mainly related to the computation of vowel duration differences, this possibility receives support: children with SLI usually display temporal processing deficits, i.e. their ability to discriminate between tones of different duration is reduced in comparison with normal controls (Tallal, 1975).

The present study is part of the German Language Development Study (GlaD, [www.glad-study.de](http://www.glad-study.de)). The GlaD study is an interdisciplinary effort to investigate normal and impaired language production and perception during the first years of life. Its main focus is the aetiology of Speech and Language Impairment (SLI). Infants with primary deficits like, for example, neurological and/or mental impairment, hearing impairment and/or social deprivation are excluded. Also, children raised in a bilingual environment cannot participate. At the age of 18 months, children at-risk for SLI can be identified according to their language skills which are assessed by a standardized questionnaire (ELFRA, Grimm & Doil, 2000). The aim of the study at hand was

1. to investigate the influence of long term memory traces for language specific stress pattern in bisyllabics on the brain discrimination response in German and French adults (Experiment I a & I b);
2. to determine the developmental time point of emerging stress pattern discrimination in German infants using an electrophysiological paradigm (Experiment II a & II b);
3. to find out about discrimination abilities for different stress patterns at the determined developmental time point in a matched group of infants at-risk for SLI (Experiment III) and
4. to examine the discrimination abilities for differences in vowel duration as a crucial prerequisite for stress pattern discrimination in German adults, infants not-at-risk for SLI and infants at-risk for SLI (Experiment IV a & IV b, Experiment V).
5. Throughout all experiments the influence of methodological differences between studies on the morphology of the infant's brain discrimination was investigated.

In order to exclude any influence of attentional and motoric abilities, neurophysiological measures which are independent of other cognitive or motor skills were used, i.e. event-related potentials (ERPs).

In adults, ERPs have been applied successfully to study auditory discrimination. Numerous investigations have demonstrated that the adult listener's brain produces a discrimination response as early as 100-200 ms after change onset when a deviant auditory stimulus is presented in a series of standard stimuli (for a recent review, see Näätänen, Tervaniemi, Sussman, Paavilainen & Winkler, 2001). This response is a negative component observable in the difference wave (ERP deviant stimulus minus ERP standard stimulus) named mismatch negativity or MMN (Näätänen & Winkler, 1999). The MMN is interpreted to reflect the detection of a deviance in the auditory input from information established in sensory memory. The paradigm has been successfully used to investigate a number of phonemic contrasts including the perception of durational contrast in adults and normally developing infants (Čeponienė et al., 2002b; Cheour et al., 1998a; Cheour et al., 1998b; Dehaene-Lambertz & Baillet, 1998). In a cross-linguistic study Näätänen and coworkers (1997) furthermore demonstrated an enhancement of the component when native language phonemes were presented to adult listeners.

Considerable debate with respect to the polarity of the infant mismatch response (MMR) is reported in the literature. In the work at hand it is hypothesized that one possible source of the heterogeneity of results might relate to methodological differences between studies. Therefore, throughout all experiments, the contribution of a major methodological difference, i.e. filter settings was examined.

In *Experiment I* the influence of long term memory traces for language-specific stress patterns in bisyllabics on the MMN was determined. Therefore, a cross-linguistic study in German and French adults was conducted. In contrast to German, lexical stress in French varies depending on the position within a prosodic phrase (Jun & Fougeron, 2002). It was thus hypothesized that, due to the language-specific distribution of iambs and trochees only in the German language, the MMN in German adults should be enhanced in response to the trochaic item and reduced in response to the iambic item when compared to MMN in French adults. In fact, both groups discriminated between trochaic (stress on the first syllable) and iambic (stress on the second syllable) bisyllabics, i.e. between complex patterns of vowel duration. When compared with Germans, French adults displayed an enhanced MMN in response to the iambic stress pattern which is very rare in the German language. Hence, an influence of long term memory traces on the discernibility of the iambic stress pattern was demonstrated. Still, the MMN morphology in response to the trochaic stress pattern was not a function of its distribution in the ambient language. It was concluded that the trochaic item must be easier to discern when presented among iambic standards which might be due to some perceptual advantage. The second hypothesis was that different filter settings should not change the adult MMN morphology. This hypothesis was confirmed, i.e. it

was demonstrated that varying filter settings did not have any influence on the morphology of the adult mismatch response.

In *Experiment II a and II b* it was examined at which developmental time point stress pattern discrimination emerged in German not-at-risk infants. For the first time, neurophysiological measures were used to address this question. As demonstrated behaviorally by Hoehle (2002), stress pattern discrimination is observable at the age of 6 months in German infants. Here, it was hypothesized that – in case an electrophysiological paradigm independent of attention and/or motor skills is used – discrimination should be measurable in German infants younger than 6 months. In *Experiment II a* stress pattern discrimination in German 5-month-olds was examined using the same experimental design as in the previous experiment. The results confirmed the hypothesis: At the age of 5 months already, German infants' brain response indicated discrimination of the trochaic stress pattern from the iambic one but not vice versa. However, it remained unclear whether this result was related to language-specific knowledge about the typical stress pattern in bisyllabics or either was a result of a general perceptual advantage for the trochee (*Experiment I a*). Still, it was demonstrated that 5-month-olds were able to process complex temporal patterns with respect to vowel duration. Due to the higher ratio of slow wave activity present in the infant EEG it was hypothesized that filter settings might alter the morphology of the infant MMR (Niedermeyer, 1998). The hypothesis was confirmed: It was clearly shown that in 5-month-olds, filter settings altered the morphology of the mismatch response considerably.

*Experiment II b* was conducted in 4 months old German infants who were not-at-risk for SLI. The same design as in the previous experiment was used in order to determine whether stress pattern discrimination was already present at the age of 4 months. However, at a group level, no discrimination response was seen. Still, when single-subject analysis were performed, a discrimination response for the trochaic as well as for the iambic two syllable item was observed in some infants. However, no stable 'preference' was seen. The hypothesis with respect to the influence of filter settings on the morphology of the infant ERP was confirmed again. Thus, in *Experiment II* the developmental time point of stress pattern discrimination was determined at the age of 5 months in German infants. Infants of the latter age demonstrated a 'trochaic bias'. It was also shown, that the infant ERP varied considerably depending on the filter settings used.

In *Experiment III*, stress pattern discrimination in 5 months old German infants at-risk for SLI was examined. Again, the same experimental design was used. Due to impaired prosodic development seen in SLI it was hypothesized that German 5-month-olds at-

risk for SLI are not able to discriminate different stress patterns in bisyllabics (Penner et al., 1998). In fact, reduced discrimination abilities for the trochee were found in infants at-risk for SLI. The results confirmed the hypothesis indicating reduced prosodic bootstrapping capacities in terms of word segmentation at the age of 5 months. There are at least two possible sources of impaired discrimination in infants: one relates to the exactness of the auditory encoding process of the stimulus which is a crucial prerequisite of discrimination; the other relates to infant discrimination abilities per se. In order to discern these processes, the encoding of the stimuli was examined in both, infants with and without risk for SLI. However, no differences regarding the electrophysiological response to the encoding of the stimulus were seen. Therefore, the reduced MMN in 5 months old German infants at-risk for SLI can only be related to impaired discrimination abilities for different stress patterns per se. As the present material had realized stress by duration (long for stressed, short for unstressed syllables) a crucial question was whether the inability to discriminate between trochee and iamb might relate to the inability to process differences in vowel duration which had already been demonstrated for infants at-risk for dyslexia (Leppänen, Pihko, Eklund, & Lyytinen, 1999; Pihko, Leppänen, Eklund & Lyytinen 1999). It was hypothesized that a basic auditory processing deficit with respect to discrimination of complex durational stress patterns might underlie reduced prosodic bootstrapping capacities for word segmentation at the age of 5 months. Hence, an additional series of mismatch experiments investigating discrimination abilities for vowel duration as a crucial prerequisite for stress pattern processing in infants at-risk for SLI was performed.

The following experiments aimed at determining infants' abilities to discriminate the very basic parameter of vowel duration. Since behavioral as well as neurophysiological evidence suggests that processing of native language speech sounds is influenced by categorical perception of native language sounds already at the age of 3 months, the experiment addressing the question of temporal processing in infants was conducted in German 2-month-olds (Dehaene-Lambertz & Pena, 2001; Jusczyk, 1997). In order to determine possible differences in the processing of vowel duration, the experiment was performed in 2-month-olds with and without risk for SLI. According to the rapid processing hypothesis, deficits in processing transient rapid acoustic signals impair the ability to discriminate acoustic cues that are necessary to distinguish phonemes. Persistent reduced discrimination abilities for consonants which are basically differentiated by rapidly changing frequency discrimination have been demonstrated behaviorally in SLI as well as in dyslexia (Tallal & Benasich, 2002; Tallal, 2000). However, using an ERP mismatch design in infants at-risk for dyslexia vowel duration discrimination problems have been reported for the first half year of life (Leppänen et al., 1999). As the basic temporal processing deficit was suggested to underlie SLI as well as dyslexia, it is hypothesized that 2-month-olds at-risk for SLI – similar to infants

at-risk for dyslexia – will display impaired discrimination of vowel duration when investigated using a mismatch paradigm.

*Experiment IV* was conducted in order to determine the MMR to vowel length processing in adults and infants not-at-risk for SLI. It was hypothesized that both groups were able to discriminate between vowels of different duration as indicated by their brain discrimination response. Furthermore, the effect of filter setting on infant ERPs was hypothesized to be replicable. Hence, in Experiment IV a, the latency of the MMN for long and short vowels contained in CV stimuli as well as the influence of filter settings was determined in German adults. It was demonstrated that German adults were able to discriminate between both stimuli. Filter setting did not have any influence on the morphology of their discrimination response. The same experiment was then conducted in German 2-month-olds not-at-risk for SLI (Experiment IV b). Here, it was hypothesized that infants not-at-risk were able to discriminate vowels of different duration due to the fact that Finnish infants do so (Leppänen et al., 1999). With respect to the influence of different filter settings on the infant mismatch response, the effect seen in the previous experiments conducted in 5-month-olds was hypothesized to be replicable. It was found that German 2-month-olds not-at-risk for SLI were able to discriminate long vowel deviants when presented among short vowel standards contained in CV-stimuli but not vice versa. Hence, the perceptual saliency of the presented deviant stimulus obviously had an influence on auditory discrimination abilities in infants at the age of 2 months. Moreover, the influence of filter settings on the morphology of the infant mismatch response was confirmed.

In *Experiment V* discrimination abilities for long and short vowels contained in CV-stimuli was investigated in infants at-risk for SLI. It was hypothesized that due to a basic temporal processing deficit in SLI and dyslexia, the at-risk group for SLI – similar to infants at-risk for dyslexia – display poor discrimination abilities for different vowel duration. The results obtained in this experiment confirmed the hypothesis as a reduced discrimination response was seen in those infants. Further analysis of stimulus encoding revealed that the reduction of the discrimination response did not relate to the differences with respect to the encoding of the stimuli but rather to reduced discrimination abilities per se.

Taken together, the reported results determine the developmental timepoint of the emergence of the discrimination of trochees in German infants, i.e. at 5 months of age. When the discrimination abilities for trochaic and iambic bisyllabics were investigated in German 5-month-olds at-risk for SLI, the hypothesis with respect to reduced prosodic bootstrapping capacity regarding word segmentation was confirmed: Thus, it was for the first time demonstrated that reduced prosodic bootstrapping abilities in terms of word segmentation can already be seen in German 5-month-olds at-risk for SLI.

It was furthermore suggested that reduced prosodic bootstrapping capacities in German 5-month-olds at-risk for SLI might relate to a basic temporal processing deficit with respect to vowel length discrimination. The mere ability to compute durational differences in vowels was assessed in 2-month-olds. Indeed, a temporal processing deficit with respect to vowel duration could be demonstrated in German infants at-risk for SLI for the first time. As the temporal processing deficit is known to underly SLI as well as dyslexia, it can be assumed that it is persistent during the first half year of life as previously shown for dyslexia (Leppänen et al., 1999; Pihko et al., 1999; Tallal, 2000). However, if the observed deficit at the age of two months indeed relates to impaired discrimination of complex patterns of vowel duration at the age of 5 months, has to be addressed by future research.

Furthermore, the work at hand provides evidence for a major methodological influence on the morphology of the infant mismatch response (MMR) as the prominence of the discrimination related ERP peaks in infants varied significantly depending on the filter settings used. Whereas the negative MMR was prominent after application of a band-pass 1-15 Hz filter, the positive MMR was prominent after application of a highpass 0.3 Hz filter.





## Chapter 2

### From Senses to Language: Prosodic Cues

One of the central claims of modern theoretical linguistics is that languages exhibit properties that must be innately known to the child, as the language input does not provide enough evidence for them (*'poverty of input'*; Crain, 1991). The observation that language input affords unlimited opportunities for the child to make reasonable but false generalisations seems to oppose the fact that children rapidly acquire the languages to which they are exposed without pursuing these many alternatives. According to bootstrapping accounts, domain-specific innate knowledge and constraints on language learning provide the solutions to these learnability puzzles.

A group of various *bootstrapping accounts* is based on models of linguistic parameters whose setting is 'triggered' by information provided through language-specific input. *Prosodic bootstrapping* accounts state that language learners could derive information about relevant syntactic units, word segmentation as well as about rhythmic organization, by relying on the prosodic information of the language in question (Gleitman & Wanner, 1982; Mehler, Dupoux, Nazzi & Dehaene-Lambertz, 1996; Morgan & Demuth, 1996; Peters, 1985; Weissenborn & Hoehle, 2001). Accordingly, bootstrapping from the signal crucially depends on the presence of acoustic cues to rhythmic organization, word segmentation and syntactic organization of the spoken language as well as the childrens' sensitivity to it<sup>1</sup>. In the following, the relevant acoustic-phonetic correlates of rhythmic organization in stress-timed languages will be presented. Also, the acoustic-phonetic correlates of word stress in German (and English) as well as infants' sensitivity to it will be introduced.

## 2.1 Acoustic Cues for Prosody

### 2.1.1 Acoustic Cues for Rhythmic Language Organization

Prosodic organization of a given language can be described in terms of acoustic-phonetic variation of the speech signal as well as in terms of phonological categories. Several types of hierarchically structured phonological systems have been proposed to describe the English language (Beckman & Pierrehumbert, 1986; Nespor & Vogel, 1986; Pierrehumbert & Beckman, 1988; Selkirk, 1984). According to the *Strict Layering Hypothesis* (Nespor & Vogel, 1986; Selkirk, 1984), phonological systems are non-

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<sup>1</sup> However, considerable debate regarding the autonomy of the phonetic-articulatory basis of speech representation in the language learning infant can be found in the literature (for a review, see Jusczyk, 1997).

recursive (syllable – phonologic minimal word – phonologic phrase – intonational phrase – utterance). Overall, these systems are also applicable to the German language.

Crucially, a given acoustic parameter like F0 (pitch), duration, amplitude, spectral tilt and segmental reduction can be part of different phonological phenomena. Hence, only a small number of acoustic variables encode different phonological information. Note that the same phonological information can also be realized with the help of different acoustic-phonetic parameters.

However, phonologically speaking, stress-timed languages like English or German are characterized by heavier syllables, a greater variety of syllable types, weights and durations than, for example, syllable-timed languages like French (Dauer, 1983). For stress assignment in stress-timed languages, syllable weight plays a crucial role as stress most often falls on the heaviest syllable.

Unstressed syllables in stress-timed languages usually have a reduced vocalic system where the unstressed vowel is reduced to schwa. Unstressed vowels also are consistently shorter (Bertinetto, 1991). Taken together, accent rules that are sensitive to the structure of the syllables are often said to be quantity-sensitive suggesting that the accent rule is primarily sensitive to length distinctions. However, other factors such as whether the syllable is open or closed might also be involved (van der Hulst, 1999).

According to Ramus and Mehler (1999) the linguistic classification of languages with respect to their rhythmic properties, e.g. stress-timed versus syllable-timed languages can also be described in terms of characteristic temporal acoustic-phonetic properties of these languages. In fact, when conducting a language discrimination task in French adults, these investigators showed that – in case the phonological category rhythm was phonetically realized as varying temporal organization of vocalic and consonantal intervals while F0 was held constant – this was a necessary and sufficient cue to discriminate English (stress-timed) from Japanese (not stress-timed) sentences (Ramus & Mehler, 1999)<sup>2</sup>.

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<sup>2</sup> To determine vocalic and consonantal intervals, the authors applied the following method. First, the phonemes of each sentence were marked with a sound-editing software, using both auditory and visual cues. Second, segments were identified and located as precisely as possible, using the phoneme inventory of each language. Phonemes were then classified as vowels or consonants. This classification was straightforward; however, in the case of glides the following rule was applied: Prevocalic glides were treated as consonants, post-vocalic glides were treated as vowels. Vocalic intervals are located between the onset and the offset of a vowel, or of a cluster of vowels. Similarly, a consonantal interval is located between the onset and the offset of a consonant, or of a cluster of consonants. The duration of vocalic and consonantal intervals adds up to the total duration of a sentence. The proportion of vocalic intervals within the sentence is the sum of vocalic intervals divided by the total duration of the sentence noted as %V.

With respect to language acquisition, these researchers proposed a framework called TIGRE. They suggested that infants' ability to discriminate between utterances from prosodically different languages could be based on their sensitivity for the correlation of characteristic acoustic-phonetic features of vowels with phonological qualities associated to them. In general, vowels are considered to be the more salient speech signals as they carry most of the energy in the speech signal, are mostly of longer duration than consonants and consist of a 'steady-state' part with little change in formants over time. In stress-timed languages, for example, they also carry phonologically important information as accent or whether a syllable is strong or weak<sup>3</sup>. Within the latter account it is also assumed that detection of the native-language rhythm type might be a cue to the relevant segmentation unit, i.e. in case of stress-timed languages, the foot (Ramus, Nespor & Mehler, 1999).

### 2.1.2 Acoustic Cues for Word Prosody

Pertaining to bisyllabic words of stress-timed languages, the foot assigns stress in most cases (Ramus et al., 1999)<sup>4</sup>. The rhythmical pattern within the minimal word in German as well as in English follows the trochaic foot, i.e. the foot is prominent on the left side of the German word (Wiese, 1996)<sup>5</sup>.

From an acoustic-phonetic point of view, word stress is related to greater loudness, higher pitch and greater duration of the more prominent syllable. It also varies with vowel quality (Grewendorf et al., 1990; Penner, 2000; Shattuck-Hufnagel & Turk, 1996). However, in German, vowel duration has proven to be one of the most reliable correlates of word stress (Dogil, 1995; Heike, 1969; Jessen et al., 1995; Maack, 1949; van der Hulst, 1999).

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<sup>3</sup> Behavioral evidence also suggests that vowels might be easier to process as they are, in general, categorized earlier than consonants (Juszyk, 1997).

<sup>4</sup> In stress-timed languages, the foot is the smallest rhythmical unit which constitutes a rhythmical pattern. The foot organizes syllables or morae according to a strong/weak pattern (Penner, 2000). In English, the foot serves as the first unit to compose a rhythmical pattern, i.e. to determine relative prominence. Many suprasegmental phonological processes are related to the foot. In German, for instance, duration-related suprasegmental phonological processes like ambisyllabicity, gemination or vowel shortening are realized within it (Fischer, in prep).

<sup>5</sup> However, according to the Celex-Database, 26.8% of all monomorphemic disyllabic words in German are stressed on the final syllable (Féry, 1998). Thus, a high proportion of words following the iambic foot can also be observed. However, according to several authors, the trochaic foot is involved in various kinds of prosodic-morphological mechanisms (Wiese, 1996). Therefore, in contrast to the iambic foot, the trochaic foot constitutes a functional unit within the German language.

In stress-timed languages like English and German, word stress is related to word segmentation: Following the *Metrical Segmentation Strategy*, adult English listeners make a first pass at segmenting fluent speech by assuming word boundaries at the onsets of each strong syllable, i.e. in the case of bisyllabic words the non-reduced syllable (Cutler, 1994; Cutler & Norris, 1988). Thus, it has been proposed that the sensitivity of the child to acoustic-phonetic features of word stress, along with domain-specific knowledge of their linguistic relevance, could help her to develop segmentation strategies for the incoming speech stream (Jusczyk, 1997).

Within this account, of course, the ability of the learner to extract the relevant cues is of vital importance. In the following, evidence of infants' sensitivity to perceptual cues of the rhythmic organization of languages as well as to word stress will be presented.

## 2.2 Prosodic Bootstrapping: Behavioral Evidence in Infants

### 2.2.1 Sensitivity to Prosodic Organization of Languages

It has been demonstrated that, during the last three perinatal months, infants are sensitive to the prosodic information contained in the speech signal (Lecanuet & Granier-Deferre, 1993).

Furthermore, when presented with their mother's voice right after birth, infants are able to recognize their mother's voice. This is still the case when the voice is low-pass filtered, thus preserving only prosodic characteristics like changes in fundamental frequency (F0), intensity and rhythmic properties (pauses, syllable stress) (DeCaspar & Fifer 1980; Fifer & Moon, 1989)<sup>6</sup>. Hence, the latter acoustic-phonetic parameters were potential cues for prosodic processing in perinatal infants.

Also, newborns' ability to discriminate the suprasegmental prosodic properties of different languages has been shown. Using the *High Amplitude Sucking* paradigm (HAS)<sup>7</sup>, Mehler and colleagues (1988) were the first to demonstrate that French newborns

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<sup>6</sup> The low-pass filter technique allows for the removal of all phonetic information in the speech signal. The resulting speech material most resembles the speech signal infants heard before birth.

<sup>7</sup> During a HAS experimental procedure (Siqueland & DeLucia 1969, Eimas, Siqueland, Jusczyk & Vigorito, 1971), subjects are seated in a sound-proofed chamber and offered a standard sterilized pacifier. One experimenter, out of view of the baby and deaf to the stimuli, checks out that the pacifier stays in the baby's mouth throughout the experiment. A second experimenter monitors the experiment on a computer outside the chamber. The

suck at higher rates when listening to French utterances than when listening to Russian utterances. This result indicated discrimination between the two latter languages.

To further explore whether the infants relied on phonetic-segmental or on prosodic information during the discrimination task, they low-pass filtered their stimuli at 400 Hz to prevent the recognition of phonetic, but not of the prosodic characteristics of speech. In the following experimental study, French newborns who listened to the filtered material showed comparable results to infants who had heard the unfiltered utterances. Thus, it was concluded that the prosodic information of the utterances provided a sufficient basis for the discrimination between both languages.

Nazzi, Bertoncini and Mehler (1998) demonstrated that newborns indeed rely on language-specific rhythmical information when discriminating low-pass filtered utterances of different languages as they cannot discriminate between languages with the same rhythmical organization. Nevertheless, they can discriminate between languages with differing rhythmical organization.

Ramus and coworkers (1999) further explored the role of stress-related phonetic features for the discrimination task. The authors assumed that the infant primarily perceives speech as a succession of vowels of variable durations and intensities, alternating with periods of unanalyzed noise, i.e. consonants (cf. *TIGRE* by Mehler et al. 1996). To test this assumption they provided a computational network with information about the variability of consonantal intervals as well as the proportion of vocalic intervals in sentences of languages with different rhythmical organization (stress-timed vs. syllable-timed). In order to determine vocalic and consonantal intervals, they used the same method as in the adult study previously described (cf. 2.1). The authors assumed that the infant's ability to discriminate between different rhythmical organization of languages is based on their capacity to compute the vowel/consonant temporal ratio %V and that their categorization of sentences and languages depends on the %V. The outcome of the discrimination simulation replicated the behavioral data obtained in 26 infant studies using 8 different languages. It also resembled the results obtained in adults who were able to discriminate stress-timed languages from other language types by relying on the same type of information (Ramus & Mehler, 1999).

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*computer records the pressure of the infant's sucks via an analogue-digital card, detects the sucking responses and delivers the stimuli according to a reinforcement schedule. The computer also saves the moment, the amplitude of each suck as well as the stimuli triggered by the sucks. Hesketh and colleagues (1997) report that the number of stimuli triggers is the cleanest measure. They furthermore proposed to present each infant with two changes: one in stimulation, i.e. one experimental (language) change and one in speaker (control) change. The key measure is then the difference between those changes.*

Hence, the discrimination of different rhythmical organizations of languages in newborns and infants might indeed be related to their sensitivity to coarse acoustic-phonetic features like the overall duration and proportion of vocalic intervals in a given language<sup>8</sup>.

### 2.2.2 Sensitivity to Prosodic Organization of Words

One of the next questions was on which cues infants would rely when deciding whether a particular word belongs to their native language rather than to a foreign one. Jusczyk (1997) proposed three possible grounds to start from: native-language phonetic segments, native-language sequential ordering of these segments (i.e. phonotactics) and native-language prosodic characteristics of the words in question. In different experiments, a stepwise examination of the latter points was completed.

*Phonotactic and Phonetic Sensitivity in Infants.* According to several authors, English and Dutch have very similar prosodic characteristics, i.e. they share vowel reduction, complex syllabic structure and the same sort of word stress with English (Crystal & House, 1988; Cutler, Dahan & van Donselaar, 1997).

In order to determine infants' sensitivity to phonotactic and phonetic properties of their native language, a cross-linguistic study was conducted using a *Headturn Preference* paradigm<sup>9</sup> (Jusczyk, Friederici, Wessels, Svenkerund & Jusczyk, 1993). Infants were presented with two different word lists: one list contained items which followed the phonetic and phonotactic structure of Dutch but not English, whereas the other list consisted of items following the phonetic and phonotactic structure of English but not Dutch. American 9-month-olds listened significantly longer to the English than to the Dutch words, whereas in American 6-month-olds no preference was found. In a next step, only the sequential organization of phones was varied, i.e. the phonotactics:

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<sup>8</sup> It was also demonstrated that infants are sensitive to syllabic entities of a given language. Bijeljac-Babic and coworkers (1993) provided support for French newborns' ability to discriminate bisyllabic from trisyllabic stimuli. However, 3-day-old French infants were unable to discriminate a change between two morae to three morae – the sub-syllabic rhythmic unit of Japanese (Bertoncini, Floccia, Nazzi & Mehler, 1995; Mehler et al., 1996). Moreover, it was demonstrated that syllabic units - which were at the same time the vowels carrying the rhythmical information - are particularly salient during the initial stage of speech processing (Bertoncini et al., 1995; Mehler et al., 1996).

<sup>9</sup> The *Headturn Preference Paradigm* is a behavioral paradigm (Fernald, 1985; Hirsh-Pasek et al., 1987; Jusczyk et al., 1993). It is used when an infant is able to turn the head, i.e. at the earliest at 4 months of age. The dependent variable in such experiments is the duration of the headturn towards different stimuli presented via loudspeakers placed at the left and right of the infants' head. In order to examine infants' processing of speech stimuli, the following variant of the *Headturn Preference paradigm* is used: during a familiarization phase the infant listens to a series of speech stimuli. After familiarization is completed, the test phase follows. Throughout the test phase, the infant is presented with different speech

some of the English items on the list contained sequences of phones which were illegal in Dutch and vice versa. Again, Dutch infants at the age of 9 months listened significantly longer to the Dutch words, whereas American infants at the same age listened significantly longer to the English words. This result was not replicated when all phonetic and phonotactic features were removed by low-pass filtering indicating that Dutch and American 9-month-olds are sensitive to both phonetic and phonotactic regularities of their mother tongue. In fact, sensitivity to the phonetic and phonotactic information of their native language is supposed to be useful to the infant when determining potential word-boundary cues.

*Sensitivity to Phonotactic and Prosodic Information Pertaining to Word Boundaries.* In a next step, sensitivity to phonotactic information pertaining to word boundaries was provided. Friederici and Wessels (1993) showed that 9 month old Dutch infants distinguished between phonotactically legal and illegal clusters at the beginning of words, thus demonstrating language-specific knowledge about possible word boundaries based on phonotactic information<sup>10</sup>. This result even held when the critical items were presented in contexts where language processing requirements were held low. Christophe, Dupoux, Bertoncini and Mehler (1994) presented additional evidence that infants are sensitive to prosodic information pertaining to word boundaries: French newborns discriminated pairs of bisyllabic stimuli that contained the same phonetic elements but were distinguished in terms of prosodic features, i.e. word boundary containment (e.g. [mati] from panorama typique vs. [mati] from mathematicien)<sup>11</sup>.

Jusczyk, Cutler and Redanz (1993) investigated infants' sensitivity to differences in the kinds of prosodic patterns that appear in native-language words. In a *Headturn Preference* study American infants were presented with lists of bisyllabic English words that either followed a trochaic (stress on the first syllable) or an iambic (stress on the second syllable) stress pattern. Whereas 6-month-olds did not display differences in listening times to either list, 9-month-old infants listened longer to items following the trochaic stress pattern which is the regular ambient language stress pattern (Jusczyk & Thompson, 1978; Spring & Dale, 1977)<sup>12</sup>.

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*stimuli. Depending on the ability of the baby to process the presented difference, she will display a different duration of the headturn towards the test stimulus.*

<sup>10</sup> Still, when presented with more information, i.e. with unfiltered sentences containing phonemic and phonotactic information instead of words, some infants at the age of 2 months already seemed to be sensitive to the differences between English and Dutch (Christophe & Morton, 1998).

<sup>11</sup> Also, infants proved to be sensitive to allophonic variants, which can serve to mark word boundaries (Hohne & Jusczyk, 1994)

<sup>12</sup> To find out whether the discrimination behavior of American infants was related to syllable weight, another experiment was conducted: in English, stress is very often related to heavy opened (i.e., CV) or closed (i.e., CVC) syllables which contain a tense vowel. Behavioral



This finding has been extended in German infants lately. According to Wiese (1996) the predominant stress pattern in German is also trochaic. German infants at the age of 6 months were presented with lists of CVCV-pseudowords following the trochaic respectively the iambic stress pattern (Hoehle, 2002). German infants of both age groups displayed longer listening times for the trochaic stress pattern, indicating preference for the trochee at an earlier age than the American infants. Hoehle (2002) argued that this effect was related to the less difficult discrimination task the German infants had to accomplish: whereas American infants were presented with 96 phonetically different English iambic and trochaic words, German infants only listened to several examples of CVCV-items differing in their rhythmic organization (i.e. iambic vs. trochaic).

Still, it cannot be concluded from this data whether the results are based on a general perceptual advantage of the trochaic stress pattern or if they are based on language-specific representations of the regular stress pattern in bisyllabics. However, if infants indeed learn about the ambient language stress pattern, they should be sensitive to the distributional properties of input.

*Sensitivity to Distributional Properties of Language Input.* Goodsitt, Morgan and Kuhl (1993) examined infants' sensitivity to distributional properties of language input. They trained 7-month-olds to discriminate two isolated syllables, [ti] and [de]. When infants were able to complete the task, they were presented with trisyllabic items containing one of the familiar syllables. Infants were best at detecting a change from [ti] to [de] when these syllables were presented with so called invariant order strings, i.e. when the target syllable was placed either before or after two other syllables in invariant order (*kogati* vs. *dekoga* etc.). These results suggested that infants at this age found it easier to group both nontarget stimuli into a single cluster which was then separated from the target syllable. Hence, the distributional properties of the input had an influence on the segmenting strategy in these infants<sup>13</sup>.

Further evidence was provided by Morgan and colleagues (Morgan & Saffran, 1995; Morgan, 1994). They found that the most effective way for grouping nontarget syllables

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*studies indicated that 9 month old English learning infants still demonstrate a preference for trochaic words even when they only contain a light syllable with a tense vowel at the beginning (Turk, Jusczyk & Gerken, 1995). However, to finally determine if infants' segmentation strategy is related to syllable weight, it is crucial to vary all acoustic-phonetic features (e.g. duration, intensity, etc.) related to syllable weight which is determined by the structure of the syllable's nucleus.*

<sup>13</sup> *Infants at this age are also sensitive to the distribution of phonotactic sequences in monosyllabic as well as in bisyllabic items: American 9-month-olds, but not 6-month-olds, listened significantly longer to lists of English words containing high-frequency phonotactics than to English lists containing low-frequency phonotactic clusters (Jusczyk, Luce & Charles-Luce, 1994).*



in 8- and 9-month-olds was to combine a rhythmic pattern with distributional cues provided by an invariant syllable order. Infants at the age of 6 months, however, were not able to take advantage of the integration of both cues. In an additional experiment with 6- and 9-month-olds it was shown that, at the age of 9 months, rhythmic grouping according to the trochaic pattern was much more robust than rhythmic grouping according to the iambic pattern (Morgan, 1996). One of the next questions was whether a tendency towards trochaic stress pattern segmentation strategies could be observed in infants.

*Stress Pattern based Segmentation Strategies.* Further research addressed the question whether there was a stable representation of the trochaic stress pattern in infants. In a study conducted in 7 and 9 month old American infants, Echols and coworkers (1997) demonstrated that the elder age group was able to recognize familiarized as well as unfamiliarized trochaic sequences in multisyllabic strings of speech. In the same infants, only recognition of familiarized, but not of unfamiliarized, iambic items was observed.

Cross-linguistic studies demonstrated that infants were also able to segment according to the trochaic stress pattern in speech material coming from a foreign language following the same rhythmical organization as the native language. Thus, 8 month old American infants were able to recognize German trochaic items, and 9 month old Dutch infants successfully segmented English words following the trochaic stress pattern (Hoehle 2002; Houston, Jusczyk, Kuipers, Coolen & Cutler, 2000).

In several headturn preference experiments including American infants around 7 months of age, Jusczyk, Houston and Newsome (1999) showed that the application of a segmentation strategy based on the trochaic stress pattern lead these infants to mis-segmentations. For instance, infants of the latter age were familiarized with passages containing iambic items always followed by an unstressed monosyllabic item (i.e., the guitar is). When they were tested on the recognition of pseudowords consisting of the strong syllable of the iambic item and the monosyllabic item (i.e. taris), they recognized the latter 'items'. This result suggests that infants at this age were obviously misguided by some kind of trochaic segmentation strategy. However, infants between 10 and 11 months of age recognized the iambic items (i.e., guitar) in the test phase. Hence, at this age, as infants are able to rely on several sorts of cues in the speech signal, the exclusive role of word prosody to complete the task seems to diminish.

To further determine whether the applied segmentation strategy relies on the more robust representation of the trochaic stress pattern as a whole, Jusczyk et al. conducted a study with approximately 7 months old American infants (Jusczyk & Luce, 2002; Jusczyk et al., 1999). The question was if infants at this age would be able to segment

and recognize the stressed syllable of iambic and/or trochaic items. Infants of the latter age group were not able to segment the stressed syllable (i.e. ham) of a familiarized trochaic item (i.e. hamlet) when presented with the stressed syllable alone. On the other hand, they were able to segment the stressed syllable (i.e. tar) in a familiarized iambic item (i.e. guitar) indicating rhythmic grouping in case of the presentation with a trochee as opposed to the presentation of an iamb.

For similar experiments in adults, target position effects have been reported by several authors (Dumay, Frauenfelder & Content, 2002; Norris, McQueen, Cutler, & Butterfield, 1997). Any effect of this sort was excluded in the next study. This time, infants were familiarized with stressed syllables only. It was then demonstrated that they recognized the iambic (i.e. guitar), but not the trochaic (i.e. hamlet), items containing the familiarized strong syllable (i.e. tar, ham). Hence, it was concluded that only trochaic items were processed as a rhythmical entity.

*Infants Retention Abilities for Sound Patterns.* Also, infants' retention of sound patterns occurring in fluent speech was examined (Jusczyk & Hohne, 1997). When 7.5 month-old infants were familiarized with a pair of words they performed as good as another group of 7.5-month-olds who were tested without any delay in discriminating the same words 24 hours later. Thus, infants at this age are indeed able to retain recurring words in their memory.

## 2.3 Summary

Taken together, it can be seen that newborn infants are sensitive the rhythmical organization of a given language. Furthermore, it was shown that infants' sensitivity to acoustic parameters like durational and relational aspects of vocalic and consonantal intervals plays a decisive role in acquiring the prosodic representations of their native language. However, it has not been determined yet if or to what extent the infant representation is associated to phonological knowledge about the language in question, e.g. in case of stress-timed languages its segmentation unit, the foot. Nevertheless, the capacity to process differences in the acoustic-phonetic dimension is a necessary prerequisite to represent phonological knowledge of this kind.

The combined data from these behavioral studies indicate a high sensitivity to phonological cues between the age of 6 and 9 months. Yet, behavioral experimental designs rely on attentional and motoric abilities of the child. Neurophysiological measures, in contrast, are able to provide direct evidence for the neurobiological processes underlying speech discrimination abilities independent of other cognitive and motor abilities.

## Chapter 3

### Senses or Language: Different Approaches to SLI

According to the World Health Organization (*International Classification of Diseases ICD-10*, 1992) the diagnostic criteria for Specific Language Disorders (SLI) are specified as follows: language skills, as assessed by standardized tests, are below the 2 standard deviations cut-off point; they are at least one standard deviation below nonverbal IQ as assessed by standardized tests; there are no neurological, sensory, or physical impairments that directly affect use of spoken language; there is no pervasive developmental disorder.

A distinction is made between *receptive* language disorder, where comprehension is more than 2 *SD* below age level, and *expressive* language disorder. In the latter, only expressive language is severely affected, whereas understanding and use of nonverbal communication and imaginative language functions are within the normal range.

According to the American Psychiatric Association's *Diagnostic and Statistical Manual* (DSM-IV; 1994), the prevalence of SLI with additional production deficits is only approximately 5%, and drops to around 3% for combined comprehension and production deficits. However, higher prevalence rates have also been reported (Esser, Lehmkuhl & Schmidt, 1983; Tomblin, 1996). Typically, males are more vulnerable to develop SLI than females (ICD-10, 1992; Ingram, 1959; Johnston, Stark, Mellits & Tallal, 1981; Tallal, Ross & Curtiss, 1989). Haynes (1992) reported ratios as high as 4.8:1 in selected settings such as residential schools.

#### 3.1 Pitfalls in Definition and Diagnostics

Bishop (1998) pointed out the inherent circularity of the statistically based definition of SLI suggested in the ICD-10 (1992): if language impairment is defined as a score of a certain percent of the entire population, then the definition of SLI does not take the age of the children, the country they live in and the time in history into account. Therefore, its prevalence will be a constant and arbitrary figure. One possibility to overcome this problem is proposed in the DSM-IV (1994), where an additional criterion, namely disability, is introduced.

Thus, a diagnosis of SLI also indicates whether the impairment interferes with academic or occupational achievement and therefore places the child at a disadvantage in society. The concept of disability, though, may also constitute a problem, as opinion about what really constitutes a communicative disability may vary considerably.

Stark and Tallal (1981) proposed an alternative approach which involves translating a child's language score into an 'age-equivalent' language score. If the gap between chronological age and language test age exceeds a certain value, the child is regarded as language-impaired. However, relationships between age and test means and variances are seldom constant, especially in children. In general, measures of age-equivalent scores are so dependent on normative distributions of test scores as to be uninterpretable at best and positively misleading at worst (cf. Bishop 1998). Problems in defining SLI consequently have an effect on diagnosing SLI (Table 1).

*Table 1: Common Diagnostic Criteria for SLI*

<b>Factor</b>	<b>Criterion</b>
Language ability	Language test scores of -1.25 SD or lower
Nonverbal IQ	Performance IQ of 85% or higher
Hearing	Pass screening at conventional levels
Otitis media with effusion	No recent episodes
Neurological dysfunction	No evidence of seizure disorders, cerebral palsy, brain lesions, not under medication for control of seizure
Oral structure	No structural anomalies
Oral motor function	Pass screening using developmentally appropriate items
Physical and social interactions	No symptoms of impaired reciprocal social interaction or restriction of activities

Adapted from Leonard (2000), p. 10.

In practice, several clinical classifications of SLI have been proposed (cf. Table 2). Unfortunately, diagnosis of a language problem still occurs very late, namely shortly before school readiness. (Bishop & Rosenbloom, 1987; Rapin & Allen 1983, 1987; Wolfus, Moskovich & Kinsbourne, 1980).

Another diagnostic approach consists in distinguishing SLI from other social, emotional or behavioral problems with comorbid language disorder. On the other hand, psychiatric or behavioral problems might have developed partly as a consequence of a neglected language problem (cf. Rice, 1993, *Social Consequences Account*). Therefore, as Bishop (1998) points out, it is inappropriate in clinical settings to exclude children with co-existing neurological, social or psychiatric problems, as this also often reduces their access to proper treatment of their language difficulties.

In many cases the available language tests do not cover the individual language difficulty profile of a child, nor do they provide any measure of the relative importance of the disorder for the child's day-to-day functioning (Table 2). Hence, additional analysis need to be conducted.

Typically, mean length of utterance (MLU) measures are then performed. MLU can be computed in terms of morphemes (Rice & Oetting, 1993) or in terms of words (Leonard, Bortoloni, Caselli, McGregor & Sabbadini, 1992) and is afterwards compared to normative data from control children matched by chronological and/or mental age (Miller & Chapman, 1981; Templin, 1957). Unfortunately, normative data are not available for German. Analysis of the child's spontaneous speech can, nevertheless, add important information to the language profile already obtained from the standardized language test (Clahsen & Hansen, 1993; Dunn, Flax, Sliwinski & Aram, 1996).

*Table 2: Example of Clinical Subclassification of Speech and Language Impairment*

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**Verbal auditory agnosia/word deafness**

Inability to comprehend spoken language, with intact understanding of gestures. Speech is absent or very limited with poor articulation.

**Verbal dyspraxia**

Comprehension is adequate, but speech is extremely limited, with impaired production of speech sounds and short utterances. There may be signs of oromotor dyspraxia, but the child's difficulty with speech sounds cannot be accounted for in terms of dysarthria.

**Phonologic programming deficit syndrome**

The child speaks fluently in fairly long utterances, but speech is hard to understand. Comprehension is adequate.

**Phonologic-syntactic deficit syndrome**

The child mispronounces words and speech is dysfluent. Utterances are short and grammatically defective, with omission of function words and grammatical inflections. Although the deficit may appear superficially to affect only expressive language, comprehension problems can be seen for complex utterances and abstract language.

**Lexical-syntactic deficit syndrome**

Production of speech sounds is normal, but the child has word-finding problems and difficulty in formulating connected language, e.g. in conversation or when narrating a story. Expressive syntax is immature rather than faulty. Comprehension of abstract language is worse than understanding of here and now.

**Semantic-pragmatic deficit syndrome**

The child speaks in fluent and well-formed utterances with adequate articulation. However the content of language is bizarre and the child may be echolalic or use overlearned scripts. Comprehension may be over-literal, or the child may respond to just one or two words in a sentence. Language use is odd, and the child may chatter incessantly or produce language without apparently understanding it. The child is poor at turn-taking in conversation and at maintaining a topic.

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### 3.1.1 SLI: Delayed or Deviant Language Acquisition?

A crucial issue discussed in the literature is whether SLI represents a delay in language acquisition or if it represents a deviant pattern of language acquisition as such. Studies in adults who exhibited SLI in childhood revealed that their overt language problems often resolved with age but can still be demonstrated as persisting on formal tests (Bishop, North & Donlan, 1996; Lewis & Freebairn, 1992; Tomblin, Freese & Records, 1992). Other children diagnosed as language-impaired seem to catch up later (Whitehurst & Fischel, 1994). Observations of this kind lead to considerable debate as to whether language development in children exhibiting SLI constitutes a delayed as opposed to a deviant acquisition process.

Leonard (2000) points out that the theoretical dichotomy between delayed and deviant language acquisition in SLI is probably an inadequate oversimplification of the problem as there is no exact definition of what constitutes delay in contrast to deviance. Instead, he presents five characteristic ways in which the language of children with SLI differs from normally developing children (Table 3).

Importantly, a number of different researchers agree on the importance of one characteristic feature of language development in SLI; children exhibiting language difficulties show a relatively late onset of speech production (*late talkers*, Grimm & Doil, 2000; Grimm, 1999; Rescorla, Hadicke-Wiley & Escarce, 1993;). Of course, this does not mean that every *late talker* will develop SLI; still, late talkers are at risk for language difficulties (Grimm & Doil, 2000). This observation almost automatically leads to the question of what kind of relationship should be assumed between impaired speech perception and poor speech production in children with SLI.

Studies in school-age children have indeed revealed a non-linear relationship between deficits in speech perception and poor speech production. It seems that the association of these deficits is strongly dependent on the age of the child (Bird, Bishop & Freeman, 1995; Bird & Bishop, 1992; Bishop, 1998). Therefore, it cannot be ruled out that an earlier, more a general impairment of speech perception might have actually be resolved, having left lasting deficits in language processing as its consequence. On the other hand, it could also be the case that a defective language-learning module leads to poor auditory language processing.

*Table 3: Language Acquisition Profile in SLI***Delay**

For many children with SLI, a delay involves not only the late emergence of language but also slower than average development of language from the point of emergence to the point of mastery.

**Plateau**

There is late emergence and protracted development of language, but a plateau is reached before certain critical aspects of language are mastered.

**Profile Difference**

At any given age, normally developing children show greater ability with some features of language than with others in their language profile. However, in children with SLI, the relationship between features of language seen in their profile does not match that seen in younger normally developing children. Technically, a SLI pattern might be described as resulting from different degrees of delay across features.

**Abnormal Frequency of Error**

SLI children exhibit a particular type of error that can also be seen in the speech of younger normal developing children, but never with such high frequency. Also, this type of difference persists for a longer period in the speech of children with SLI.

**Qualitative Difference**

It turns out that unique phonological patterns are seen in children with SLI. However, reports of highly unusual patterns can be seen in the literature on normal phonological development as well.

Modified after Leonard (2000)

In the following, two accounts based on different assumptions on the etiology of SLI are presented. Due to the diversity of the field and the topic of the work at hand, only exemplary theories related to prosodic processing in very young children and infants are considered.

## 3.2 The Linguistic Perspective on SLI

In the following, Fikkert's account (1994) of prosodic development in normal Dutch children will be presented. She argues within the linguistic principles and parameters framework, assuming that innate knowledge in the form of a Universal Grammar (UG) is composed of several subsystems, each of which contains a set of parameters.

### 3.2.1 Prosodic Development in Normal Children

At the initial state of acquisition, all parameters have the unmarked value. Therefore, during the language learning process, the child must derive the correct parameter values of the native language from the input. The acquisition of stress parameters in Dutch has six different stages (see also Demuth, 1995; Demuth & Fee, 1995).

At stage 1, children produce only monosyllabic words. All parameters, including the stress parameters, still have default value.

At stage 2, childrens' disyllabic initial-stressed words which correspond to initial-stressed disyllabic target words are produced correctly. Also, stressed syllables of disyllabic target words are always produced. Hence, the child begins to acquire features of the stress system. The correctly produced trochaic patterns of stage 2 are supposed to constitute quantity-insensitive trochees (QI) where knowledge of syllable structure like, for example, vowel length distinctions, is not necessary. Comparison of output and target forms reveals that the items typically produced in stage 2 do not show any stress errors, although – especially in the case of final-stressed target words – they typically consist of a reduced number of syllables.

At stage 3, children add an additional syllable to their monosyllabically produced forms corresponding to di- and polysyllabic final-stressed targets. The child produces this extra syllable without changes in stress parameters, consistently applying the trochaic stress pattern. Hence, output forms show stress errors. Up until stage 4, typical mismatches between the child's produced forms and the corresponding adult forms are of two types: either stress was placed correctly but the child's production forms were monosyllabic, whereas the target forms contained more syllables (stage 2); or all produced items were trochaic (stage 3). At stage 4, the child is able to detect the feature of quantity-sensitivity (QS) after realizing his own stress errors – probably through monitoring his own output. Hence, she must have acquired the relevant aspects of feet syllable structure related to QS in her mother tongue, e.g. vowel length distinctions in German, or closed versus open syllables in Dutch. The child is now able to iteratively parse the previously produced forms into feet or, from the child's viewpoint, words, which all receive equal stress (level stress).

During stage 5, children learn how to stress compounds of feet or words (Compound Stress Rule). They typically stress the first full foot or prosodic word.

Finally, at stage 6, the acquisition process is completed, i.e. the Main Stress parameter is acquired.

### **3.2.2 Behavioral Evidence for the Stagnation of Prosodic Development in Preschoolers with SLI**

Penner and coworkers (cf. Penner et al., 1998; Penner & Hamann, 1997, Penner, Kölliker-Funk & Zimmermann, 1992; Penner, 2000) argue that due to the reduced learning ability of SLI children, they are not as adept as others in detecting the relevant



cues in the input data, which are, however, needed to trigger further prosodic development.

According to their UG based view, a therapy enabling the language-impaired child to detect the relevant cues in the actual input, e.g. through increased frequency of critical data, should trigger further prosodic development (cf. Clahsen & Hansen, 1993; Dannenbauer, 1994).

Following this assumption, Penner and coworkers (1998) transferred the prosodic language learning task formulated for Dutch children to Swiss-German children, as the acquisition task is very similar in Swiss-German and Dutch<sup>14</sup>. Dutch and Swiss-German only differ with respect to the Weight parameter, which is sensitive to closed syllables in Dutch and to rhymes in Swiss-German. Also, the Unit of Extrametricality differs between both languages.<sup>15</sup>

The authors did a speech therapy study including two Swiss-German children with SLI. Child 1 was a typical late talker who did not show age-adequate language with respect to both syntax and phonology. At the age of 3;4 she only produced monosyllabic CV words clearly, indicating her stagnation or plateau of prosodic development (stage 1, cf. Leonard 2000). After increased input of trochaic nicknames (cf. Jusczyk, 1997), target trochaic words – not only nicknames – were more often produced by the child, indicating that the child actually overcame stage 1 (e.g. she now produced her proper name – Seline – correctly).

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<sup>14</sup> *Stress parameters with settings for Swiss German*

- a. **Foot-shape parameters**  
*Headedness parameter:* Feet are strong on the left/right  
*Quantity-sensitivity (QS) parameter:* Feet are QS/QI  
*Weight parameter:* Feet are QS to closed syllables/nucleus/rhyme
- b. **Parameters of foot construction**  
*Directionality parameter:* Feet are built from the right/left  
*Iterativity parameter:* Feet are built iteratively [yes/no]
- c. **Word tree dominance parameters**  
*Main stress parameter:* The word-tree is strong on the right/left  
*Extrametricity (EM) parameter:* There is an extrametrical unit [yes/no]  
*Unit of EM parameter:* The unit of EM is a [consonant C, a mora m, a heavy syllable s, a foot F, a monosyllabic foot, etc.]
- d. **Compound stress parameter**  
*Compound stress parameter:* Stress the [left/right] prosodic word of a compound.  
 (adapted from Penner et al., 1998, p. 236)

<sup>15</sup> *Contrary to Dutch, Swiss German has a Minimal Word Constraint. Content words in Swiss-German are minimally a disyllabic trochaic foot, or, if monosyllabic, they must be superheavy. (Penner et al., 1998)*

Child 2 also started talking relatively late. At the age of 5;6 he still showed many level stress forms and had problems with superheavy syllables. In particular, he could not handle vowel length contrasts. According to the model sketched in 4.2.1, this child showed a stagnation at stage 4, where superheavy syllables are not systematically produced correctly, forms of more than one foot occur and forms with more than one foot are typically produced with level stress. The intervention focused on providing the child with the triggers or cues necessary to move beyond stage 4, i.e. the cues for the Compound stress parameter, as well as the cues for the Main stress parameter. At the age of 6;0, the child frequently realized superheavy syllables according to the required targets (e.g. Bank `bank`, Mais `corn`, Baum `tree`). Vowel length was often realized correctly and stress errors were infrequent, indicating that child 2 also profited from the therapy.

In sum, the data obtained during the therapy study not only seem to sustain the importance of an accurate linguistic model for diagnosis and therapy of SLI as proposed by Penner and colleagues (1998) but also support their acquisition model. Still, to further validate the outcome of this sort of speech therapy, standardization of the tool through reference to comparison groups of the same chronological and mental age has to be completed.

Also, as is true for similar accounts which try to explain the language acquisition problems of SLI children by postulating a genuine linguistic deficit<sup>16</sup>, the objection still holds that the linguistic problem could as well be the result of more general auditory language processing problems. This view is especially supported by the fact that predictions of similar accounts only hold for a limited number of languages (for a review, see Leonard 2000)<sup>17</sup>.

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<sup>16</sup> In the following, some generally accepted linguistic accounts of grammatical deficits in SLI are listed (for a review, see Leonard, 2000):

- a. Functional Category Deficits: Some authors (Guilfoyle, Allen & Moss, 1991; Eyer & Leonard, 1995; Leonard, 1995; Loeb & Leonard, 1991) have proposed that individuals with SLI have special problems with the acquisition of functional categories.
- b. Extended Optional Infinitive: This proposal has its basis in the work of Wexler (1994) who argued that young normally developing children go through a stage during which they fail to obligatorily mark tense in main clauses. This stage is supposed to be extended in SLI (Rice & Wexler, 1995; Rice, Wexler & Cleave, 1995).
- c. Implicit Grammatical Rule Deficit: Gopnik and colleagues (Gopnik 1990a, 1990 b, 1994a, 1994 b; Gopnik & Crago, 1991, Ullman & Gopnik, 1994) suggested that the grammatical problems seen in SLI are a serious and possibly permanent inability to acquire implicit rules or mark tense, number and person.
- d. Narrow Rule Learning: Ingram and colleagues (Ingram & Carr, 1994; Morehead & Ingram, 1973) have proposed that the grammatical deficits seen in children with SLI are due to a restriction in the range of contexts to which rules are applied.

### 3.3 Non-Linguistic Accounts: SLI as a Result of Impaired Processing of Auditory Information

Several authors suggest that – instead of or in addition to a specific linguistic deficit – a more basic difficulty in processing rapidly presented and/or brief auditory stimuli, for both speech and non-speech stimuli, may underlie the poor phonological skills so frequently observed in SLI populations.

It has been hypothesized that limitations in rapid auditory processing (RAP) may directly interfere with adequate perception of spoken language by disrupting efficient processing of the speech stream. According to these authors, such difficulties could impair or delay the formation of distinct, phonological representations and thus possibly play a causal role in SLI (for a review see Leonard, 2000; Studdert-Kennedy & Mody, 1995; Tallal, Merzenich, Miller & Jenkins, 1998; Wright, Bowen & Zecker, 2000).

#### 3.3.1 The Rapid Auditory Processing Deficit Account (RAP)

Along with other researchers, Tallal and Piercy (1973) demonstrated temporal constraints on auditory processing in children with SLI (Benton, 1964; Eisenson, 1966; Hardy, 1965; Lowe & Campbell, 1965; Masland & Case, 1968; Monsees, 1961).

Using a non-verbal task, it was demonstrated that – in comparison to controls – children with SLI needed a longer Inter-Stimulus interval (ISI) to judge the sequential order of two different tones of the same duration (75 ms) but of different frequency. These results indicated that children exhibiting SLI had a problem discriminating tones when they were presented in rapid succession.

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e. Problems with Structural Relationships: Clahsen (1989, *The Missing Agreement Account*) proposed that the grammatical deficits of children with SLI are a result of a selective impairment in establishing the structural relationships of agreement. It is assumed that these children lack the knowledge of asymmetrical relations between categories.

f. Problems with Specifier-Head relations: Van der Lely (1994, 1996, *Representational Deficit for Dependent Relationships*) also assumes problems with grammatical agreement. In addition, this account shares with Rice and Oetting (1993) the assumption that specifier-head relations not involving grammatical agreement (e.g. past tense) also fall within the domain of difficulty for children with SLI.

<sup>17</sup>Cross-linguistic differences in the language of children with SLI indicate that there seems to be no universal gap in these childrens' linguistic knowledge. Rather, non-linguistic language processing factors like frequency, perceptual salience or phonological redundancy, as well as their role in instantiating the particular grammatical properties of a given language, seem to contribute to their acquisition problem.

Tallal and colleagues went on to show that similar results could be obtained if the tone duration, rather than ISI, was manipulated; i.e. when tone duration was 250 ms rather than 75 ms, children with SLI had no difficulty in completing the discrimination task at the shortest ISIs. At this point, it is not entirely clear how brief stimuli and a rapid rate of presentation of stimuli can actually cause the same effect. However, it follows that the lengthening of brief stimuli should result in more successful completion of the discrimination task by children with SLI.

In order to extend their findings to the processing of language, Tallal and colleagues conducted experiments using speech stimuli instead of tones (Tallal, Stark & Curtiss, 1976; Tallal & Piercy, 1974). They demonstrated that the discrimination of consonants represented a more difficult task than the discrimination of vowels for children with SLI. These results were explained with reference to the physical properties of consonants in contrast to vowels: whereas consonants are basically differentiated by rapidly changing transient frequency information, vowels are not only of greater duration but also include substantially less change in frequency and energy throughout their course (*steady state*). Therefore, children with RAP deficits should have more difficulties discriminating consonants.

Still, the exact relation between the rapid auditory processing (RAP) deficit and the language-impairment seen in SLI needs to be determined. Several attempts were made to relate the RAP deficit to language perception in children diagnosed with SLI. A significant relationship between RAP and the comprehension of a collection of grammatical forms that require discrimination of brief acoustic information (e.g. noun plural -s, regular past -ed), in contrast to grammatical forms of longer duration (object pronouns him, her), was seen in children with SLI: they had greater difficulty in discriminating of grammatical forms of brief duration than controls (Fellbaum, Miller, Curtiss & Tallal, 1995). However, this result has not been universally replicated (Studdert-Kennedy & Mody, 1995).

Several researchers have observed improved discrimination performance by school-age children with SLI when the formant transitions in [ba] and [da] were doubled (Alexander & Frost, 1982; Frumkin & Rapin, 1980). A similar modification of language input was used in a treatment study by Tallal and colleagues (Tallal et al., 1996). As part of their treatment, a group of children presenting with SLI received extensive practice in listening to stories and other exercises in which the verbal material was systematically modified. The duration of the speech was prolonged by 50%, and fast transitional elements were differentially amplified by as much as 20dB. A control group of children with SLI participated in a training program with unmodified speech material. For the children who listened to the altered speech, large gains on standardized

measures of language comprehension were achieved, whereas controls made much smaller gains.

It was argued that the impressive results obtained during the 4-week-treatment support the RAP hypothesis. On the other hand, the great improvement in language competence could only be explained by assuming that participants had already developed considerably more language competence than they were able to demonstrate beforehand (Merzenich et al., 1996). The question as to how these children acquired this language competence, despite demonstrating a RAP deficit still needs to be answered (cf. Leonard, 2000). In sum, it is not entirely clear which components of the treatment package have been essential to the critical changes seen in these children.

Lately, the high incidence of concomitant rapid processing deficits in the auditory, visual and motor systems, seen in individuals with SLI, has led to the assumption that some underlying, more basic impairment impacts multiple systems (for a review, see Stein & Talcott, 1999; Tallal, 2000). Flax and coworkers (2000) demonstrated a high co-occurrence of language, reading and auditory rate processing impairment in SLI probands using a multigenerational family aggregation research design. Following this line of argument, RAP deficits have also been examined in individuals exhibiting dyslexia (for a review, see Habib 2000).

Several other hypothesis regarding the etiology of the RAP deficits seen in SLI have also been formulated. One addresses the functioning of the sensory trace of auditory stimuli: it was suggested that, in SLI, the failure to discriminate brief auditory stimuli in rapid succession might result from a defective or rapidly decaying sensory trace which cannot be linked to the phonological representation. Yet, performing a comparison study between 22 nine-year-olds with SLI and 12 control children, Neville and coworkers (Neville, Coffey, Holcomb & Tallal, 1993) found no difference in either amplitude or latency of cortical auditory evoked responses, even at short ISIs.

Another possibility to account for the RAP deficit seen in SLI was suggested by Gillam and colleagues (Gillam, Cowan & Day 1995). They proposed that, in children with SLI, interpretation of incoming auditory information might be slowed. In fact, Kail (1994) examined the reaction times (RT) of children with SLI and age-matched normally developing children across a range of tasks. The results indicated that the RT's for the children exhibiting SLI increased linearly as a function of the RT's for the control children, indicating generalized slowing in SLI. On the other hand, Tallal and coworkers showed that the performance profile of children with RAP insufficiency did not match that of normally developing children at any age, indicating a general deviance rather than a generalized slowing during the processing of rapidly changing auditory information.

If SLI is assumed to involve basic sensory, perceptual and motor abilities that support language but are not speech specific, it is legitimate to examine such processes in animal models. This makes even more sense, as volumetric, hemispheric and metabolic differences have been reported in brain imaging studies of subjects exhibiting SLI (Cowell, Jernigan, Dennenberg & Tallal, 1995; Jernigan, Bellugi, Sowell, Doherty & Hesselink, 1993; Leonard et al., 1993; Neville et al., 1993;). Moreover, in several studies, group differences for anatomical and functional measures were found to be significantly correlated with performance differences on tasks requiring rapid auditory processing of verbal and non-verbal stimuli (for a review see Tallal & Benasich 2002, for a review of the ERP data see chapter 6).

Following the neurobiological approach, Fitch and coworkers (Fitch, Tallal, Brown, Galaburda & Rosen, 1994) developed a rodent behavioral paradigm modeled after tasks to identify auditory processing thresholds in humans. Rats with induced cortical microgyric lesions showed significant deficits in RAP, but normal processing of the same stimuli when presented more slowly. However, the precise neural mechanisms linking the physiological findings with the linguistic deficit are still unknown.

Other, more basic cognitive skills, like the capacity to focus attention, are also candidate hypothesis to explain the processing deficits seen in SLI (Powell & Bishop, 1992)<sup>18</sup>.

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<sup>18</sup> The following general cognitive deficits have been found to correlate with Specific Language Impairment (for a review, see Leonard 2000).

**a. Mental Representation:** Based on the theoretical framework of Piaget where language is but one of several interrelated mental representations, Morehead and Ingram (1973; Inhelder, 1963; Morehead, 1972) proposed that the grammatical deficits in the children with SLI were attributable to a broader deficit in mental representation.

**b. Mental Imagery:** Another form of representational ability that has been studied in connection with SLI is mental imagery (Inhelder, 1963; Kamhi & Catts, 1981; Siegel, Lees, Allan & Bolton, 1981). In all the tasks discussed thus far, it was not possible to determine whether mental imagery was invoked. Johnston and Ellis Weismer (1983) took this extra, important step by making use of a mental rotation task. In this task, drawings of a pair of geometric forms were presented and the children were to push one of two buttons corresponding to 'same' and 'different'. The form on the left was always vertical whereas the form on the right was either vertical or rotated about its center. Response times that increase linearly as a function of degree of rotation are interpreted as evidence that imagery was involved. It was shown that school-age children with SLI exhibited slower response times than age controls overall, but that for both groups, response times were slower with increasing degree of rotation. However, no group differences were revealed.

**c. Hypothesis Testing:** Hoskins (1979) found differences in the hypothesis-testing abilities of school aged children with SLI and a group of age controls. Masterson (1993, Ellis Weismer, 1991) examined how school-age children with SLI would perform on hypothesis testing, involving the discovery of a rule, in comparison to a second task where the children were given the rule to apply. According to Masterson's results, children exhibiting SLI may have a problem with on rule induction or with limitations in processing capacity, rather than with rule application.

This suggestion, however, seems to be paradox, as children are only then diagnosed as language-impaired if they score at age level on non-verbal tests of intelligence.

Over the past decades, much evidence in favor of the RAP deficit hypothesis has been collected. So far, evidence in favor of the RAP deficit account remains correlational and is thus open to more than one interpretation. To better understand a possible causal role of RAP deficits in SLI it is necessary to examine cognitive and language development prospectively and longitudinally in very young children born to families at risk for the disorder, as well as in controls. As differences in outcomes of SLI studies are often reported, it is also imperative to implement transparent subject selection criteria from early on. The studies which will now be described were designed to systematically examine RAP abilities in early infancy, and to then determine their relation to subsequent language outcome.

### **3.3.2 Behavioral Evidence for RAP Deficits in Infants at-risk for SLI**

In the studies summarized here, performance on RAP tasks and perceptual-cognitive measures were evaluated in two groups of infants: normal control infants and infants with a family history of a language disorder. One of the study aims was the identification of children at risk for language delays by exhibited RAP abilities as this is a necessary step for early and appropriate intervention. Moreover, information that would elucidate the causal chain of events leading to SLI should be obtained.

To date, results obtained in a longitudinal study examining RAP abilities with behavioral paradigms have only been reported by Benasich, Tallal and coworkers (Benasich, Thomas, Choudhury & Leppänen, 2002; Benasich & Tallal, 1996; Tallal & Benasich, 2002). In their initial study, RAP skills in two groups of 6 to 10 month old infants were tested using a headturn paradigm. Infants received a series of auditory-visual habituation and memory tasks. In order to index RAP abilities, an infant was habituated to a static visual stimulus which was coupled with either a tone or a speech stimulus (400-400 Hz tone pair, or synthetic consonant vowel syllable /ba/). After the infant was habituated, a series of test trials were conducted, either consisting of the same auditory stimulus or a different one (a novel tone pair: 400-600 Hz or either a novel consonant vowel syllable: /da/). The coupled visual stimulus remained unchanged during the procedure. The infant's ability to discriminate between the two auditory stimuli was represented by a significant novelty preference. By varying the ISI between the auditory stimuli, the infant's auditory processing threshold was assessed. At a mean age of 7.5 months, infants from families with a positive history of SLI had significantly lower mean RAP thresholds than control infants. Prospective follow-up of this group revealed a robust predictive relationship between RAP abilities and language outcome at age 3 years



(Tallal & Benasich, 2002). Whereas RAP was the single best predictor of expressive and receptive language outcome in both groups, gender, i.e. being male was the next best predictor.

In another longitudinal study, children at risk for SLI, as well as controls, were seen in the laboratory at 6, 9, 12, 16, 24 and 36 months (Benasich et al., 2002). Once the children were 12 months old, cognitive and language development were assessed with a series of standardized psychometric tests at each visit. The experimental part of the study consisted in the same Conditioned Head-Turn Tasks. Again, processing of rapidly changing auditory cues in speech as well as in non-speech sounds, proved to be related during infancy. Moreover, it was found that the RAP thresholds measured in both infants at risk for SLI and controls were significantly related to later language comprehension and production at 16 to 36 months of age (Benasich & Tallal, 1998; Spitz, Tallal, Flax & Benasich, 1997; Tallal & Benasich, 2002).

Yet, although converging evidence speaks for the importance of a basic sensory mechanism, i.e. RAP abilities in the language acquisition process, it is still not clear how it might affect linguistic learning. It is therefore very likely that linguistic, sensory, perceptual as well as cognitive processes are essential parts of an interactive language acquisition process which needs to be studied in much more detail.

### **3.4 Possible Genetic Components of SLI**

Over the past decade, a possible genetic component of the language disorder has been examined (Bishop, North & Donlan, 1995; Brzustowicz, 1996; Flax, 2001; Gopnik & Crago, 1991; Lahey & Edwards, 1995; Lewis & Thompson, 1992; Rice, Haney & Wexler, 1998; Spitz et al., 1997; van der Lely & Stollwerck, 1996). Family aggregation studies were conducted to determine the incidence and pattern of occurrence of SLI in families (Gopnik & Crago, 1991; Hurst, Baraitser, Aiger, Neils & Aram, 1990; Tomblin & Buckwalter, 1994; Tomblin, 1989). Tallal and coworkers (2001) were the first to employ a case-control family study design in which the current language-related abilities of all biological, primary relatives of probands exhibiting SLI, as well as matched controls and their primary relatives were investigated. It was shown that the rates of SLI for the mothers, fathers, sisters, and brothers of the impaired probands were significantly higher than for control family members (31% versus 7%). Interestingly, the rates for brothers were significantly higher than for sisters. In the families of the SLI probands, SLI occurred in 13% of offspring (excluding the proband) with neither parent affected, 40% of offspring with one parent affected and 71% of offspring in families with both parents affected.



The degree of heritability of SLI was also estimated conducting twin studies (Lewis & Thompson, 1992; Tomblin & Buckwalter, 1998). Twin studies are based on the fact that monozygotic twins should have identical genetic material, whereas dizygotic twins share an average of 50% of their genetic material. Therefore, monozygotic twins should be concordant for inherited traits approximately twice as often as dizygotic twins. In line with this expectation for genetic transmission, higher rates of concordance for monozygotic than for dizygotic twins were reported across studies. Bishop and colleagues (1995) reported a stronger concordance for male twins than for females. However, to determine whether a disorder is truly genetic, gene linkage studies that aim at linking the phenotype with the genotype are necessary.

Indeed, specific genes have been linked to dyslexia as well as to speech impairments with orofacial dyspraxia (Enard et al., 2002; Fisher & DeFries, 2002; Marcus & Fisher, 2003). To date, no specific genes have been linked for SLI which, in fact, constitutes a very complex behavioral disorder.

Although research on a possible genetic component to SLI holds promise, it should be kept in mind that, across all studies, between 30 and 60% of all probands exhibiting SLI are the only family member with a language problem (Tallal & Benasich, 2002).



## Chapter 4

### From EEG to ERP

Electroencephalography (EEG) makes it possible to determine the activity of the brain by recording its electrical activity. The principle source of EEG activity is thought to be the extracellular current flow from the summated postsynaptic activity of many pyramidal cells (e.g. cell assemblies), which, in turn, are the major projection neurons of the cortex.

EEG patterns are characterized by typical electrical frequency and amplitude changes evoked by certain activities of the living brain. Compared to other brain imaging techniques like, for example, PET or MRI, the temporal resolution of an EEG is much more accurate; its spatial resolution, however, is less precise.

#### 4.1 The Adult EEG

The normal human adult EEG shows activity within the range 1-40 Hz, with amplitudes in the range 1 to 100  $\mu$ V (microvolt) being recorded at the scalp (Rugg & Coles, 1995). The amplitude of EEG potentials (microvolts) is much smaller than the voltage changes in single neurons (millivolts). This is due to the distortion of the electrophysical signal by the filtering and attenuation produced by intervening layers of tissue and bone acting like resistors and capacitors in an electric circuit.

Electrical brain activity crucially depends on age and level of vigilance. In adults, the surface EEG shows typical age-dependent patterns of activity which can be correlated to various stages of sleep and wakefulness. The specific rhythmic pattern of the adult EEG waveform reflects synchronized waves of excitatory synaptic potentials reaching the cerebral cortex from thalamic relay neurons. The observed frequencies have been divided into four groups: alpha (8-13 Hz), beta (13-30 Hz), delta (0.5-4 Hz) and theta (4-7Hz) waves.

Alpha waves of moderate amplitude, for example, are typical of relaxed wakefulness and are most prominent over parietal and occipital sites in normal adults. Lower-amplitude beta activity is more prominent in frontal areas and over other regions during intense mental activity. Alerting a relaxed subject results in so called desynchronization of the EEG, i.e. in a reduction in alpha and an increase in beta activity.

In adults, EEG can be used to diagnose and monitor several pathological conditions. For example, theta and delta waves are normal during drowsiness and early slow-

wave sleep, but, if present during wakefulness, represent a sign of brain dysfunction (Kandel, Schwarz & Jessell, 2000).

## 4.2 The Infant EEG

As in adults, the surface EEG of infants (0-1 year of age) shows age-dependent, typical patterns of activity which can be correlated to various stages of vigilance. Typically, the following arousal states can be distinguished with specific EEG patterns in infants: wakefulness, active sleep and quiet sleep.

The classification of sleep and waking states is accomplished with the help of certain physiological and behavioral variables such as the EEG, heart rate, regularity of respiration, eye and body movements, vocalization and the eyes being open or closed (Niedermeyer, 1998). Active sleep is the predominant sleep stage in neonates. With maturation, however, the amount of time spent in this state diminishes (cf. Table 4)<sup>19</sup>.

The waking baby around the age of 2 months shows considerable slow wave activity of 2-3.5 Hz. Medium to high voltage (50-100  $\mu$ V) is widely preponderant (Niedermeyer, 1998). At the age of 3-4 months, the waking baby shows rhythmical posterior activity around 4 Hz which is a precursor of the posterior alpha rhythm. According to Dreyfus-Brisac and Curzi-Dascalova (1975), this rhythm accelerates to 6-7 Hz by the age of 12 months, with amplitudes still ranging from 50 to 100  $\mu$ V.

## 4.3 The 10-20 system

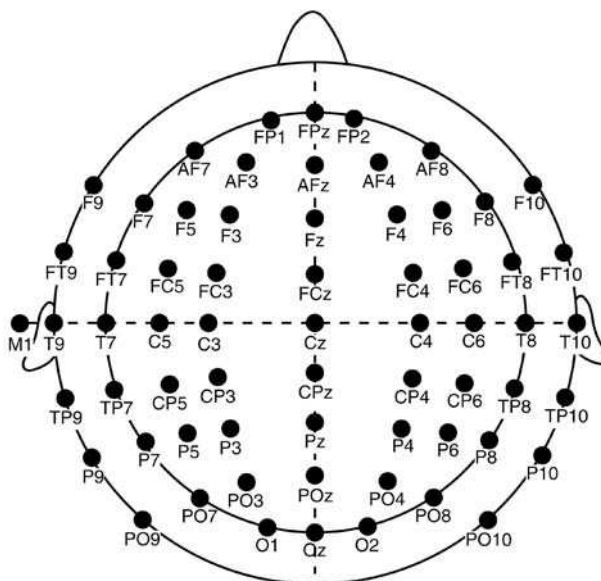


Figure 1: Placement of electrodes on the human scalp according to the 10-20 system (Sharborough, 1991).

Most commonly, electrode positions for scalp-recorded EEGs are determined according to the 10-20 system (Jasper, 1958). The system specifies electrode positions in relation to particular brain regions (F: frontal, C: central, P: parietal, O: occipital, T: temporal). Laterality is indexed by numbers, i.e. odd numbers indicate the electrodes position over the left hemisphere, even numbers indicate their position over the right hemisphere. Midline electrodes have the index z.

Nowadays, a larger number of electrodes are often used. Therefore, the American Society for Electroencephalography has established an extended version of the 10-20 system (Figure 1). However, due to the small infant head artefacts could arise from placing too many electrodes with too little distance from each other. Therefore, it makes sense to use a reduced number of exploring electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4).

#### 4.3.1 EEG Recording in Infants

The recording of the EEG is based on the difference of voltage between each exploring electrode located on the scalp and the same common reference electrode. The reference site is chosen as to be relatively uninfluenced by the electrical activity of experimental interest. Note that the location of the reference sites influence the detectability of selective activity in certain brain regions. For example, nose reference (nasoid) is best used when examining the auditory system's activity.

However, another criterion for choosing reference sites is related to practicability, i.e. using the nasoid as a reference site in babies is not possible as they would not tolerate it. Therefore, in babies, mastoids (behind the ears: A1, A2) are usually used as reference sites when measuring brain activity related to the auditory system (Leppänen & Lyytinen, 1997).

For successful EEG recording in infants, several considerations must be taken into account. First of all, the babies as well as the parents need to feel comfortable in the laboratory. Therefore, recordings should be taken in a quiet atmosphere, allowing the child to feel at ease.

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<sup>19</sup> *The peak period of EEG maturation occurs well into adulthood, i.e. after age 30. The process of cerebral maturation is not characterized by steady growth but rather by several quantum jumps during prematurity, as well as during infancy and childhood (Martin et al., 1983).*

Table 4: Vigilance Level of Infants younger than 6 months as Determined by Behavioral and electrophysiological Markers

States	wakefulness	Quiet sleep (QS)	Active sleep (AS)
Behavior	eyes mostly open gross and fine body movements cries	eyes closed startles no body movement	eyes closed small facial movements small digit or limb movements cries
Eye movement	present	absent	present
EEG (4 –8 weeks)	mostly delta-theta activity muscle artefact	tracé alternant* mixed** High Voltage Slow****	Low Voltage Irregular*** Mixed** High Voltage Slow****
EEG (4-5 months)	mostly delta-theta activity muscle artefact	beginning: mostly delta-theta activity (beta possible) Sleep spindles K-Complexes deep sleep: high bilateral synchronic delta waves	delta-theta activity rarely low vertex waves

Modified after Quandt (2002)

*tracé alternant\**: is characterized by an alternating background EEG pattern with 2-4 s bursts of high voltage slow theta and delta activity mixed with continued, low voltage activity in alpha and beta frequencies as well as some isolated theta waves with the duration of 4s. *mixed\*\**: consists of Low Voltage Irregular as well as of High Voltage Slow. The amplitude is usually lower than that seen in High Voltage Slow.

*Low Voltage Irregular\*\*\**: is characterized by a low voltage mixture of theta and beta activity with alpha ripples. It is quite similar in all scalp regions and shows little variability during an epoch.

*High Voltage Slow\*\*\*\**: is characterized by continuous, diffuse, and moderately rhythmic EEG activity. Dominant frequencies are in the theta band mixed with frequent delta, and some alpha and faster EEG rhythms.

When choosing a recording system, the fact that babies cannot be instructed with respect to movement control is essential. Therefore, the system should not be too sensitive to sudden movement. It is also important to use a system which is easy to apply to the infant head. Special emphasis should be placed on the electrode gel used as infant skin is very sensitive. Due to the small infant head, it does not always make sense to use very many electrodes. Technical artefacts may arise as a result of too little distance between them.

Up to now, it is not known to which extent the arousal state of the infant might influence the morphology of certain ERP components. Therefore, it is of crucial importance to determine the child's vigilance level at short intervals, e.g. every 2 minutes (cf. Table 4).

In order to evaluate the single ERP data properly later, it is imperative to closely monitor and document the child's behaviour, i.e. motor activity, eyes closed or open, crying, sucking et cetera.

Obviously, the ongoing EEG includes frequencies that are often outside those that are of interest to the ERP researcher. For this reason, the signal might be filtered online by the amplifiers used. The data might as well be filtered after the recordings (offline) using optional filter settings. Hence, filtering the data allows the investigator to attenuate activity above and below selected frequencies, choosing a certain range of frequencies which are allowed to pass through a certain filter (band pass filtering). Of particular importance in this regard is high-frequency activity that is attributable to muscle rather than brain activity, activity at the line frequency (60 or 50 Hz) as well as low-frequency activity (high pass filtering).

#### 4.4 Event-Related Potentials (ERPs)

The Event-Related Potential (ERP) is a set of voltage changes contained within an epoch of EEG that is time-locked to the occurrence of a stimulus event (Figure 2)<sup>20</sup>.

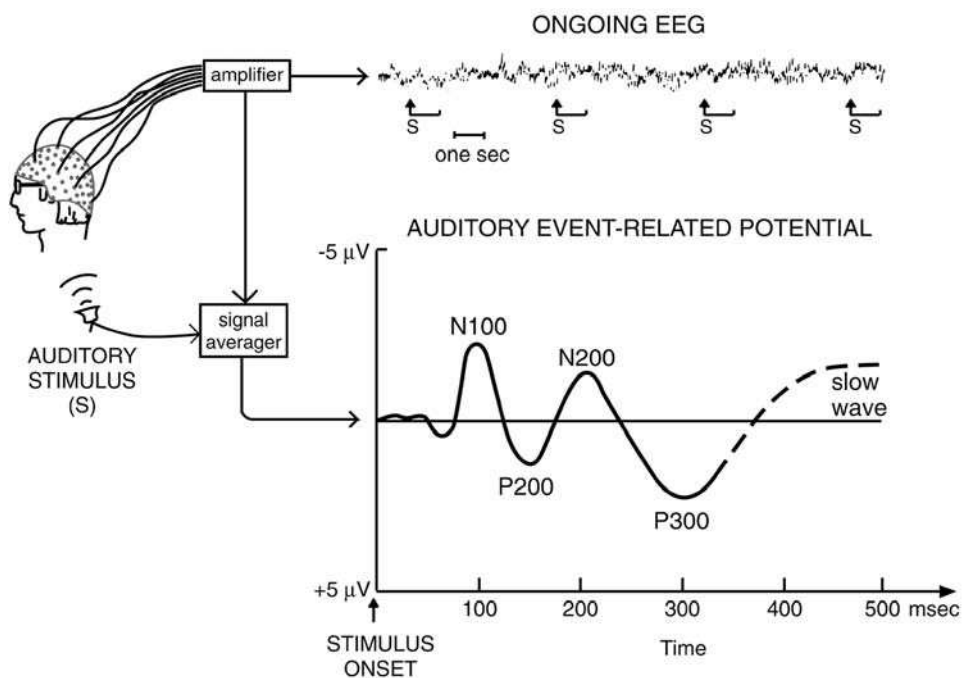


Figure 2: Measuring auditory event-related potentials (ERPs) in humans (modified after Rugg & Coles, 1995, p.6)

ERP components are usually measured by determining their amplitude and latency. Amplitudes can be measured in relation to some other feature of the waveform (peak-to-peak) or in relation to a baseline (usually defined as the mean voltage level for some period preceding the stimulus or event). The latency of an ERP component is then measured in terms of the temporal relationship between the peak of the waveform and the stimulus or event of interest. These features are also important with respect to the naming of ERP components. Most commonly, they are named according to their polarity (P or N) and their latency (e.g. P300 means a positivity with a peak around 300 ms).

It is assumed that ERP recordings from the scalp represent net electrical fields associated with the post-synaptic dendritic activity of sizeable populations of neurons. Electrical fields to be measured at the scalp comprise individual neurons which are synchronously active and have a certain geometric configuration. In particular, these neurons must be configured in such a way that their individual electrical fields summate to yield a dipolar field. Note that, in most cases, the changes induced by the stimulus event are very small. In order to extract the signal (time-locked event ERP) from the noise (background EEG), it is therefore necessary to average a considerable number of EEG epochs each of which is time-locked to repetitions of the same event or event class.

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<sup>20</sup> *There is considerable debate in the literature regarding the definition of an ERP component (Rugg & Coles, 1995). Some researchers adopt what might be called a physiological approach to component definition. According to their view, a defining characteristic of an ERP component is its anatomical source within the brain. For other ERP researchers who adopt what might be called a functional approach to ERP definition, an ERP component is defined more in terms of the information processing operation related to its occurrence. However, the classical view of ERP components implies both accounts. Donchin and colleagues (1978) argued that a component should be defined in terms of its polarity and topography across the scalp which would refer to the physiological features of the component. Moreover, their definition of an ERP component implies its sensitivity to characteristic experimental manipulation as well as its latency which, in turn, would rather refer to the functional features of ERP components.*



## Chapter 5

### ERP Components of Auditory Processing in Adults and Infants

Different states of auditory processing can be distinguished according to ERP components. In adults, they have an established relationship with certain aspects of sensation, perception and cognition (Kandel, Schwartz & Jessell, 2000). Most commonly, auditory ERPs are described in terms of exogenous and endogenous components (Donchin, Ritter & Callum, 1978). Whereas the morphology of exogenous components is related to the physical properties of the external stimulus, the properties of endogenous components are influenced by the subject's intentions and actions during processing.

Yet, in infants, the morphology and functional relevance of ERP components are still under investigation. Both endogenous and exogenous components differ considerably in amplitude, latency and distribution when adults and infants are compared. However, with respect to MMN paradigms used in infants, it is of crucial importance to be able to discern exogenous components from the infant mismatch response. Therefore, the most important auditory ERP components in adults as well as in infants are presented in the following.

#### 5.1 Exogenous Components

##### 5.1.1 Exogenous Components in Adults

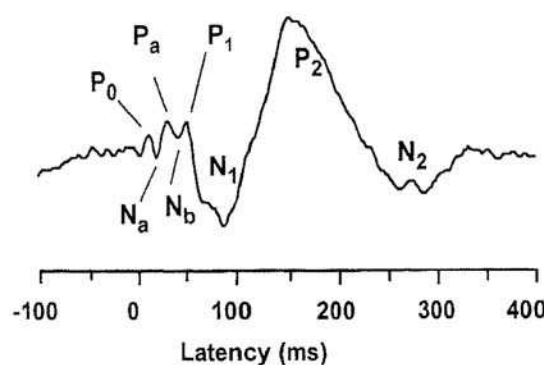


Figure 3: Middle and long-latency obligatory components as recorded from Cz to clicks (adapted from Eggermont & Ponton, 2002, p. 76).

The typical complex response waveform to an acoustic stimulus is shown in Figure 3. The earliest components to be identified after stimulus onset are short latency brainstem

responses which occur within the first 10 to 12 ms. They are followed by Middle Latency Responses (MLR) emerging at 9 to 50 ms after stimulus onset and long latency cortical responses (P1, N1, P2, N2)<sup>21</sup>.

In adults, important long latency cortical responses are the N1 - P2 components. The N1 is assumed to reflect the 'detection of any discrete change in any subjective dimension of the auditory environment' (Hyde, 1997)<sup>22</sup>. Its peak is composed of multiple components which partially overlap in time. The generators of N1 are independent from each other and considered to be located in the supratemporal plane, the temporo-parietal association cortex and the motor and premotor cortices (Alcaini, Giard, Thevenet & Pernier, 1994; Näätänen & Picton, 1987; Ponton, Eggermont, Kwong & Don, 2000; Vaughan & Ritter, 1970; Wolpaw & Penry, 1975).

The P2 emerges at about 160 ms after stimulus onset (Picton, Hillyard, Krausz & Galambos, 1974). Different suggestions have been made regarding its functional significance. At present, its sensitivity to pitch discrimination and musical training is often used in experimental designs (Friedrich, 2003; Shahin, Bosnyak, Trainor & Roberts, 2003). Lately, the P2 was suggested to arise from Heschl's Gyrus (Steinsträter & Lütkenhöner, 1998).

### 5.1.2 Exogenous Components in Infants

In infants, all short latency components resemble the ones seen in adults. Usually, they are discernible by the age of 40 weeks (Moore, 2002; Niedermeyer, 1998). Considerable variation in latency and amplitude of brainstem responses is found up to the age of approximately 5 years (Kraus, McGee & Comperatore, 1989; Stapells, Galambos, Costello & Makeig, 1984). Still, a clear maturational pattern can be seen as the latencies of individual waves and their interpeak intervals decrease with age.

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<sup>21</sup> Most commonly, the following MLR components are distinguished, namely P0, Na, Pa, Nb and Pb (P1). Their latencies are approximately 8, 12, 18, 30, 40 and 50 ms (Howard et al., 1996, 2000; Liegois-Chauvel et al., 1991; 1994, 1999; Picton et al. 1974, 2000). P0 is most likely generated subcortically. As far as the generator of the Na-Pa complex is concerned, different suggestions have been made. According to the analysis performed by Deiber and colleagues (1988), distinct generators must be responsible for these two components, as the generator of the Na is possibly located at the midbrain or thalamus level and therefore would not produce a magnetic response. Other results rather point to a single source located in the primary auditory cortex (Scherg & von Cramon, 1986). The Pb is at least partly similar to the long-latency P1 component. Its source is most likely the planum temporale, i.e. in the secondary auditory cortex (Reite, Teale, Zimmerman, Davis & Whalen, 1988).

<sup>22</sup> It may also reflect attention switching as proposed by Näätänen and Picton (1987).

In contrast, the cortical long latency responses in infants have no resemblance to adult ERP waveforms. Generally, long latency components are reported to increase in waveform complexity during development. Also, an enhancement of amplitudes, along with a decrease in latencies with aging, can be observed during the first year of life (cf. Figure 4, Kushnerenko et al., 2002).

In the following, maturation of long latency cortical responses in infants during their first year of life will be described according to Figure 4 as presented below.

When presented with speech or tones, full-term healthy newborns show ERPs with a predominant positive component starting at 100-300 ms after stimulus onset (Figure 4, top). Throughout their first months, a discontinuity, i.e. a negativity dividing the large positivity into two peaks (P150, P350) at about 250 ms (N250) is typically seen (Kurtzberg, Hilpert, Kreuzer & Vaughan, 1984; Novak, Kurtzberg, Kreuzer & Vaughan, 1989; Nubel, Kruck, Lange & Gross, in prep.). A negative component at 400-600 ms can also be observed (N450) (Molfese, 2000). Finally, by the age of 12 months, a

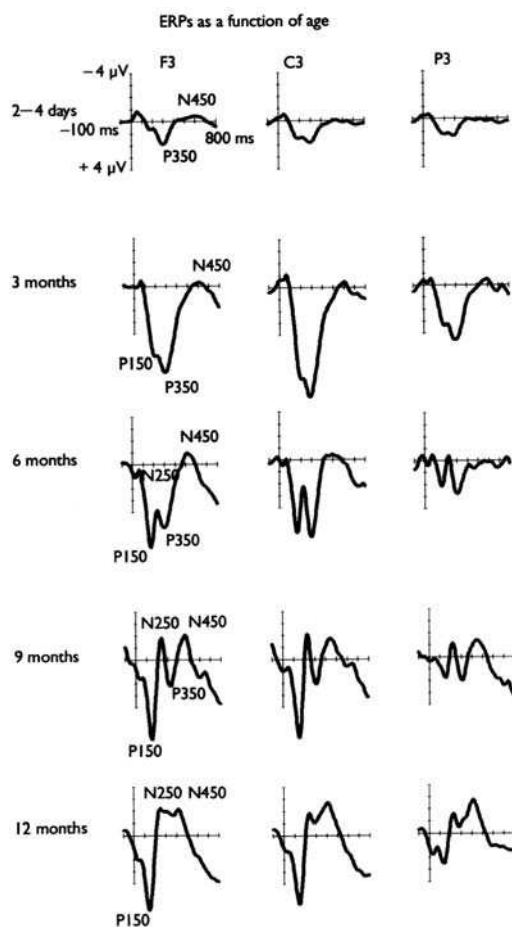


Figure 4: Group-average ERPs obtained in response to 100 ms harmonic tones at birth (2-4 days) and at 3, 6, 9 and 12 months of age (adapted from Kushnerenko et al., 2002, p. 48).

P150-N250-N450 complex is consistently reported. However, the functional relevance of the P150-N250-N450 complex in infants still needs to be determined<sup>23</sup>.

### 5.1.3 Exogenous Components in Infants at Risk for Language Problems

In the following, neurophysiological data obtained in infants at risk for SLI as well as in infants at risk for dyslexia will be reported. Support for presenting both data sets comes from the fact that many of the studies that have followed children with SLI into school age report atypically high proportions of reading problems: i.e. phonological awareness, speech perception, syntactic proficiency and rapid naming are typically affected in both groups (Aram, Ekelman & Nation, 1984; Catts, 1991; Habib, 2000; Stark et al., 1984; Tallal, Curtiss & Caplan, 1988). Therefore, many children can be placed in both of these diagnostic categories, i.e. in the SLI as well as the dyslexic group (Habib, 2000). Also, the same basic temporal processing deficit is assumed in both groups. However, it should be kept in mind that they cannot be treated as synonymous, as there are also dyslexic children who never demonstrate language problems, and vice versa.

Brainstem potentials in four to nine year old children were not of diagnostic value when assessing the function of the auditory cortex (Steinschneider, Kurtzberg & Vaughan, 1992). In infants, this question is still under examination.

Possible differences in long latency cortical activation as evoked by speech stimuli in infants at and not at risk for language problems have been investigated by Molfese and colleagues (1985, 2000). Molfese (2000) investigated infant ERPs to speech and nonspeech stimuli. He identified three newborn ERP components (negativity around

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<sup>23</sup> Several suggestions concerning this question have been made. For example, it has been proposed that the persistence of the P150 peak during infancy, with its stable amplitude and steadily decreasing latency by 3 months of age, might indicate that it is the precursor of the childhood P100. The childhood P100, in turn, is considered to develop into the mature P1 response through further decreases in latency and amplitude between 6 to 20 years of age (Sharma, Kraus, McGee & Nicol, 1997; Ponton et al., 2000). The infantile N250 seems, furthermore, to be the correlate of the childhood N2 (or N250). Although the N2/N250 varies considerably in amplitude and distribution throughout brain maturation, there seems to be no substantial change in function (Ceponiene, Rinne & Näätänen, 2002). The ontogeny of the N2/N250 parallels that of the P1. Hence, it was suggested that the P100-N250 complex reflects basic processes mainly concerned with sensory sound analysis in children (Ponton et al., 2000; Ceponiene et al., 2002a; Kushnerenko et al., 2002). In contrast, the development of the N1 generators seems to be protracted. Given that fact, it seems likely that the function of the childhood N1 is different from the one in adults which is related to sensory sound analysis. Source modelling in children also indicates that the N1 and (P1-)N2 are generated by anatomically distinct generators which are set by the age of 9 years (cf. Ceponiene et al., 2002a).

174 ms, positivity around 310 ms, negativity around 460 ms) which distinguished between children with dyslexia ( $n=17$ ), poor readers ( $n=7$ ) and control children ( $n=24$ ) at the age of 8 years. However, the functional significance of these differences remains to be determined yet.

Guttorm and colleagues (2003) also investigated newborns' ERPs. The infants were presented with two consonant sounds varying in brief transitions (/ba/: 20 ms; /da/: 35 ms, /ga/: 45 ms). In general, the ERPs obtained from newborns at risk for dyslexia displayed the typical infant waveform (Kurtzberg et al., 1984; Kushnerenko et al., 2002; Novak et al., 1989). However, hemispheric differences in amplitude and latency between infants at risk and infants not at risk were seen: The obligatory positive responses obtained after single presentation of the CV-stimulus /ga/ of the at-risk group had larger and more positive amplitudes than those observed in control infants in the right hemisphere. In addition, the obligatory negativity visible in the infant ERP around 500 ms (N450) was delayed in the right hemisphere of the at risk group when compared to controls indicating a possible maturational delay with respect to N450 development.

These results are well in line with data obtained from older infants at risk for dyslexia. When comparing 6-month-olds at risk for dyslexia with matched controls, Leppänen and coworkers (1999) reported a greater right hemispheric obligatory activation in infants at risk when a standard CV-stimulus /ka/ was presented to them in a mismatch paradigm.

Still, several questions regarding these findings need to be answered. First, the functional significance of the reported right hemispheric 'over'-activation during the phoneme encoding process in infants at risk for dyslexia remains to be explained. Second, it remains unclear why the group differences with respect to obligatory responses investigated by Guttorm (2003) and Leppänen (1999) were only found for the CV-stimuli /ga/ (newborns) and /ka/ (6-month-olds), whereas the CV-stimuli /ba/ and /da/ did not elicit the same difference in ERP pattern. The authors argue that different CV transient duration may account for the results. However, the duration of the transient phase in their stimulus /ga/ was longer than in all other CV-stimuli used and should therefore have been the least difficult to encode.

## 5.2 Endogenous Components

### 5.2.1 Endogenous Components in Adults: Mismatch Negativity

MMN can be elicited in a passive oddball design by presenting the subject with a block of identical stimuli (standards) occasionally replaced by acoustically deviant stimuli (deviants)<sup>24</sup>. It is interpreted to reflect the detection of a deviance in the auditory input

from information established in sensory auditory ('echoic') memory (Näätänen, 1992). Hence, the MMN component is considered to provide a neurophysiological correlate of sound representation and discrimination accuracy (for a review, see Näätänen et al. 2001; Picton, Alain, Otten, Ritter & Achim, 2000; Kujala & Näätänen, 2001; Paavilainen, Simola, Jaramillo, Näätänen & Winkler, 2001; Kraus, McGee & Koch, 1998; Näätänen & Winkler, 1999). It is elicited by many kinds of stimulus changes, for example changes in frequency, intensity, spatial location or phonetic and phonological aspects (Näätänen et al., 1997, 1992).

MMN, as well as its magnetic equivalent, the MMNm, occurs irrespectively of direction of attention and usually peaks at 100-200 ms from change onset (Escera, Alho, Schröger & Winkler, 2000; Näätänen, 1992; Näätänen & Winkler, 1999; Schröger & Wolff, 1998). Its main neural generators are bilaterally located in the supratemporal plane<sup>25</sup>.

Another important feature of the MMN component is its characteristic frequency range involving mainly theta (4-8 Hz) but also as low beta (16-20 Hz) activity (Başar, 1999). Figure 5 shows the obligatory evoked response components on the left for duration discrimination. To indicate MMN, the difference wave (standard ERP minus deviant ERP) is usually plotted (Figure 6). Usually, the MMN is fronto-centrally distributed. Note that its amplitude becomes smaller and its peak latency longer as discrimination

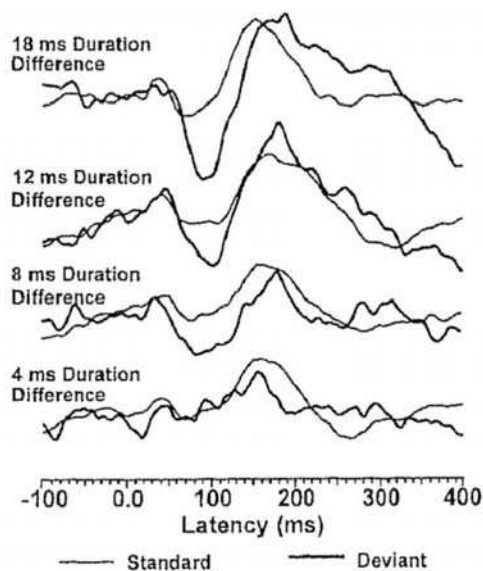


Figure 5: Obligatory auditory responses to stimuli differing in duration when presented as the standard (thin line) or as the deviant (thick line; adapted from Eggermont & Ponton, 2002, p. 77).

<sup>24</sup> During active oddball designs, i.e. when the subject is required to consciously detect the randomly occurring deviants, MMN is usually followed by N2b and P3a (Näätänen, 1992).

<sup>25</sup> This was shown by different methods like, for example, scalp recorded event-related potentials (Giard, Perrin, Pernier & Bouchet, 1990) and fMRI studies (Opitz et al., 1999, 2002).

difficulty increases (indicated by arrows in Figure 6). The shape or size of the MMN is generally not indicative of the deviating feature when more than one is present. It only indicates that a stimulus contrast exists and how large the difference might be (Eggermont & Ponton, 2002).

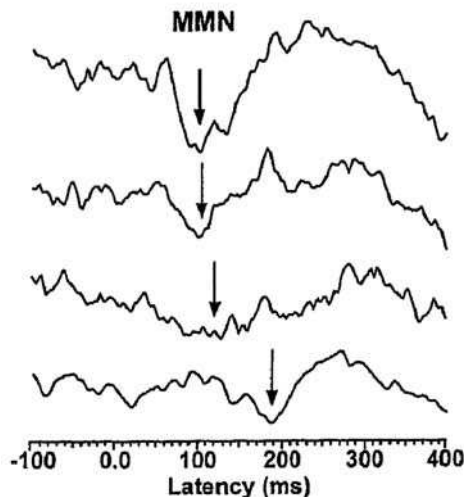


Figure 6: A difference between the waveforms shown in Figure 5 is called MMN (adapted from Eggermont & Ponton, 2002, p. 77).

The MMN paradigm can also be used to investigate speech stimuli processing in adults and infants. In fact, Näätänen and colleagues (1997) demonstrated that language specific speech stimuli induce a specific MMN pattern in adults: It was observed that an infrequent vowel deviant elicited a larger MMN when it was a prototypical exemplar of a vowel category in the adult participants' native language than when it was not. These results were interpreted to indicate long term memory traces' enhancement of MMN amplitude for prototypical native language speech sounds in adults. Additional magnetic MMN (MMNm) studies demonstrated that neural phoneme traces were located in the left hemisphere, whereas both the left and the right hemisphere seemed to be involved in acoustic discrimination. Cross-language studies with a similar design using English and Japanese phonemes or French and Hindi phonemes confirmed the latter results (Phillips, 1985; Winkler et al., 1999).

## 5.2.2 Endogenous Components in Infants: Mismatch Response

### 5.2.2.1 Endogenous Components in Infants: Mismatch Response to Phonemes

Mismatch Responses (MMR) have been consistently reported in newborns and young infants. However, the MMR morphology in infants is different as compared to adults. Whereas the adult MMN is fronto-centrally distributed, the infant MMR can also be



observed over parietal areas (Leppänen & Lyytinen, 1997). The most striking difference between adults and infants with respect to the mismatch response is the polarity of the component since in infants positive MMRs have been also reported (Friederici, Friedrich & Weber, 2002; Leppänen et al., 1999; Pihko et al., 1999). In the following, infant MMR data obtained during language processing will be presented. The overview will mainly deal with categorical perception and perceptual constancy in infants and also serves as an illustration of the debate regarding MMR polarity in infant studies (Table 5)<sup>26</sup>.

Dehaene-Lambertz and coworkers attempt to delineate acoustic and language processing in infants. Throughout their MMR research, the group consistently reported a positive MMR at about 300 ms after change onset in infants (Dehaene-Lambertz, Dehaene & Hertz-Panier, 2002; Dehaene-Lambertz & Pena, 2001; Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz & Dehaene, 1994).

Table 5:

*Summary of mismatch studies to speech stimuli in infants (0-6 months, not in quiet sleep). N = negativity, P = positivity*

study	subjects	deviant stimulus	change onset (ms)	ISI (off/on in ms)	filter (Hz)	MMR polarity	MMR latency (ms)
Cheour, M. et al. (1997)	3-month-olds N=6	<u>vowel difference</u> 1./i/: 100ms	0ms	700	band 0.1-30	N	200
Cheour, M. et al. (1998a)	6-month-olds N=9	<u>vowel difference</u> 1./ö/: 400ms 2./õ/: 400ms	0ms	700	band 0.1-15	N	250-450
Dehaene-Lambertz, G. et al. (1994)	2-3-month-olds N=16	<u>place of articulation</u> 1./ba/: 289ms 2./ga/: 289ms	0ms	SOA 600	band 0.5-20	P N	390 680
Dehaene-Lambertz, G. et al. (1998)	3-month-olds N=24	<u>categorical perception</u> 1.within-category syllable: 275ms 2.across-category syllable:275ms	0ms	SOA 600	band 0.5-20	P	400m
Friederici, A.D. et al. (2002)	2-month-olds N=10	<u>vowel duration</u> 1./ba/: 341ms	30ms	855	high 0.3	P N	370 770
Kushnerenko, E. et al. (2001)	Newborns 1.N=12 2.N=9 3.N=15	<u>consonant-duration</u> in /asa/ 1./s/: 240ms 2./s/: 80ms 3./s/: 80ms	170ms	310	band 1-15	1., 2.: N 1.,2.,3. : N	150-200 350-450
Leppänen, P. et al. (2002)	6-month-olds 1.N=12 2.N=27	<u>consonant-duration</u> in /ata/ 1.95ms 2.255ms	167ms	1: pooled 610 450 2: 610	band 0.5-35	1.N 2.N	380 400
Pihko, E. et al. (1999)	6-month-olds N=23	<u>vowel duration</u> 1./ka/: 110ms	110ms	425	band 0.5-35	P P	160 340

<sup>26</sup> Different results with respect to the influence of arousal states on the mismatch response in infants have been reported (Martynova, Kirjavainen & Cheour, 2003; Friederici et al., 2002). However, most studies presented in the following report data obtained from infants who were not in quiet sleep stage which seems to be the stage most critical for the morphology of MMR.



In their first study, it was demonstrated that 2-3 month old infants were able to discriminate CV-stimuli varying in the consonant's place of articulation, i.e. /ba/ (289 ms) versus /ga/ (289 ms) (Dehaene-Lambertz & Dehaene, 1994). In a subsequent study, Dehaene-Lambertz and Baillet (1998) addressed the existence of categorical processing mechanisms at the age of 3 months. They presented four synthesized syllables to infants, one serving as a standard and the others as deviant items. According to adults' judgments, two of the deviant items were perceived as belonging to the same phoneme category, whereas one of them was judged to belong to a different category. Although the acoustical change was of similar magnitude in all deviants, the electrophysiological discrimination response in infants was larger for a categorical phonological change deviant than for an acoustic change deviant. The latter result was therefore interpreted as an indication of the existence of categorical perception mechanisms already at the age of 3 months.

Using the same stimuli in adult controls it was demonstrated that MMR amplitude also varied as a function of categorical change (Dehaene-Lambertz, 1997). Hence, it was concluded that separate phonological processing networks exist in both adults and infants. In a further study, Dehaene-Lambertz and Pena (2001) investigated perceptual constancy in newborns. This time, neonates were presented with CV-deviants (/pa/: 227-257 ms, /ta/: 219-229 ms) which never were of the same phonetic category as the standard. The deviant items occurred in different standard contexts: in the first condition, standard and deviant were produced by the same speaker, whereas in the second condition all standards, including the deviants, were produced by different speakers. Neonates displayed a positive MMR to both the different-speaker as well as the same-speaker deviants. This result indicated that during the processing of the different-speaker exemplars of the same phoneme a common feature, i.e. phoneme identity had been identified and afterwards successfully discriminated from the categorical deviant phoneme. Hence, perceptual constancy seems to be in place at birth.

Categorical perception of vowels in infants has been studied by Cheour and colleagues who, in contrast to Dehaene-Lambertz and coworkers (Dehaene-Lambertz, Dehaene & Hertz-Panier, 2002; Dehaene-Lambertz & Pena, 2001; Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz & Dehaene, 1994) consistently report a negative infant MMR (Cheour et al., 1998a; Cheour et al., 1998b). These researchers demonstrated how language-specific memory traces for vowels develop. Using a longitudinal design, a comparison between MMR amplitudes to native-language vowels and foreign-language vowels was made for Finnish and Estonian infants. In this study, all stimuli were vowel prototypes in both languages, except one that was a prototype only in the Estonian language. It was found that at the age of 6 months, the negative MMR amplitude in Finnish infants only reflected the acoustical difference between the deviant and standard stimuli. However, by 1 year of age, the MMR to

prototypes of the infants' native language was enhanced when compared to the response obtained to non-prototypes. As opposed to the results obtained for consonants by Dehaene-Lambertz and colleagues (1998), this study suggests a later onset of categorical perception for vowels in infants as well as a negative polarity of the mismatch response.

So far, no satisfactory explanation for this difference in timing and polarity of the Mismatch Response (MMR) in infants has been provided. A review of the infant MMN studies conducted in subjects younger than 7 months who were not in quiet sleep stage, however, raises the possibility that the difference in the polarity of the MMR might also be dependent on methodological differences like the filter setting used (cf. Table 5).

#### **5.2.2.2 Endogenous Components in Infants: Mismatch Response to Complex Speech Sounds**

Leppänen and colleagues (2002) investigated discrimination abilities in 6-month-olds using complex speech stimuli in a mismatch paradigm. In their study, infants were presented with two VCV-stimuli differing in consonant duration (/ata/: 95 ms, /atta/: 255 ms) during two experimental conditions. In the first one, the long /atta/ served as the deviant whereas the short /ata/ functioned as the standard. The second condition was constructed the other way around. Data was pooled for different ISIs (610 ms; 450 ms) for the short /ata/ condition; for the long /atta/ condition, an ISI of 610 ms was used. A negative MMR peaking at about 400 ms after change onset was seen for both conditions, indicating normal 6-month-olds' sensitivity to duration increment and decrement of plosives in complex speech stimuli. This finding is in line with results obtained in a similar study conducted in newborns (Kushnerenko et al., 2001).

Kushnerenko (2001) presented newborns with different fricative durations throughout three stimulus conditions. In the first condition, the frequent standard stimulus was /asa/ with an overall duration of 390 ms and fricative /s/ duration of 80 ms ('asa 80'). The infrequent stimulus was /assa/ with overall duration of 550 ms and fricative /s/ duration of 240 ms ('assa 240'). In the second condition, the stimulus probabilities were reversed, so that 'assa 240' served as the standard and 'asa 80' as the deviant stimuli. In the third condition, the duration of the fricative /s/ in the standard stimulus was lengthened to 320 ms ('assa 320') with stimulus 'asa 80' serving as the deviant. The duration of the whole standard stimulus was then 630 ms. In all conditions, an ISI (offset to onset) of 310 ms was used.

Two significant negativities in response to fricative duration increment and decrement were observed in the neonates' ERP difference waves. The first negative MMR peaked

around 200 ms from change onset and the second peaked around 400 ms from change onset. The second negativity was seen in all conditions whereas the first negativity was not seen for the last condition. The authors suggested the first negativity to be an adult-like MMN. The second one was considered to be a late discrimination related response (LDN) indicating further processing of previously discriminated stimuli.

Taken together, these results indicate that differences in consonant duration embedded in a complex speech stimulus can be discriminated by newborns as well as by 6-month-olds. In newborns, a second discrimination related negativity was observed. However, as total length of all stimuli used was different in both studies, obligatory exogenous effects could not be unambiguously discerned from the MMR.

### 5.2.2.3 Endogenous Response in Infants: Late Discriminative Negativity

Besides MMN, a second negativity related to changes in auditory stimulation can be elicited using a passive oddball design in infants (Cheour, Korpilahti, Martynova & Lang, 2001). This negativity is called late MMN (LDN) and was first reported by Korpilahti (1996)<sup>27</sup>. The LDN response usually follows MMN and peaks at about 400-430 ms in response to change in speech stimuli and tones in 5- to 10-year-olds as well as in young adults. In children, the amplitude of the LDN was a function of the speechness of the stimuli, i.e. it was significantly larger for words than for tones. The authors therefore suggested that the LDN response reflects the automatic processing of complex auditory, possibly even linguistic stimuli. However, Čeponienė, Cheour and Näätänen (1998) also obtained LDN in response to tones. Thus, the functional significance of the LDN which can also be obtained in adults and sleeping infants, has not been determined yet (Trejo, Ryan-Jones & Kramer, 1995; Martynova, Kirjavainen & Cheour, 2003).

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<sup>27</sup> The infant late negativity resembles that of the negative component (Nc), which is typically observed in children (Courchesne, Ganz & Norcia, 1981). However, both components can be discerned considering their typical distribution and elicitation pattern. In most cases, the Nc is reported for the visual domain. Typically, it is frontally distributed and increases in amplitude the more deviant, new or surprising a deviant stimulus is (Courchesne 1977, 1978). To obtain an Nc component, the deviant stimulus has to be important enough as to require further, more detailed processing (Courchesne, 1978). Since this late negativity in the auditory domain was typically seen in oddball experiments, it cannot, however, be considered a Nc: the duration of such an experiment is far too long for these deviant stimuli to remain important or new (Cheour et al., 2001; Čeponienė et al., 1998)

### **5.2.3 Endogenous Components in Infants at Risk for Language Problems: Mismatch Response**

#### **5.2.3.1 Endogenous Components in Infants at Risk for Language Problems: Mismatch Response to Phonemes**

To date, ERPs in infants at risk for language problems have only been collected in the Jyväskylä Longitudinal Study of Dyslexia (JSD). So far, no data is available for infants at risk for SLI. Therefore, the JSD data investigating speech sound duration processing in normal controls as well as in infants at risk for dyslexia will now be considered (cf. 5.1.3). First, the data obtained in normal controls included in the study are reported. Afterwards, the results obtained in infants at risk for dyslexia will be presented.

Pihko and colleagues (1999) investigated processing of vowel duration as this is a categorical dimension in the Finnish language. They presented newborns and normal 6-month-olds with a vowel length decrement discrimination task. Infants were presented with a short CV deviant (/ka/: 110 ms) among a series of long CV standards (/ka:/: 250 ms). An ISI of 425 ms (offset to onset) was used. 6-month-olds displayed a positive MMR around 300 ms after change onset whereas neonates presented with the same experiment did not display any electrophysiological indication of vowel length discrimination.

However, when the ISI for the same discrimination task was lengthened (855 ms) in again the same experiment conducted in newborns, an early positivity emerging around 50 ms after change onset was seen. The latency of this positivity, though, seems to be too short as to interpret it as a positive MMR. Nevertheless, a negative component in the left hemisphere of the newborns also was present but only after prolongation of the ISI (Leppänen et al., 1999). It occurred around 300 ms after change onset and might well be interpreted as a negative MMR occurring at a longer latency of about 300 ms after change onset as previously reported by Cheour (1998a). Thus, newborns' discrimination response was affected by slowing down the presentation rate, indicating slower processing of stimuli per se in children of this age group.

Taken together, newborns as well as 6-month-olds not at risk for dyslexia can discriminate vowels of different duration as indicated by a positive MMR obtained in 6-month-olds and a negative MMR in newborns. When Leppänen and coworkers (1999) conducted the same experiment with lengthened ISIs (825 ms) in newborns at risk for dyslexia, they found a right-hemispheric discrimination related positivity around 300 ms as opposed to a left-hemispheric negative MMR around 300 ms in controls.

Table 6: Summary of Mismatch Studies in Infants at Risk for Dyslexia and Normal Controls (mixed vigilance states, 0-6 month olds, filter: 0.5-35 Hz); N = negativity, P = positivity

study	deviant stimulus	change onset (ms)	ISI (off/on in ms)	subjects	MMR pol	MMR latency (ms)	subjects at risk	MMR pol	MMR lat (ms)
Leppänen et al. (2002)	<u>consonant-duration in /ata/</u> 1./t/: 95ms 2./t/:255ms	167	1.pooled: 610 450 2. 610	6-month-olds 1. N=12 2. N=27	1. N 2. N	1. 380 2. 400	6 month-olds: 1.N=12 2.N=25	1. absent 2. P N	1. absent 2. 280 400
Pihko et al. (1999)	<u>vowel duration</u> 1./ka/: 110ms	110	425	newborns N=31	No effects	No effects	newborns N=42	P	170
Pihko et al. (1999)	<u>vowel duration</u> 1./ka/: 110ms	110	425	6-month-olds: N=23	P P	160 340	6-month-olds N=28	P P	160 340
Leppänen et al. (1999)	<u>vowel duration</u> 1./ka/: 110ms	110	855	newborns N=11	N	340	newborns N=12	P	340

More evidence pointing to differences in hemispheric involvement in vowel length processing between infants at risk for dyslexia and normal controls was seen in another study by Pihko (1999). When 6-month-olds were presented with again the same vowel duration discrimination task, both infants at risk for dyslexia as well as normal controls displayed a discrimination related positivity around 300 ms after change onset (Pihko et al., 1999). Note that the latter effect was more pronounced in the right hemisphere of infants at risk.

Thus, in comparison to age matched controls, newborns at risk for dyslexia did not display a left hemispheric negative MMR when testing their discrimination abilities for vowel length differences. On the other hand, both 6-month-olds at risk for dyslexia as well as 6-month-olds not at risk for dyslexia did not display a negative MMR. Still, 6-month-olds at risk demonstrated a right-hemispheric enhancement of the positive MMR amplitude when compared to age matched controls<sup>28</sup>.

### 5.2.3.2 Mismatch Response to Complex Speech Sounds

When duration processing of plosives in complex speech sounds (/ata/ versus /atta/) was investigated in 6-month-olds at risk for dyslexia, a different MMR pattern was once again seen (cf. Table 6; Leppänen et al., 2002). Whereas normal controls discriminated the short /ata/ deviant sound from the long /atta/ standard item by

<sup>28</sup> These results are in line with electrophysiological evidence reported for adult dyslexics as well as for children with learning disabilities (Kraus et al., 1996; Kujala et al., 2000; Rippon & Brunswick, 2000).

displaying a negative MMR, infants at risk for dyslexia did not display any discrimination response to the short /ata/ sound. When presented with the long /atta/ deviant stimulus, infants at risk for dyslexia displayed a smaller negative MMR than normal controls. No hemispheric effect for the negative MMR was seen.

The lack of MMN in the at risk group for the deviant short /ata/ was interpreted as possibly reflecting difficulties in temporal integration (Leppänen et al., 2002; Yabe, Tervaniemi, Reinikainen & Näätänen, 1997). Thus, they are thought to have slower temporal integration or use a longer temporal integration window, which would result in a more merged or integrated sensory event (Leppänen, 2002).

### 5.3 Hemispheric Lateralization of Language Processing

Several hypothesis with respect to the lateralization of language have been formulated. One line of argument assumes that both hemispheres are initially equipotential and that the asymmetry observed in adults arises during development (Bates, Vicari & Trauner, 1999; Lenneberg, 1967). Others assume a left-hemispheric preponderance from birth on (Kinsbourne, 1976; Kinsbourne & Hiscock, 1977, 1983). Some authors emphasize the different time course of structural changes occurring in the brain during development. In fact, the left hemisphere is supposed to mature faster than the right either overall or in some regions only (Corballis, Funnell & Gazzaniga, 2000).

Others presume a pre-disposition for left hemispheric processing of language (Kolb & Wishaw, 1996; Satz, Strauss & Whitaker, 1990) but only with respect to the basic functions involved. Thus, they rather suggest that left hemispheric preponderance for language develops throughout childhood on the grounds of the aforementioned lateralized basic skills (Zatorre & Belin, 2001). Still another line of argument follows the assumption of an early right hemispheric involvement during language processing as the right hemisphere is predominantly processing prosodic information most relevant during the initial learning stage (Friederici & Hahne, 2000; Locke, 1994)<sup>29</sup>.

A recent fMRI study in 3-month-olds revealed different hemispheric activation in response to speech stimuli (Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002). The data obtained in this study revealed a stable activation of left hemispheric cortical areas which are also involved in adult auditory processing (superior temporal gyri,

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<sup>29</sup> However, in general, plasticity of the developing brain is one of its most characteristic features to be observed in the infant brain. When examining children with acquired aphasia (Friederici, 1994), right hemisphere activation during speech processing was seen. Also, during language processing in an infant with left hemispheric infarct using an fMRI design, Dehaene-Lambertz, Pena, Christophe, & Landrieu (2004) found right hemispheric activation.

angular gyri). In awake infants, additional frontal right hemispheric activation was seen. However, frontal activation is usually linked to attentional processes. Therefore, an early lateralization of language processing in the left hemisphere was suggested.

Several attempts were made to investigate left hemispheric preponderance for language processing in infants using a mismatch design. Referring to MMR lateralization of speech stimuli in adults, it has been suggested that the distribution of the MMR in response to auditory versus language stimuli in infants might serve as an important key in identifying the developmental trajectories of lateralization for language processing (Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz & Dehaene, 1994; Näätänen et al., 1997).

With respect to the infant mismatch studies already described, a left hemispheric mismatch effect has only been seen in response to differences in place of articulation when examining 2-3-month-olds (Dehaene-Lambertz & Dehaene, 1994). Neither categorical perception in 3-month-olds nor perceptual constancy in newborns was definitely related to increased left hemispheric processing (Dehaene-Lambertz & Pena, 2001; Dehaene-Lambertz & Baillet, 1998). However, with respect to the processing of vowel length differences, left hemispheric preponderance of the MMR was seen in newborns (Leppänen et al., 1999).

Concerning hemispheric differences between infants at risk for dyslexia and normal controls, different results have been reported. Whereas a less pronounced or even absent left hemispheric amplitude of the negative MMR was found for complex speech stimuli in 6-month-olds at risk for dyslexia, same age infants at risk for dyslexia displayed a right hemispheric enhancement of the amplitude of the positive MMR to varying vowel length. This result might point to functional differences underlying both components.

Taken together, infant MMR studies do not provide clear evidence for hemispheric MMR activation as a function of the speechness of the stimuli so far. Given the fact that, even in adults, consistent hemispheric effects can only be detected using fMRI, the possibility of determining hemispheric differences in language processing of infants using ERP paradigms seems to be limited at best.



## **5.4 Reduced Prosodic Bootstrapping Capacity in SLI as Revealed by ERP Components - a Working Hypothesis**

Word segmentation strategies based on the native-language prosodic pattern of two syllable content words have been proposed for infants as, in stress-timed languages like English or German, the stress pattern of two syllable content words is a very regular prosodic feature. In both languages, about 90% of these words have stress on the first syllable, indicating a strong/weak or trochaic stress pattern (Cutler & Carter, 1987; Wiese, 1996).

Cutler and colleagues suggested that this characteristic rhythmic structure of English could form the basis of an effective segmentation procedure due to the systematic relationship between rhythmic patterns and word boundary location in English (Cutler, 1990; Echols et al., 1997; Jusczyk, 1997; Jusczyk et al., 1993).

Within the prosodic bootstrapping account, it is assumed that infants acquire considerable information about possible word boundaries in their native language through different types of perceptual cues provided by the speech signal. In fact, it was demonstrated that English-learning infants' sensitivity to native-language sound structure increases between 6 and 9 months of age (for a review, see chapter 3). More recently, the latter account has been extended to the German language, which shares rhythmic organization with English.

Stress pattern discrimination has been examined in German infants without risk for SLI using behavioral paradigms (Hoehle, 2002). Throughout her experiments Hoehle (2002) demonstrated that stress pattern discrimination abilities in German infants evolved between 3 and 6 months of age. Note that, in German, stress assignment in bisyllabics is correlated with increased vowel duration of the stressed syllable (Dogil, 1995; van der Hulst, 1999). Therefore, processing of different stress patterns in bisyllabics is highly related to the ability to compute complex patterns of vowel duration.

According to Penner (1998), children exposing SLI are not as adept as others in identifying the relevant cues provided by the input to trigger further prosodic development, i.e. they display reduced prosodic bootstrapping ability. Within the present work it is therefore hypothesized that infants at risk for SLI are not able to process different stress patterns in bisyllabics in the same way as matched controls.

One possible source of reduced bootstrapping capacity in terms of stress pattern discrimination in German might be related to a persistent basic temporal processing deficit seen in SLI as well as in dyslexia (Tallal, 2000; Tallal & Piercy, 1975). As already stated, stress pattern discrimination in German crucially depends on the ability to



process complex vowel duration patterns. Yet, in order to compute relational aspects of different vowel duration it is, however, necessary to be able to discriminate differences in vowel length per se. Temporal processing deficits with respect to vowel length discrimination have been demonstrated to be persistent during the first half year of life in infants at-risk for dyslexia (cf. chapter 5.2.3.1; 5.2.3.2). Impaired temporal processing of vowel length in SLI during that same period might consequently affect stress pattern discrimination abilities in German 5-month-olds at-risk for SLI.

#### 5.4.1 Overview of experiments

The following experiments are part of the German Language Development Study (GlaD) which is an interdisciplinary effort to investigate normal and impaired language production and perception during the first three years of life. Its main focus is the etiology of Speech and Language Impairment (SLI). Only infants without primary deficits like, for example, neurological and/or mental impairment, hearing impairment and/or social deprivation are included. Children raised in a bilingual environment cannot participate.

The design of the study is comparable to the one used in longitudinal studies conducted in Finland (Prof. H. Lyytinen, Jyväskylä Longitudinal Study of Dyslexia) and the United States (Prof. P. Tallal, Rutgers University) where precursors of SLI were detected in the first perinatal months.

The theoretical framework of GlaD is based on the following assumptions: First, it is assumed that the infant's initial knowledge about language is comparable to the one seen in adults. Second, the infant's knowledge about language is the result of language learning mechanisms allowing identification and adequate application of the relevant triggers provided by the input (*bootstrapping capacity*). Third, in children exposing SLI bootstrapping capacities are reduced leading to violation of the adult language's principles.

*The work at hand aims at*

1. examining the influence of long term memory traces for language specific stress pattern in bisyllabics on the morphology of MMN as observed in German and French adults (Experiment I a & I b),
2. determining the developmental timepoint of stress pattern discrimination of bisyllabics - with special emphasis on the trochee - in German infants as this is a crucial prerequisite for word segmentation (Experiment II a & II b),
3. comparing stress pattern processing in matched infants at risk for SLI (Experiment III),

4. investigating vowel length discrimination abilities as a crucial prerequisite for stress pattern discrimination in German 2-month-olds at-risk for SLI (Experiment IV a & IV b, Experiment V) and
5. examining the contribution of different filter settings on the morphology of the infant mismatch response.

In the following, an overview of experiments dealing with the questions presented above will be provided.

### **Experiment I a & I b**

In Experiment I a and I b, the influence of long term memory traces for language specific stress pattern in bisyllabics on the morphology of the adult MMN will be investigated. Therefore, discrimination of iambic and trochaic bisyllabics will be examined using a passive oddball paradigm in German and French adults. The mismatch effect will be determined by conducting an additional deviant-alone paradigm in German adults. Possible contributions of different filter settings on the adult mismatch response will be tested.

### **Experiment II a & II b**

Experiment II a is concerned with the question if neurophysiological evidence for stress pattern discrimination can be provided in German infants as young as 5 months. From behavioral experiments it is known that German 6-month-olds display a preference for the trochaic pattern whereas German 3-month-olds do not. As neurophysiological designs do not rely on infants' attentional or motoric abilities it is hypothesized that stress pattern discrimination is present before the age of 6 months. In addition, contributions of different filter settings on the infant MMR will be investigated. It is hypothesized that, due to the high ratio of slow wave activity in the infant EEG as compared to the adult EEG, an impact of filter settings on the negative MMR of the theta range will be observed. In Experiment II b it will be examined whether stress pattern discrimination is present in German infants at the age of 4 months already.

### **Experiment III**

Experiment III will deal with the question whether German 5-month-olds at risk for SLI will display the same discrimination abilities for different stress pattern in bisyllabics as matched controls. It is hypothesized that German 5-month-olds at risk for SLI will display reduced discrimination abilities when compared to matched controls. If so, this might relate to encoding problems of the presented stimulus per se. Both hypothesis will be tested.

According to the working hypothesis presented above, a temporal processing deficit might relate to reduced stress pattern discrimination in German infants as young as 5 months. Discrimination of different vowel duration is a necessary prerequisite for

processing of complex vowel duration patterns contained in German iambic and trochaic items. However, a temporal processing deficit is known to be associated to SLI as well as to dyslexia. In fact, persistent temporal processing difficulties with respect to discrimination abilities for vowels of different duration have been found during the first half year of life in infants at-risk for dyslexia (Leppänen et al., 1999). Therefore, discrimination abilities for vowel duration in German infants will be examined in the following experiments. In order to exclude influences of language-specific categorical knowledge, these experiments were performed in German 2-month-olds.

#### **Experiment IV**

In Experiment IV, first, the neurophysiological discrimination response for differences in vowel duration will be determined in adult controls. Therefore, additional deviant-alone conditions will be performed. Afterwards, discrimination abilities for different vowel length will be examined in German 2-month-olds without risk for SLI. Taking the results obtained in Finnish not-at-risk infants into account, it is hypothesized that normal 2-month-olds will be able to discriminate different vowel length as indicated by MMR. Again, the influence of different filter settings on the adult and infant mismatch response will be tested.

#### **Experiment V**

Experiment V is concerned with the discrimination abilities for differences in vowel duration in German 2-month-olds at risk for SLI as compared to matched controls. According to the hypothesis of reduced temporal processing in infants at-risk for dyslexia or SLI, these infants are hypothesized to display reduced discrimination abilities for differences in vowel duration. In case the latter hypothesis is confirmed, stimulus encoding of CV items per se will also be examined as a discrimination deficit might also be influenced by less precise stimulus encoding in SLI.



## Chapter 6

### Stress Pattern Discrimination in Adults

#### 6.1 Experiment I a: Stress Pattern Discrimination in German Adults

#### 6.2 Introduction

Prosodic processing of syllable stress was introduced to be crucial for infants' segmentation of word-like units in stress-timed languages like English or German (cf. 2.1). In general, word stress is marked by increase in duration, loudness and frequency of the stressed syllable. However, in German, increase in duration is considered to be the most critical feature for assigning word stress (Jessen et al., 1995).

In order to determine stress pattern discrimination abilities in infants it is important to determine the ERP discrimination response in adult controls first. Therefore, Experiment I a was conducted in German adults. It aimed at determining the adult MMN pattern to different stress patterns in bisyllabics using a passive oddball design. Thus, in Experiment I a German adults' discrimination response to trochaic (stress on the first syllable) and iambic (stress on the second syllable) bisyllabic deviants was examined. It was hypothesized that adults will display a MMN for both stimuli (cf. 5.2). To verify a true MMN effect, two additional deviant-alone control conditions were also conducted in German adults.

Furthermore, the effect of different filter settings was determined in German adults as different filters might influence the morphology of the mismatch response in infants but not in adults, due to the differences in slow and fast wave ratio.

#### 6.3 Methods

##### 6.3.1 Subjects

Experiment I a was performed in 19 German adults (10 female). They were between 20 and 30 years old (mean: 26.7 years) and reported having normal hearing. The subjects were students of the University of Leipzig, they were paid for their participation.

##### 6.3.2 Stimuli and Procedure

Two CVCV pseudowords with different stress patterns were naturally produced in infant directed speech by a young mother who is a native speaker of standard German. She

was instructed to stress either the first or the second syllable. After recording and digitalization (44.1 kHz, 16 bit sampling rate), the first 100 ms of the trochaic item (/ba:ba/, offset 1<sup>st</sup> syllable: 355 ms, onset 2<sup>nd</sup> syllable: 405 ms, total duration: 750 ms) were replaced by the first 100 ms of the iambic item (/baba:/, offset 1<sup>st</sup> syllable: 183 ms, onset 2<sup>nd</sup> syllable: 278 ms, total duration: 750 ms). Hence, the acoustic difference started after 100 ms without any discontinuity (see Figure 7). Both stimuli were easily discernible and judged to sound like natural sounds by three independent German monolingual adult listeners.

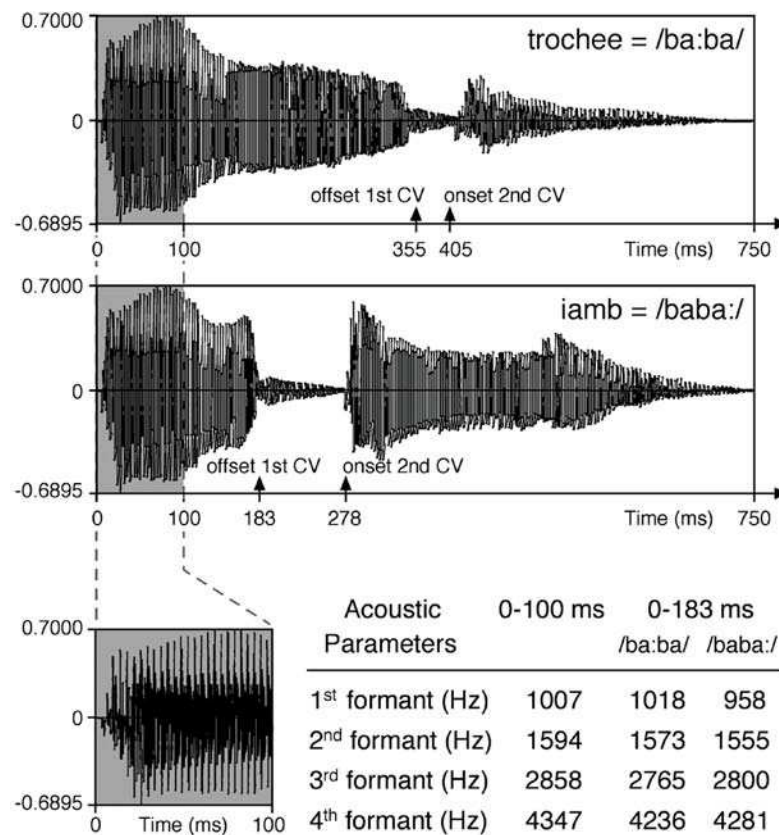


Figure 7: Illustration of the two stimuli. Physical differences start at 100 ms.

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

- (1) CONDITION TROCHEE: the frequently occurring iambic CVCV item /baba:/ was occasionally replaced by the trochaic deviant CVCV item /ba:ba/ and
- (2) CONDITION IAMB: the trochaic CVCV item /ba:ba/ functioned as the standard, whereas the iambic CVCV item /baba:/ took the deviant position.

### 6.3.3 Control condition: Deviant-alone

Deviant-alone conditions are typically conducted to control for the latency and distribution of a true MMN effect. Under such a condition, all deviant stimuli are presented with the same ISI but without any intervening standard (Näätänen, Paavilainen, Alho, Reinikainen & Sams, 1989). Hence, two additional conditions were created:

- (3) DEVIANT-ALONE TROCHEE: the trochaic deviant CVCV item /ba:ba/ was presented without the intervening standard but with the same interstimulus interval
- (4) DEVIANT-ALONE IAMB: the deviant iambic CVCV item /baba:/ was presented without the intervening standard but with the same interstimulus interval.

During each experimental run 600 trials were presented with 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 dB SPL. All adults read a book in their native language during the recordings. Each condition was presented in a separate block. Each block lasted approximately 12 minutes. The whole experiment, including preparation and pauses, lasted about 1.5 hrs and was completely painless.

### 6.3.4 EEG Recording

The EEG was registered with Ag-AgCL electrodes attached to frontal (F3, Fz, F4), central (C3, Cz, C4) and parietal (P3, Pz, P4) scalp sites according to the International 10-20 electrode system (cf. chapter 4.3). An electrode-cap was used. 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 referenced to the left mastoid. The right mastoid was actively recorded. Impedances were below 5 k $\Omega$ . The EEG and EOG channels were amplified using a PORTI-32/MREFA amplifier (Twente Medical Systems), digitalized on-line at a rate of 250 Hz, and stored on hard disk. Further analysis were processed off-line. EEG was either bandpass filtered with 1-15 Hz or highpass filtered with 0.3 Hz and algebraically re-referenced to the average of both mastoids.

### 6.3.5 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline (EEP 3.2.1). Trials exceeding a standard deviation of 80  $\mu$ V within a sliding window of 200 ms in any channel were rejected automatically. Individual averages included at least 65 accepted deviant items. Statistical analysis for the adult data was carried out for 2 x 4

20 ms time windows centered around the grand-average negativity peaks at Fz (275-355 ms, 495-575 ms).

In German adults, four-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus), SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4), GENDER (female vs. male) and FILTER (0.3 Hz vs. 1-15 Hz) for each latency window for between-condition-comparisons (i.e. trochaic deviant item vs. trochaic standard item, iambic deviant item vs. iambic standard item). Hemispheric differences were tested with one-way ANOVAs for mean amplitudes of the deviant stimulus.

In the deviant-alone control condition, two-way ANOVAs with the factor MM (deviant-alone trochaic stimulus vs. deviant trochaic stimulus, deviant-alone iambic stimulus vs. deviant iambic stimulus) and SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4) were conducted for mean amplitudes of the deviant stimuli.

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following we report uncorrected degrees of freedom and corrected probabilities.

## 6.4 Results

Figure 8 shows grand-average difference waves for the trochaic and the iambic pseudoword in adults after application of the highpass 0.3 Hz filter (left) and the band-pass 1-15 Hz filter (right).

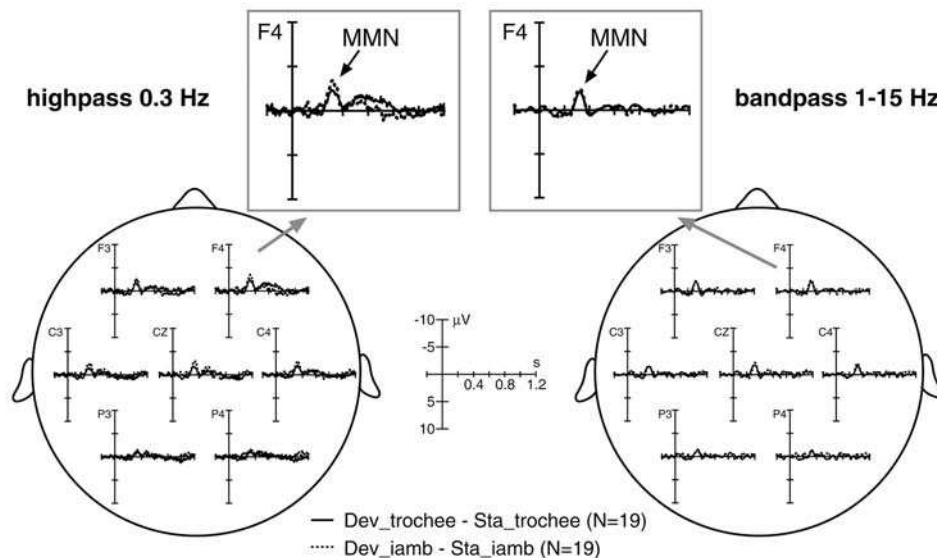


Figure 8: Grand-average difference waves (deviant minus standard) in German adults (N=19). Left: data filtered with 0.3 Hz highpass. Right: data filtered with 1-15 Hz bandpass.



## TROCHAIC PSEUDOWORD

Figure 8 (left, solid line) shows grand-average difference waves (ERP deviant stimulus minus ERP standard stimulus) for the trochaic item in German adults after application of the 0.3 Hz highpass filter. Figure 8 (right, solid line) displays grand-average difference waves of the same data after application of the 1-15 Hz bandpass filter. For both filters, a pronounced negativity peaking at about 300 ms, i.e. around 200 ms after change onset, was seen in response to the trochaic deviant stimulus. Also, around 500 ms, a second negativity was discernible for the latter stimulus. However, it was more pronounced after application of the highpass 0.3 Hz filter. Statistical analysis for the trochaic deviant revealed a significant main effect for DISCRIMINATION at 275-355 ms as well as at 495-555 ms (Table 7a). In addition, significant interactions between DISCRIMINATION and SITE were seen at 275-315 ms and 515-555 ms. Hence, at 175-255 ms as well as at 395-475 ms after change onset, statistical significant effects for the negative deflections were seen. With respect to the first negativity, no significant effects were observed for GENDER or FILTER. However, in case of the second negativity, a main effect for FILTER was revealed. For neither significant negativity, a hemispheric difference was detected.

Table 7a: Differences between ERP responses to trochaic deviant and trochaic standard stimulus in German adults (N=19).

	df								
		t1	t2	t3	t4	t5	t6	t7	t8
ms		275-295	295-315	315-335	335-355	495-515	515-535	535-555	555-575
TROCHEE									
Discrimination	1,34	13.68***	28.07***	38.70***	33.50***	5.07*	4.50*	4.51*	4.02*
Sitex Discrimination	8,272	5.25**	8.19**				6.46**	5.07**	
Discrimination xGender	1,34								
Gender	1,34								
Filter	1,34					27.82***	27.43***	20.04***	20.41***
Discrimination xFilter	1,34								

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.

## IAMBIC PSEUDOWORD

Figure 8 (left, dotted line) shows grand-average difference waves (ERP deviant stimulus minus ERP standard stimulus) for the iambic deviant in German adults after application of the 0.3 Hz highpass filter. Figure 8 (right, dotted line) displays grand-average

difference waves of the same data after application of the 1-15 Hz filter. Two negativities were discernible in response to the iambic deviant sound. The first negativity peaked at 300 ms whereas the second one peaked around 500 ms after stimulus onset. Statistical analysis revealed a main effect for DISCRIMINATION at 275-355 ms and at 495-575 ms (Table 7b). Statistically significant interactions between DISCRIMINATION and SITE were observed at 275-355 ms as well as at 515-535 ms. Taken together, significant effects for DISCRIMINATION were seen at 175-255 ms and at 395-475 ms after change onset. For the first negativity, no significant effects for GENDER or FILTER were detected. Yet, for the second negativity, a main effect for FILTER was revealed. No hemispheric differences were seen.

*Table 7b: Differences between ERP responses to iambic deviant and iambic standard stimulus in German adults (N=19).*

	df								
		t1	t2	t3	t4	t5	t6	t7	t8
ms		275- 295	295- 315	315- 335	335- 355	495- 515	515- 535	535- 555	555- 575
IAMB									
Discrimination	1,34	23.39***	50.71***	52.09***	40.46***	7.85**	7.15*	12.55**	9.10**
SitexDiscrimination	8,272	7.51***	13.54***	15.07***	5.63**		3.10*		
Discriminationx Gender	1,34								
Gender	1,34								
Filter	1,34					24.76***	11.16**	13.46***	29.28***
Discriminationx Filter	1,34								

*Note:* Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\* $p \leq 0.05$  \*\* $p \leq 0.01$  \*\*\* $p \leq 0.001$ .

#### 6.4.1 Control condition: Deviant-alone

##### DEVIANT-ALONE TROCHEE

Figure 9 shows the ERP waveforms for the trochaic stimulus obtained in the oddball paradigm, i.e. in CONDITION TROCHEE (solid line), as well as the ERP waveform for the trochaic stimulus presented alone, that is at the same ISIs without any intervening standard (DEVIANT-ALONE TROCHEE; dotted line). As expected, the trochaic deviant elicited a higher peak amplitude and had a more central distribution when presented without intervening standard. Statistical analysis revealed a main effect for MM at 275-315 ms and at 495-575 ms after stimulus onset (Table 8). Significant interactions MM x SITE were seen at 315-355 ms as well as at 495-515 ms and at 555-575 ms.

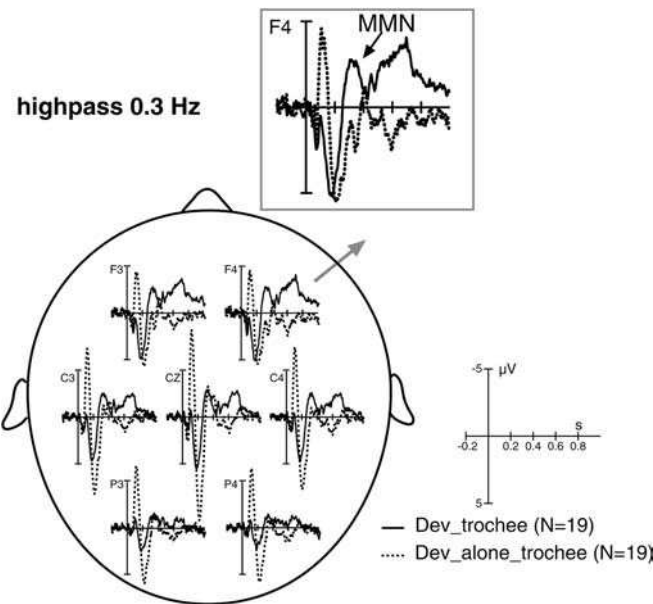


Figure 9: ERP responses to the trochaic deviant obtained for DEVIANT ALONE TROCHEE (dotted line) and for CONDITION TROCHEE (solid line) in German adults.

Table 8: Differences between ERP responses to trochaic deviant in the DEVIANT-ALONE CONDITION and trochaic deviant in CONDITION TROCHEE in German adults (N=18).

0.3 Hz highpass	Df							
	t1	t2	t3	t4	t5	t6	t7	t8
ms	275- 295	295- 315	315- 335	335- 355	495- 515	515- 535	535- 555	555- 575
TROCHEE								
MM	1,17	16.78**	10.51**		30.45***	24.95***	24.31***	17.62**
SitexMM	1,8		9.94***	24.33***	3.49*			3.83*

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.  
\*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.

DEVIANT-ALONE IAMB

Figure 10 displays the ERP waveforms obtained from the iambic deviant stimulus in CONDITION IAMB (solid line) as well as the ERP waveform resulting from its presentation without intervening standard, i.e. as DEVIANT-ALONE IAMB (dotted line). Again, the typical difference between both conditions was observed. Statistical analysis revealed a significant main effect for MM at 275-315 ms and at 495-575 ms after stimulus onset (Table 9). Significant interactions MM x SITE were seen at 295-355 ms as well as at 495-535 ms after stimulus onset.

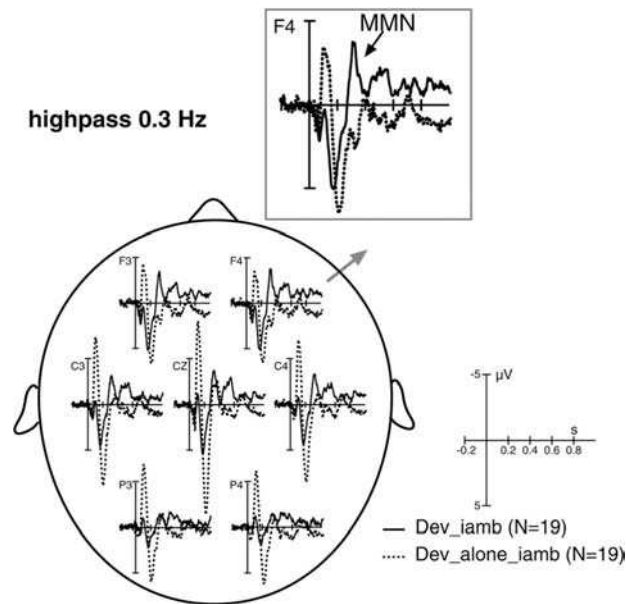


Figure 10: ERP responses to the trochaic deviant obtained for DEVIANT ALONE IAMB (dotted line) and for CONDITION IAMB (solid line) in German adults ( $N=18$ ).

Table 9: Differences between ERP responses to iambic deviant in the DEVIANT-ALONE CONDITION and iambic deviant CONDITION IAMB in German adults ( $N=18$ ).

0.3 Hz highpass	df								
		t1	t2	t3	t4	t5	t6	t7	t8
ms		275-295	295-315	315-335	335-355	495-515	515-535	535-555	555-575
<b>IAMB</b>									
MM	1,17	13.30**	9.92**			12.69**	11.52**	11.89**	8.54*
SitexMM	1,8		7.68***	16.71***	8.88***	5.58**	4.40*		

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\* $p \leq 0.05$  \*\* $p \leq 0.01$  \*\*\* $p \leq 0.001$ .

## 6.5 Summary

Experiment I a aimed at determining the MMN pattern to different stress patterns in German adults using a passive oddball paradigm. A trochaic (stress on the first syllable) as well as an iambic (stress on the second syllable) two syllable pseudoword was presented. Moreover, it was examined whether different filter settings had an influence on the morphology of the adult discrimination response.

As expected an early negativity was observed (275-355 ms) for both deviant items. In addition, a later discrimination related negativity (495-575 ms) was seen. In case of

the first negativity, no effect for different filter settings was observed. Nevertheless, in case of the second negativity, an influence of filter settings was seen: the second negativity was present after application of both filters but it was more pronounced in case the highpass 0.3 Hz filter was applied. In order to control for true discrimination effects, however, two additional deviant-alone control conditions were conducted in the same subjects.

The DEVIANT-ALONE control condition for the trochaic pseudoword indicated that the negativity elicited by the trochaic deviant item observed at 275-355 ms, i.e. at 175-255 ms after change onset was a typical Mismatch Negativity with respect to latency. Visual inspection confirmed the typical fronto-central distribution for the latter response. The DEVIANT-ALONE control condition revealed that the second negativity at 495-575 ms, i.e. at 395-475 ms after change onset was related to the discrimination response. Taking its latency into account, this response can be interpreted as an adult LDN (cf. Cheour et al., 2001).

The DEVIANT-ALONE iamb control condition also confirmed a true discrimination effect for the first negativity, i.e. at 175-255 ms after change onset as well as for the second negativity emerging at 395-475 ms after change onset. Thus, an early MMN as well as a Late Discriminative Negativity in response to the iambic deviant was detected in German adults. Neither hemisphere nor gender related effects were seen.

## **6.6 Experiment I b: Language-specific MMN to differing Stress Patterns in Adults**

### **6.7 Introduction**

In Experiment I b, the influence of long term memory traces for language-specific stress pattern distribution on the morphology of the mismatch responses was tested (Näätänen et al., 1997). Therefore, a cross-linguistic study in German and French adults was performed. It was hypothesized that due to the rare iambic stress pattern in German, discrimination abilities for the iambic item should be less pronounced in German adults. In turn, in case of the trochaic deviant stimulus, i.e. the most frequent German stress pattern, an enhancement was expected in German adults. Hence, a different morphology of the MMN in response was expected for both groups: its amplitude was hypothesized to vary as a function of language-specific stress pattern distribution.

In addition, a second discrimination related ERP component indicating further processing of the discriminated stimulus was expected for both stimuli in both adult groups. Its amplitude was hypothesized to vary in the same direction as the MMN amplitude.

## 6.8 Methods

### 6.8.1 Subjects

Experiment I b was performed in 9 French adults (4 female). They were between 20 and 30 years old (mean 23.4 years) and reported having normal hearing. Subjects were students of the University of Leipzig and were paid for their participation.

### 6.8.2 Stimuli and Procedure

Stimuli were the same as in Experiment I a. They were presented in a passive oddball paradigm (standard:  $p=5/6$ , deviant:  $p=1/6$ ). Two experimental runs were created:

- (1) CONDITION TROCHEE: the frequently occurring iambic CVCV item /baba:/ was occasionally replaced by the trochaic deviant CVCV item /ba:ba/ and
- (2) CONDITION IAMB: the trochaic CVCV item /ba:ba/ functioned as the standard, whereas the iambic CVCV item /baba:/ took the deviant position.

During each experimental run 600 trials were presented with 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 dB SPL. All adults read a book in their native language during the recordings. Each condition was presented in a separate block. Each block lasted approximately 12 minutes. The whole experiment, including preparation and pauses, lasted approximately 1.5 hrs and was completely painless.

### 6.8.3 EEG Recording

EEG Recording was the same as in Experiment I a.

### 6.8.4 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline. As only 9 subjects participated in the experiment, individual averages included at least 80 accepted deviant items. Trials exceeding a standard deviation of 80  $\mu V$  within a sliding window of 200 ms in any channel were rejected automatically. Statistical analysis for between-group comparisons of the adult data were carried out for 2 x 4 consecutive 20 ms time windows centered around the grand-average negativity peaks at Fz (275-355 ms, 495-575 ms).

The data of French adults as well as the data of a matched subgroup of 9 German adults who participated in Experiment I a were analyzed. For group differences three-

way analysis of variance (ANOVA) for repeated measures with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus), SITE (F3/ Fz/ F4/ C3/ Cz /C4) and LANGUAGE (French vs. German) for each latency window for between-condition-comparisons (i.e. trochaic deviant item vs. trochaic standard item, iambic deviant item vs. iambic standard item) were conducted. Hemispheric differences were tested with one-way ANOVAs for mean amplitudes of the deviant stimulus.

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 will be reported.

## 6.9 Results

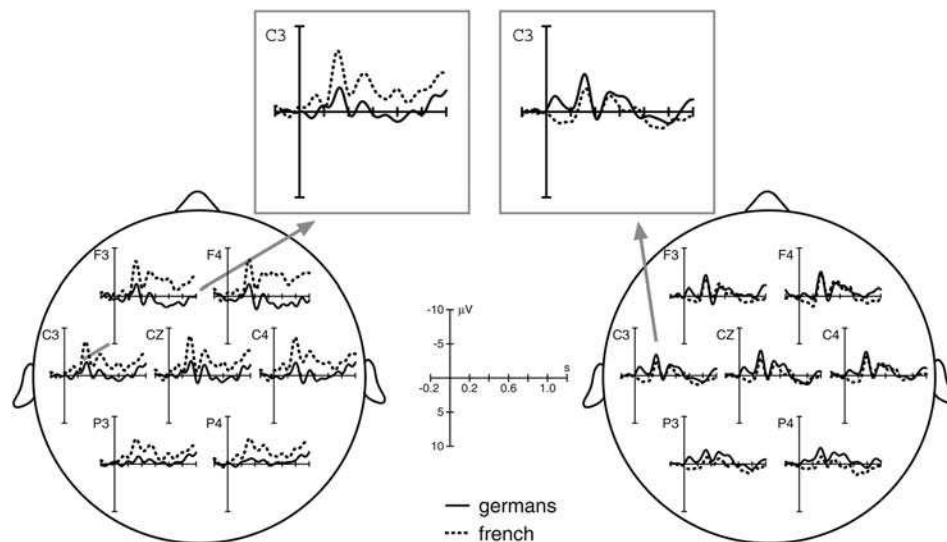


Figure 11: Grand average difference waves (deviant minus standard) to the trochaic deviant obtained in French ( $N=9$ , dotted line) and German adults ( $N=9$ , solid line). Left: Grand average difference waves to the iambic deviant stimulus. Right: Grand average difference waves to the trochaic stimulus.

### TROCHAIC PSEUDOWORD

Figure 11 (right) shows grand-average difference waves for the trochaic bisyllabic in German (solid line) and French adults (dotted line) after application of the 0.3 Hz highpass filter. For both groups, a prominent negativity peaking around 300 ms was observed. A second negativity peaking at about 500 ms was also present in both groups. Statistical analysis revealed a main effect for DISCRIMINATION at 275-355 ms and at 495-575 ms (Table 10). In case of the trochaic deviant item, no statistically significant interaction with LANGUAGE was seen.



Table 10: Differences between ERP responses to trochaic deviant and trochaic standard stimulus in German and French adults (N=9).

0.3 Hz highpass		df							
		t1	t2	t3	t4	t5	t6	t7	t8
ms		275-295	295-315	315-335	335-355	495-515	515-535	535-555	555-575
TROCHEE									
Discrimination	1,16	9.49**	19.89***	18.81**	9.17**	4.95*	6.26*	5.30*	4.49*
Discriminationx Site	8,128								
Language	1,16								
Language x Discrimination	1,16								

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.

#### IAMBIC PSEUDOWORD

Figure 11 (left) displays grand average difference waves for the iambic item in French and German adults after application of the highpass 0.3 Hz filter. For both languages, the negativities seen for the trochaic item were observed again, i.e. the first one around 300 ms, the second one around 500 ms after stimulus onset. However, in French adults, the amplitudes of the negativities in question were enhanced. Statistical analysis revealed a main effect for DISCRIMINATION at 275-355 ms as well as at 495-475 ms (Table 11). Statistically significant interactions LANGUAGE x DISCRIMINATION were observed at 275-315 ms and at 555-575 ms. No further statistically significant effects were seen.

Table 11: Differences between ERP responses to iambic deviant and iambic standard stimulus in German and French adults (N=9).

0.3 Hz highpass		df							
		t1	t2	t3	t4	t5	t6	t7	t8
ms		275-295	295-315	315-335	335-355	495-515	515-535	535-555	555-575
IAMB									
Discrimination	1,16	15.00**	20.33***	16.76**	12.25**	5.99*	9.29**	11.79**	6.64*
Discriminationx Site	8,128								
Language	1,16								
Language x Discrimination	1,16	4.95*	5.99*						6.34*

Note: Time windows (t) in ms relative to stimulus onset. \*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.



## 6.10 Summary

In Experiment I b a typical discrimination related MMN and LDN response was demonstrated for trochaic and iambic deviant two-syllable pseudowords in French and German adults (cf. 5.2.1., 5.2.1.1).

As expected, the MMN amplitude as well as the LDN amplitude in response to the iambic deviant was reduced in German adults indicating that long term memory traces for the iambic stress pattern probably enhanced discrimination in French adults. However, the hypothesis about enhanced discrimination responses for the trochaic item in German adults was not confirmed.

## 6.11 Discussion

Experiment I b was a cross-linguistic study comparing the discrimination related ERP components in response to trochaic and iambic bisyllabics in French and German adults. It was hypothesized that, due to the low frequency of the iambic stress pattern in German, the amplitude of the Germans' MMN should be reduced when compared to French adults. In turn, the amplitude of the discrimination related ERPs in response to the trochaic items should be enhanced in German adults as this is the most frequent stress pattern in the latter language.

In fact, significant differences between German and French adults were found for the iambic item, i.e. the amplitude of the MMN and LDN in response to the iambic deviant in Germans was less pronounced when compared to the one seen in French subjects (Näätänen et al., 1997). Hence, in Germans, the hypothesis of a reduced discrimination response for the iambic item was confirmed.

For the first time, a language-specific influence with respect to the amplitude of the LDN was found. Again, only in case of the iambic deviant stimulus a reduced LDN was seen in Germans. This result is well in line with a study on LDN in children between 4 and 7 years of age (Korpilhati, Krause, Holopainen & Lang, 2001). Korpilhati and colleagues (2001) found that the amplitude of the LDN in response to tones, pseudowords and words increased as a function of speechness of the stimuli used. The authors claimed that acoustical information might be processed in a different way depending on its cognitive meaning. This might hold for the present results in adults as well, i.e. due to the higher frequency of the iamb in French more elaborate further processing of the previously discriminated stimulus might take place as indicated by the higher amplitude of the LDN. Alternatively, the LDN amplitude might simply vary as a function of discrimination accuracy as indicated by the MMN amplitude.

Regarding the trochaic stress pattern, no influence of language specific frequency on MMN and/or LDN amplitude was seen. This might be due to a general perceptual advantage, e.g. of stimulus onset, which renders the trochaic item more salient when presented among iambic standards. It is also possible that the MMN amplitude is only sensitive to large differences in language specific distribution of speech stimuli which only was the case for the iambic stress pattern.

In neither experiment, hemispheric differences were seen. This might be due to the fact that the spatial resolution of ERP data is limited. In fact, hemispheric differences for phoneme processing in adults were better seen when the MMN was examined (Näätänen et al., 1997).

In Experiment I a, also the influence of filter settings on the morphology of the discrimination related ERPs in German adults was examined. It was demonstrated that filter settings had no influence on the polarity and/or statistical significance on both, MMN and LDN in adults. However, in case of the LDN amplitude a major contribution of EEG activity outside the 1-15 Hz range was seen indicating differences with respect to the brain activity involved in MMN and LDN discrimination responses.

## Chapter 7

### Stress Pattern Discrimination in Infants

#### 7.1 Experiment II a: Stress Pattern Discrimination in German 5 months old Infants

#### 7.2 Introduction

In Experiment I a and I b it was demonstrated that French as well as German adults displayed MMN and LDN responses when presented with trochaic and iambic deviant pseudowords in an oddball study. It is known that stress pattern information is used to guide early segmentation processes in adults and infants (cf. chapter 2.1).

Experiment II a and II b were concerned with the question whether infants at the age of 4 and 5 months would display discrimination related ERP responses when presented with trochaic and iambic deviant pseudowords during the same passive oddball paradigm. From previous studies it is known that, already in newborns, discrimination related ERP response can be elicited using complex speech stimuli in an oddball paradigm. The stimuli used were produced in infant-directed speech (IDS). IDS is commonly preferred by infants of a few days of age to 9 months. These items are usually spoken at a slower rate, at a higher pitch and with a wider frequency range (Fernald & Simon, 1984; Fernald & Kuhl, 1987). The latter features are supposed to promote language learning in infants (Kuhl et al., 1997). Behavioral evidence suggested that German 6-month-olds but not German 3-month-olds displayed a preference for the trochaic stress pattern. However, the headturn paradigm crucially relies on attentional and motoric abilities of the child and might therefore suggest a later onset of discrimination abilities for different stress patterns. It was therefore hypothesized that discrimination abilities for different stress patterns can already be seen in 5-month-olds when using a neurophysiological paradigm.

Furthermore, considerable differences in timing and polarity of the Mismatch Response (MMR) have been reported in infants (cf. chapter 5.2.2). In Experiment I a it was shown that different filter settings had no influence on the polarity or statistical discernibility of the MMN in adults. However, due to the differences in the ratio of slow wave activity in the infant EEG as compared to the adult EEG an influence of filter settings on the morphology of the infant MMR is well possible. This hypothesis will be tested in the following experiments using again a bandpass 1-15 Hz and a highpass 0.3 Hz filter.

## 7.3 Methods

### 7.3.1 Subjects

The present experiments are part of the German Language Development Study (GLaD, [www.glad-study.de](http://www.glad-study.de)) established at the Children's Hospital *Lindenholz*, Charité, Medical Faculty of the Humboldt University, Berlin. Families requested to participate in the study followed institutional informed consent procedures. One aim of the GLaD study is to determine possible processing differences of speech stimuli in infants at risk for Speech and Language Impairment (SLI). Usually, boys are at greater risk to develop SLI than girls (cf. chapter 3). With respect to future comparisons between infants at risk and infants not at risk, it is therefore of crucial importance to control for gender effects in both groups.

Recordings were taken from 20-week-olds ( $\pm 5$  days, GA: 37 to 41 +6; APGAR 1'  $> 6$ , APGAR 5'  $> 8$ , APGAR 10'  $> 9$ ; birth weight females:  $> 2460$  g, birth weight males:  $> 2570$  g). 33 infants (16 female) completed both runs of the experiment with the required number of accepted deviant items (i.e. 65). 10 infants (5 female) were excluded from further analysis as they spent most of the experimental time in quiet sleep. In total, 23 infants (11 female; mean gestational age: 39.95 weeks, mean conceptual age: 59.44 weeks) participated in Experiment II. Five infants spent the whole experimental time in awake state, 18 infants were in mixed states, i.e. changes between awake and active sleep stage were observed. All infants were born to monolingual German families. They passed a peripheral hearing screening with evoked otoacoustic emissions (OAE). None of them had hearing problems (OAE) or a history of neurological or hearing impairment (Griffiths, 1983; Prechtl & Beintema, 1974). Their alertness state was determined every two minutes according to the criteria presented in 4.3.1.

### 7.3.2 Stimuli and Procedure

Stimuli were the same as in Experiment I a. Due to limitations in infant studies, the deviant-alone control conditions were not performed. Thus, only CONDITION TROCHEE and CONDITION IAMB were conducted, i.e. two blocks of approximately 12 minutes duration each, with occasional breaks whenever necessary. During the recordings infants were entertained by a puppetier or watching a video. Recordings took about 1.5 hours including preparation and pauses. They were completely painless.

### 7.3.3 EEG Recording

EEG recording was the same as in Experiment I a and I b. Impedances were below 10 k $\Omega$ .

### 7.3.4 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline. Trials exceeding a standard deviation of 80  $\mu\text{V}$  within a sliding window of 200 ms in any channel were rejected automatically. Individual averages included at least 65 accepted deviant stimuli. Statistical analysis were carried out for 2 x 2 40 ms time windows: one centered around the negative peak at the Mismatch latency in adults, i.e. at 275-355 ms after stimulus onset and one centered around the positive peak of the grand-average difference wave (trochee: 460-540ms; iamb: 360-440ms). Also, for the bandpass data, one 40 ms time window was centered around the late negativity of the grand average difference wave (trochee: 900-940 ms; iamb: 860-900 ms).

Three-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus), SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4), and GENDER (female vs. male) for each latency window for between-condition-comparisons (i.e. trochaic deviant stimulus vs. trochaic standard stimulus, iambic deviant stimulus vs. iambic standard stimulus). Hemispheric effects were tested in the same way as in Experiment I a and I b.

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following, we report uncorrected degrees of freedom and corrected probabilities.

## 7.4 Results

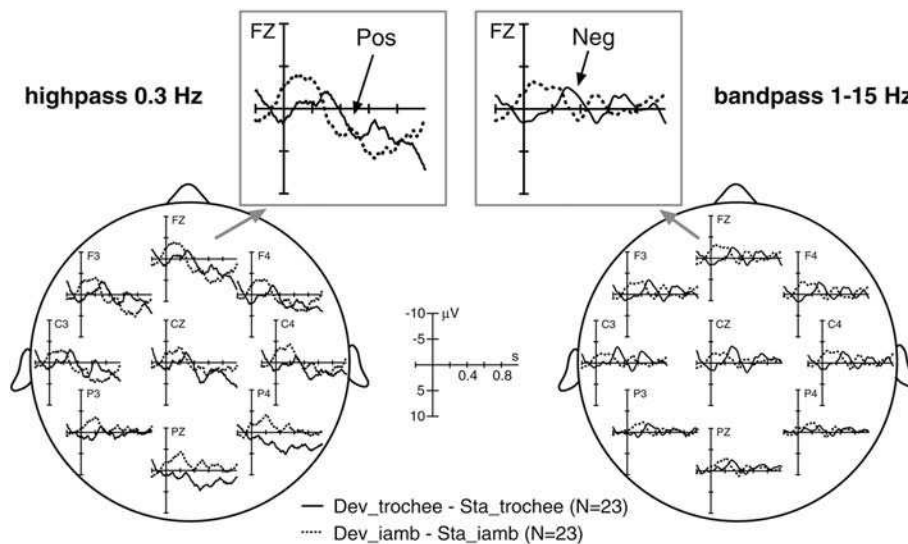


Figure 12: Grand-average difference waves (deviant minus standard) in 5-month-olds (N=23). Left: data filtered with 0.3 Hz highpass. Right: data filtered with 1-15 Hz bandpass.

## TROCHAIC PSEUDOWORD

*Filter: highpass 0.3 Hz*

Figure 12 (left, solid line) shows the grand-average difference waves for both conditions in 5-month-olds obtained after applying the highpass 0.3 Hz filter. After visual inspection, a negativity peaking at about 320 ms followed by a positivity at about 500 ms was seen for the trochaic deviant item. However, between-condition-comparisons only revealed a main effect for DISCRIMINATION at 460-540 ms, i.e. for the positivity starting at 400 ms after change onset (Table 12a). Neither topographic nor gender differences were seen.

*Filter: bandpass 1-15 Hz*

In Figure 12 (right) difference waves for both conditions obtained after applying the 1-15 Hz filter to the same data are displayed. For the trochaic deviant stimulus, again, a prominent negativity was identified at about 320 ms. It was followed by a smaller positivity at about 500 ms as well as a small late negativity around 900 ms. Between-condition-comparisons revealed a significant main effect for DISCRIMINATION at 275-355 ms, i.e. at the same latency as MMN was seen in adults (Table 12b). Also, a statistically significant main effect for DISCRIMINATION was seen at 900-940 ms.

*Table 12a: Differences between ERP responses to deviant and standard in German infants (5 months old, N=23).*

0.3 Hz highpass	df	t1	t2	t3	t4
ms		275-315	315-355	460-500	500-540
<u>Dev trochee-Sta trochee</u>					
Discrimination	1,21			6.26*	5.78*
DiscriminationxSite	8,168				
DiscriminationxGender	1,21				
Gender	1,21				

**Note:** Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.

*Table 12b: Differences between ERP responses to deviant and standard in German infants (5 months old, N=23).*

1-15 Hz bandpass	df	t1	t2	t3	t4	t6
ms		275-315	315-355	460-500	500-540	900-940
<u>Dev trochee-Sta trochee</u>						
Discrimination	1,21	10.97**	7.29*			11.96**
DiscriminationxSite	8,168					
DiscriminationxGender	1,21					
Gender	1,21					

**Note:** Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p≤0.05 \*\*p≤0.01 \*\*\*p≤0.001.

### IAMBIC PSEUDOWORD

*Filter: highpass 0.3 Hz*

Visual inspection suggested that the iambic deviant stimulus elicited a negativity at around 200 ms as well as a positivity peaking at about 400 ms (Figure 12, left). However, statistical analysis did not reveal any significant effect for the iambic deviant item at the MMN latency.

*Filter: bandpass 1-15 Hz*

For the iambic deviant item a negativity was detected at about 200 ms (Figure 12, right). A positivity was observed at around 400 ms. Also, a late negative deflection was seen around 880 ms. However, no statistically significant discrimination related effect was revealed when the iambic item functioned as the deviant stimulus.

## 7.5 Summary

In Experiment II a it was examined whether 5-month-olds were able to discriminate between different stress patterns. In fact, infants at the age of 5 months discriminated the trochaic deviant stimulus from the iambic standard but not vice versa. Moreover, in the same infants, a late negativity was seen for the trochaic pseudoword but not for the iambic one. However, the late negativity appeared at a longer latency than the LDN observed in adults, i.e. at about 800 ms after change onset.

The morphology of the discriminative response varied as a function of the filter settings used. In case a highpass 0.3 Hz filter was used, a positive discrimination related response starting at about 360 ms after change onset was seen. In case a bandpass 1-15 Hz filter was used, an early discrimination related negativity was seen starting at 175 ms after change onset, i.e. at about the same latency as the MMN appeared in adults. Furthermore, the late negativity was only discernible in case the bandpass 1-15 Hz filter was used.

## 7.6 Experiment II b: Stress Pattern Discrimination in German 4 months old Infants

### 7.7 Introduction

In Experiment II a it was demonstrated that German 5-month-olds displayed a MMR for the trochaic deviant stimulus. The same experiment was conducted in German 4 months old infants who were not at-risk for SLI in order to determine the developmental timepoint of stress pattern discrimination in German infants.

## 7.8 Methods

### 7.8.1 Subjects

Experiment II b was conducted in 16-week-olds (+/- 5 days) who were not at risk for SLI. A total of 35 (14 female) full-term infants (GA: 37 to 41 +6; APGAR 1'  $\geq$  6, APGAR 5'  $\geq$  8, APGAR 10'  $\geq$  9; birth weight females:  $\geq$  2460 g, birth weight males:  $\geq$  2570 g) entered this study. They completed both runs of the experiment and had the required number of accepted deviant items. 8 infants (3 female) were excluded from further analysis as they spent most of the experimental time in quiet sleep stage (Cheour et al., 2002). To control for gender effects, the data from an additional 5 randomly selected boys was not included. Taken together, 22 infants (11 female; mean gestational age: 39.45 weeks, mean conceptual age: 55.41 weeks) participated in Experiment II b. T-tests revealed significant differences of conceptual age between the infant group participating in Experiment 2 and 3 ( $p < .001$ ). During the recordings they were either awake or in active sleep (3 infants were awake throughout the whole experimental time, 19 infants were in mixed states). As no differences in MMR between awake infants and infants in active sleep were found at a SOA of 1.500 ms (Cheour et al., 2002), data were pooled in the present study where SOA was approximately the same. All infants were born to monolingual German families. They passed a peripheral hearing screening with evoked otoacoustic emissions (OAE). None of them had hearing problems (OAE) or a history of neurological or hearing impairment (Griffiths, 1983; Prechtl & Beintema, 1974). Their alertness state was determined every two minutes according to the criteria presented in 5.3.1.

### 7.8.2 Stimuli and Procedure

Stimuli and Procedure were the same as in Experiment I a and I b.

### 7.8.3 EEG Recording

EEG Recording was the same as in Experiment I a and I b. Impedances were below 10 k $\Omega$ .

### 7.8.4 Data Analysis

Data analysis were the same as in Experiment II a. However, in case no MMR was seen at a group level, an additional analysis of the infant data was performed with only those infants showing a typical MMN response. For single subject analysis, the negativity was regarded a MMN when it exceeded - 2.0  $\mu$ V in at least three out of five fronto-central electrodes (F3, Fz, F4, C3, C4) at the MMN latency. Statistical analysis for the single-subject data was only performed in case a minimum size of 6 subjects per group was reached (Cheour et al., 1998a).



Three-way analysis of variances (ANOVA) for repeated measures were carried out for 2 x 2 40 ms time windows centered around the grand-average MMR peaks at Fz in the same way as in Experiment II a. The same analysis were also carried out for one 40 ms time window centered around the late negativity (trochee: 880-920 ms; iamb: 860-900 ms) in case the bandpass filter was used.

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following we report uncorrected degrees of freedom and corrected probabilities.

## 7.9 Results

Figure 13 displays the grand-average difference waves of ERPs in 4-month-olds for the trochee and the iamb condition after applying a highpass filter of 0.3 Hz (left) and a bandpass filter of 1-15 Hz (right).

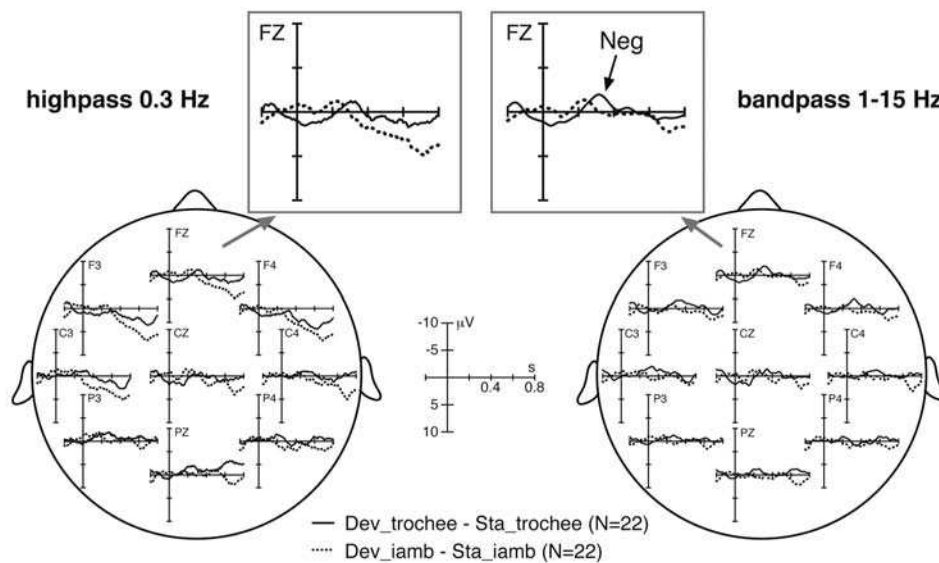


Figure 13: Grand-average difference waves (deviant minus standard) in 4-month-olds (N=22). Left: data filtered with 0.3 Hz highpass. Right: data filtered with 1-15 Hz bandpass.

### TROCHAIC PSEUDOWORD

Filter: highpass 0.3 Hz

Figure 13 (left) shows the grand-average difference waves after application of the highpass 0.3 Hz filter in 4-month-olds. When the deviant stimulus was the trochaic item, visual inspection suggested a negatively displaced peak at about 300 ms which was discernible at fronto-central sites. Yet, a positive peaks at about 430 ms was

much more prominent. None of the described effects were statistically significant.

*Filter: bandpass 1-15 Hz*

In Figure 13 (right) the grand-average difference waves for the same infant data are displayed after application of the 1-15 Hz bandpass filter. Visual inspection indicated that the negative peak around 300 ms which was elicited by the trochaic deviant stimulus was more prominent with the 1-15 Hz filter. Its distribution as well as its latency resembled the MMN elicited by the trochaic deviant stimulus in adults. On the contrary, the positivity was now less pronounced. Also, a late negative peak around 870 ms was seen. None of the described effects were statistically significant.

#### IAMBIC PSEUDOWORD

*Filter: highpass 0.3 Hz*

When the iambic item was the deviant stimulus, a small negatively displaced peak at about 240 ms was observed at fronto-central sites. Again, the more prominent wave was a positivity peaking at about 690 ms at fronto-central sites. None of the described effects were statistically significant.

*Filter: bandpass 1-15 Hz*

The iambic deviant item elicited a small negative deflection at 240 ms as well as a negative shift starting at 880 ms. Again, the positivity was clearly reduced after the bandpass filter was applied. None of these effects were statistically significant.

#### 7.9.1 Additional Analysis: Infants showing a Negative Mismatch Response

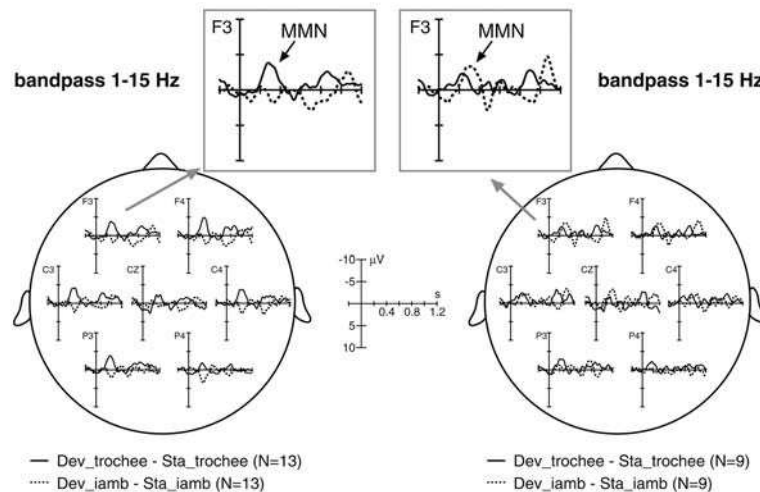


Figure 14: Right: Grand average difference waves (deviant minus standard) in 4-month-old infants showing a negative mismatch response in individual average after applying 1-15 Hz filter. Difference waves in 4-month-old infants showing MMN for condition TROCHEE (N=13). Left: Grand average difference waves (deviant minus standard) in 4-month-old infants showing a negative mismatch response in individual average after applying 1-15 Hz filter. Difference waves in 4-month-old infants showing MMN for condition IAMB (N=9).

## TROCHAIC PSEUDOWORD

As the MMN criteria was not reached for 6 subjects in each group after applying the 0.3 highpass filter, this analysis was only conducted for the data obtained after applying the 1-15 Hz bandpass filter. Figure 14 (left) displays grand-average difference waves at F3 for 13 infants showing MMN in response to the trochaic deviant stimulus after applying the 1-15 Hz bandpass filter. A significant main effect for DISCRIMINATION was seen at 260-300 ms, i.e. 160-200 ms after change onset (Table 13, top). No hemispheric differences were revealed. These infants did not show any significant effects when the deviant was the iambic item.

## IAMBIC PSEUDOWORD

In addition, we checked whether individual infants showed MMN for the iambic deviant stimulus. Indeed, there were 9 infants showing such an effect. These data are displayed in Figure 14 (right) which illustrates grand-average difference waves for infants showing MMN for the iambic deviant. Six of these infants were also included in the first group, i.e. they displayed a negativity in response to the iambic and the trochaic deviant. Significant interactions between DISCRIMINATION and SITE were found at a latency of 260-300 ms, i.e. at 160-200 ms after change onset (Table 13, bottom). No further significant effects were revealed.

Table 13: Analysis of variance of ERP data for single-subject-analysis in Experiment II b.

1-15 Hz	df	t1	t2
ms		260-300	300-340
<u>TROCHEE</u>			
MMN	1,12	5.87*	
MMNxSite	8,96		
<u>IAMB of TROCHEE-group</u>			
MMN	1,12		
MMNxSite	8,96		
<u>IAMB</u>			
MMN	1,8		
MMNxSite	8,64	4.70**	3.65*
<u>TROCHEE of IAMB-group</u>			
MMN	1,8		
MMNxSite	8,64		

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p<0.05 \*\*p<0.01 \*\*\*p<0.001

## 7.10 Summary

In Experiment II b, ERPs to trochaic and iambic two syllable items in 4-month-old infants were recorded in a mismatch paradigm. Additionally, the possible impact of different filter settings on the morphology of the mismatch response in 4-month-olds was evaluated.

It was demonstrated that infants of the latter age were not able to discriminate either the trochaic or the iambic deviant item at a group level. However, single-subject analysis indicated discrimination of both stress patterns in some 4-month-olds. The negative discrimination response seen appeared at about the same latency as in adults but was only clearly discernable when the 1-15 Hz bandpass filter was applied.

## 7.11 Discussion

In the present experiments, evoked responses to trochaic and iambic two syllable items in 4- and 5-month-old infants were recorded in a mismatch paradigm. Additionally, the possible impact of different filter settings on the morphology of the mismatch response in infants was evaluated. The same experiments had been conducted in German adults before. Here, discrimination related MMN as well as LDN responses were seen for the trochaic as well as for the iambic deviant stimulus. Hence, German adults discriminated both stress patterns (Experiment I a & I b). No hemispheric differences were observed. Cross-language comparisons revealed a language-specific reduction of the MMN and LDN amplitude for the iambic deviant stimulus in German adults as compared to French adults. However, no language specific differences with respect to MMN or LDN amplitude were observed for the trochaic deviant. In adults, different filter settings did not have any impact on the polarity and/or statistical discernibility of the discrimination related responses.

Infants at the age of 4 months were not able to discriminate either the trochaic or the iambic deviant item at a group level. Still, single-subject analysis indicated discrimination of different stress patterns in some 4 months old subjects as suggested by behavioral results (Sansavini, Bertoncini & Giovanelli, 1997) Here, a discrimination related negativity at about the same latency as the MMN in adult controls was observed.

Infants at the age of 5 months, however, were able to discriminate the trochaic deviant stimulus from the iambic standard at a group level. Thus, a developmental change in discrimination abilities only for the trochaic stress pattern occurred. The negative discrimination response observable in 5-month-olds appeared at the same latency as in adults, i.e. between 175 and 255 ms after change onset. The present finding for the

trochaic deviant item is in line with an earlier study showing a negative MMR to vowel differences in 3-month-old infants at about the same latency as adults (Cheour et al., 1998a). It also supports behavioral findings in German 6-month-olds who displayed a trochaic bias when presented with both stress patterns (Hoehle, 2002).

Furthermore, a late negativity was seen in 5-month-olds. Still, it was only significant after application of the bandpass 1-15 Hz filter for the trochaic but not the iambic stress pattern. A late negativity occurring well after stimulus offset has been reported before for deviant stimuli presented to infants in an oddball-paradigm. Some authors suggested it to be an indication for novelty detection (Dehaene-Lambertz & Dehaene, 1994). Others proposed that the late negativity might be related to higher cognitive processing of a previously discriminated stimulus (Friederici et al., 2002). It might also be related to the LDN seen in children when conducting an oddball study (Cheour et al., 2001).

#### *Comparison between Highpass and Bandpass filtering*

In both the 4-month-old and 5-month-old infants, a negative MMR was prominent when the 1-15 Hz bandpass filter was applied, but not when the filter was set at 0.3 Hz. Rather, with highpass filtering at 0.3 Hz, a significant positive MMR starting at 360 ms after change onset was observed in 5-month-olds. This result clearly demonstrates the importance of filter setting in the analysis of infant ERP data. In general, it is known that infant EEGs show a considerable amount of slow wave activity during all vigilance states between 2 and 12 months (Niedermeyer, 1998). The specific finding reported for the highpass 0.3 Hz filter may be due to a significant overlap of slow wave activity, possibly related to the positive MMR, and higher frequencies (e.g. Mismatch Negativity related theta waves) (Başar, 1999; Sabri & Campbell, 2002).

A positive mismatch response with a latency of about 300-400 ms after deviance onset has been reported before in infant studies (Dehaene-Lambertz & Dehaene, 1994; Dehaene-Lambertz, 2000; Friederici et al., 2002; Pihko et al., 1999). However, the functional significance of the latter positive MMR remains to be determined yet (cf. chapter 5.2.2).

Concerning the observed negativity after bandpass filter, it should be noted that there is a number of studies which report negative brain responses in a MMN paradigm for infants (Cheour et al., 1998b; Leppänen et al., 2002). Such negativities were found for the discrimination of vowel differences in one syllable items in 3- and 6-month-old infants (Cheour et al., 1998a; Cheour et al., 1998b) and for the discrimination of consonant duration in two syllable stimuli only in 6-month-olds (Leppänen et al., 2002).

However, there is one previous study using two syllable items which reports an early MMR already in newborns (starting at 150 ms after deviance onset) (Kushnerenko et al., 2001). This study, similar to the present one, used a bandpass filter (1-15 Hz). One reason for which no such MMR was found in the 4-month-olds in the present study could be the difference in the complexity of the stimuli used. Whereas the aforementioned study tested phoneme discrimination in infants, the present experiment investigated stress pattern discrimination which might develop later in life.

Hence, with respect to the stress patterns investigated here, the finding that both MMR responses, i.e. negativity and positivity, are only observable for the trochaic item by the age of 5 months, is crucial. However, in order to determine whether this result is based on language-specific knowledge about the distributional properties of trochees in German or rather reflects a perceptual advantage for the trochaic item (cf. Experiment I b) remains to be investigated in a cross-language infant study including a language with a different stress pattern rule.

## Chapter 8

### Stress Pattern Discrimination in Infants at Risk for SLI

#### 8.1 Introduction

Experiment III aimed at determining whether 5 months old infants at-risk for SLI were able to discriminate different stress patterns as indicated by their brain responses elicited in the same mismatch paradigm. SLI has been demonstrated to be associated to poor word production at the age of 18 months as well as to prosodic language skills in children (cf. chapter 2). Therefore, in the present experiment, it is hypothesized that a deficit with respect to rhythmic processing of stress patterns in word like units might be observable at the earliest developmental timepoint of stress pattern discrimination in German infants, i.e. at the age of 5 months.

Due to the fact that, up to now, only the functional significance for the negative infant mismatch component is well defined, in the following, only the negative MMR known to be associated to the ERPs theta range will be compared in infants at-risk and infants not-at-risk. As the negative MMR was only clearly observable after application of the 1-15 Hz filter only data obtained after application of the latter filter will be presented.

In order to determine whether possible differences in the MMN morphology between infants at-risk and infants not-at-risk are related to poor encoding abilities for the stimuli per se, additional analysis of differences in the processing of standards will be performed in infants at-risk and in infants not-at-risk for SLI. Those analysis will be conducted after application of the highpass 0.3 Hz filter which preserves most of the signal involved in stimulus encoding per se.

#### 8.2 Methods

##### 8.2.1 Subjects

The present experiments are part of the German Language Development Study (GLaD, [www.glad-study.de](http://www.glad-study.de)). One aim of the GLaD study is to examine possible processing differences for speech stimuli in infants at risk for Speech and Language Impairment (SLI) as compared to controls. In order to determine the at-risk status with respect to language problems, word production of all participants of the GLaD study is examined using a standardized parental questionnaire when infants reach the age of 18 months (ELFRA, Grimm & Doil 2000). Confirming the higher vulnerability of boys for SLI (cf. chapter 3; ICD 10, 1992), within the GLaD-study a majority of boys turned out to be at-

risk for SLI. Therefore, in Experiment III, the at-risk group only comprised boys. In the present experiment, recordings from 20-week-olds ( $\pm 5$  days; GA: 37 to 41 +6; APGAR 1' > 6, APGAR 5' > 8, APGAR 10' > 9; birth weight females: > 2460 g, birth weight males: > 2570 g) who were judged to be at-risk for SLI at the age of 18 months (N=6, 6 male) were compared to those obtained in age matched controls (N=6, 3 male). All infants completed both runs of the experiment with the required number of accepted deviant items (i.e. 80). The subgroup of 6 not-at-risk infants (3 male) was recruited from the sample examined in Experiment II a. All infants were in mixed vigilance states, i.e. changes between awake and active sleep stage were observed.

### 8.2.2 Stimuli and Procedure

Stimuli were the same as in Experiment II a.

### 8.2.3 EEG Recording

EEG recording was the same as in Experiment II a. Impedances were below 10 k $\Omega$ . Only the bandpass filter 1-15 Hz was used.

### 8.2.4 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline. Trials exceeding a standard deviation of 80  $\mu$ V within a sliding window of 200 ms in any channel were rejected automatically. Due to the small group size, individual averages included at least 80 accepted deviant stimuli (mean: 95.5 deviants). Statistical analysis were carried out for two 40 ms time windows centered around the negative peak at the Mismatch latency in adults, i.e. at 275-355 ms after stimulus onset.

The not-at-risk subgroup was examined conducting three-way analysis of variance (ANOVA) for repeated measures with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus), SITE (F3/ F4/ C3 /C4) and GENDER (male vs. female) for each latency window for between-condition-comparisons (i.e. trochaic deviant stimulus vs. trochaic standard stimulus, iambic deviant stimulus vs. iambic standard stimulus). In the at-risk group, two-way analysis of variance (ANOVA) were carried out with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus) and SITE (F3/ F4/ C3 /C4). In both groups, hemispheric effects were tested in the same way as in Experiment II a and II b.

The MMN is prominent at fronto-central sites. Therefore, only those sites entered statistical analysis for the discrimination effect in the smaller subgroups. Peak analysis



of the negative maxima at the MMN latency were conducted at fronto-central sites for each subject in order to examine MMN differences between groups (F3, F4, C3, C4). Afterwards, T-tests including the group variable RISK were performed for fronto-central sites.

Processing differences in the obligatory ERP to each standard response between infants at-risk and infants not-at-risk were carried out for 20 consecutive time windows of 40 ms starting at stimulus onset until 800 ms. These differences were examined for data obtained after application of the highpass 0.3 Hz filter to preserve most of the signal involved in stimulus encoding. In order to determine differences in the processing of the standards, two-way analysis of variances (ANOVA) for repeated measures were carried out with the factors GROUP (standard long infants at-risk vs. standard long infants not-at-risk, standard short infants at-risk vs. standard short infants not-at-risk) and SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4).

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following we report uncorrected degrees of freedom and corrected probabilities.

### 8.3 Results

Figure 15 displays the grand average difference waves in 5-month-olds at-risk for SLI as well as the grand average difference waves in 5-month-olds not-at-risk for SLI.

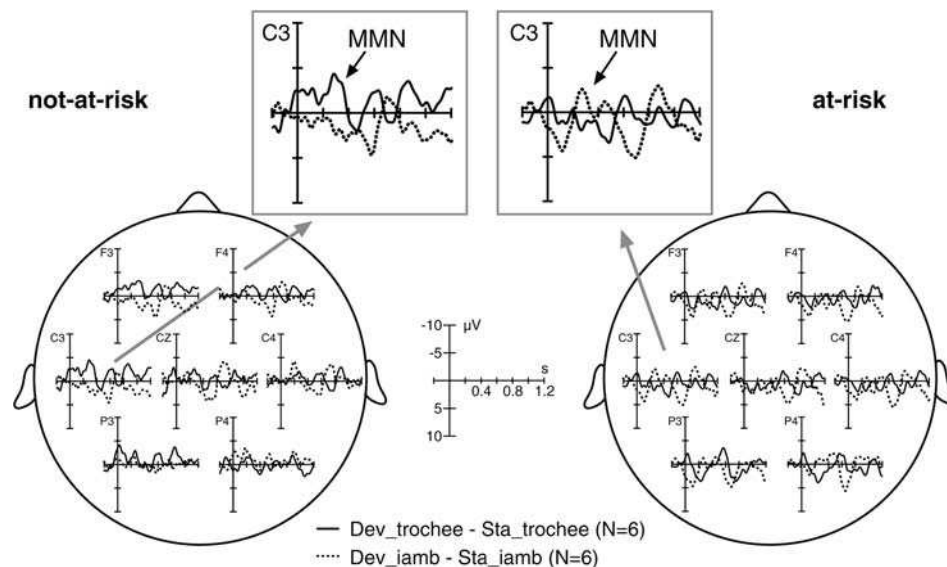


Figure 15: Grand-average difference waves (deviant minus standard) in 5 months old infants at-risk for SLI (right) and in 5 months old infants not-at-risk for SLI (left).

### TROCHAIC PSEUDOWORD

#### *Infants not-at-risk*

Figure 15 (left) shows grand-average difference waves for the trochaic pseudoword in 5-month-old infants not-at-risk (solid line). After visual inspection, a negativity peaking at about 320 ms was seen for the trochaic deviant item. Statistical analysis revealed a significant main effect for DISCRIMINATION at 275-315 ms [ $F(1,5) = 8.45, p < .05$ ]. No further statistical significant differences were observed.

#### *Infants at-risk*

In Figure 15 (right) difference waves for the trochaic item obtained in the 5-month-olds at risk for SLI (dotted line) are displayed. For the trochaic deviant stimulus, again, a prominent negativity was identified at about 320 ms. However, it was less pronounced than in the not-at-risk group. No statistical significant effects were revealed for the latter negativity.

#### *Comparison between Infants at-risk and Infants not-at-risk*

Single-subject peak analysis revealed a significant difference of the negativity's amplitude in response to the trochaic deviant at C3 indicating a group difference for the MMN ( $T=2.28, p < .05$ ).

### IAMBIC PSEUDOWORD

#### *Infants not-at-risk*

Visual inspection of Figure 15 suggested that the iambic deviant stimulus elicited a negativity at around 200 ms (left, dotted line). However, no negative deflection at the MMN latency was seen in the not-at-risk subgroup. Statistical analysis did not reveal a significant effect at the MMN latency for the iambic deviant item.

#### *Infants at-risk*

In infants at-risk, a small negativity was detected at about 220 ms (right, dotted line). Again, no statistical significant discrimination related effect was revealed at the negative MMR latency.

## 8.4 Summary

Experiment III aimed at determining whether a subgroup of 5-month-olds not-at-risk for SLI displayed reduced discrimination abilities for stress patterns in bisyllabics as compared to 5-month-olds not-at-risk for SLI. These abilities are considered to be a crucial prerequisite for identifying word boundaries in German.

It was demonstrated that a subgroup of infants not-at-risk for SLI displayed the same discrimination pattern as seen in Experiment II a, i.e. they were able to discriminate the trochaic deviant stimulus from iambic standards but not vice versa. On the contrary, infants at-risk for SLI did not discriminate either stress pattern.

However, in infants at-risk for SLI a small negative deflection of the difference wave at the MMN latency was seen in response to the trochaic deviant. Therefore, single-subject peak analysis of the MMN were performed in both infants at-risk and infants not-at-risk. Results indicated significant MMN amplitude differences between infants at-risk and infants not-at-risk for SLI at C3, i.e. at temporal sites of the left hemisphere. Thus, a discrimination deficit with respect to the trochaic pseudoword can be assumed in infants at-risk. However, it is necessary to determine whether the reduced MMN component in infants at-risk is related to lacking discrimination abilities per se or rather is a consequence of general difficulties in encoding of auditory stimuli. Therefore, in the following, processing of the standard stimuli will be examined in both groups.

## 8.5 Processing of Standards

In Figure 16 (right) the standard responses to the trochaic and iambic pseudoword are displayed for infants at-risk (dotted line) as well as for infants not-at-risk (solid line).

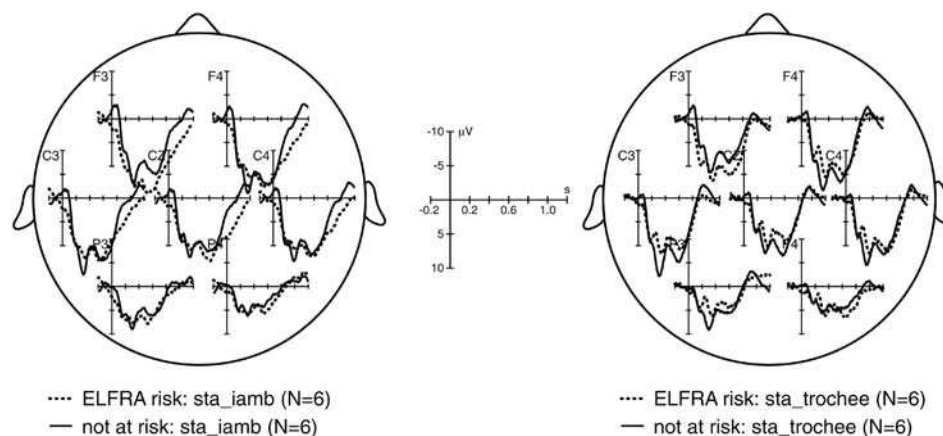


Figure 16: ERPs to the trochaic and the iambic standard in 5-month-olds at-risk for SLI (dotted line) and 5-month-olds not-at-risk for SLI (solid line). Right: ERPs to trochaic standard. Left: ERPs to iambic standards.

### TROCHAIC PSEUDOWORD

In Figure 16 (right) the standard response to the trochaic pseudoword are displayed for infants at-risk (dotted line) as well as for infants not-at-risk (solid line). In both groups, a prominent obligatory N250-P350-N450 complex was observed whereas otherwise ERP amplitudes in infants at-risk were more pronounced. At left hemispheric sites, the ERPs of infants not-at-risk for SLI were larger in amplitude and more extended. However, no statistical significant differences between both groups were revealed.

### IAMBIC PSEUDOWORD

In Figure 16 (left) ERPs to the iambic standard syllable are shown for both groups. In both infants at-risk for SLI and infants not-at-risk for SLI, a N250-P350-N450 response was seen. In general, amplitudes of infants at-risk were more pronounced. Still, no statistically significant differences were observed.

## 8.6 Summary

In Experiment III it was shown that infants at-risk for SLI were not able to discriminate the trochaic deviant stimulus from the iambic standard in the same way as did age matched controls. In order to determine whether the deficit was related to poor encoding difficulties of stimuli per se, additional analysis with respect to the processing of standards were performed in both groups.

It was observed that infants at-risk for SLI and infants not-at-risk for SLI did not differ with respect to stimulus encoding per se. Hence, the differences in MMN amplitude seen between groups seem to not arise from deficits with respect to stimulus encoding per se in 5-month-olds at-risk for SLI.

## 8.7 Discussion

In Experiment III it was examined whether discrimination abilities for different stress patterns in bisyllabics as indicated by the brain's negative mismatch response would differ in 5-month-olds at-risk for SLI when compared to age matched controls. It was hypothesized that infants at-risk would display reduced discrimination abilities for different stress patterns when compared to controls as deficits in prosodic development have been reported for SLI.

Both hypothesis were confirmed. The subgroup of infants who were not-at-risk for SLI displayed a typical MMN in response to the trochaic deviant stimulus. In case the iambic item served as the deviant stimulus, no MMN was observed. These results confirmed those seen in Experiment II where discrimination of the trochaic but not the iambic deviant stimulus was seen in a larger group of German 5 months old not-at-risk infants.

Within the GlAD-study, a majority of boys turned out to be at-risk for SLI confirming the higher vulnerability of boys for SLI, (cf. chapter 3). Therefore, the at-risk group investigated in the present experiment only comprised boys. Boys at-risk for SLI did not display a MMN when presented with trochaic or iambic deviant stimuli. However, in case of the trochaic deviant stimulus presentation, a small negative deflection at the

MMN latency was observed in the at-risk group. Therefore, single-subject peak analysis of the MMN were performed in both groups at fronto-central sites. The largest difference between groups occurred at left hemispheric temporal sites. This finding parallels the results reported by Leppänen and coworkers (2002). Using a passive oddball design, these researchers investigated whether 6 months old Finnish infants at-risk for dyslexia displayed a different mismatch pattern to varying consonant duration (/ata/ vs. /atta/) embedded in two syllable items as compared to age matched controls (cf. 5.2.3.2). It was demonstrated that 6-month-olds at-risk for dyslexia displayed a significantly smaller negative MMR in response to the long /atta/ deviant at C3 than controls. Similar to the results of Experiment III, no hemispheric effect for the negative MMR was seen in the study by Leppänen (2002).

In order to determine whether impaired encoding of stimuli per se were involved in differences in discrimination abilities between infants at-risk for SLI and infants not-at-risk, separate analysis for the processing of standard items were performed. Yet, throughout these analysis, no differences between both groups were found. Thus, impaired discrimination of the trochaic stress pattern in infants at-risk for SLI were not related to impaired encoding of auditory speech stimuli per se. Thus, in contrast to the present results, the comparison of obligatory responses to sounds per se in the latter study indicated differences between infants at-risk and infants not-at-risk for dyslexia. Leppänen and coworkers (2002) therefore suggested that reduced discrimination abilities for consonant duration embedded in two syllable items might be related to imprecisely formed representations of auditory stimuli per se in dyslexia.

With respect to the MMN, these results indicate that 5-month-olds at-risk for SLI displayed reduced discrimination of different stress patterns which mainly differed in vowel duration.

Similar results with respect to reduced discrimination abilities for consonant and vowel duration differences embedded in two syllable items have been found in 5 month old boys at-risk for SLI and in 6-month-olds at-risk for dyslexia: in both cases, a reduced amplitude of the negative MMR was found at C3 in at-risk infants as compared to age matched controls. Yet, whereas in dyslexia less elaborate discrimination abilities are supposed to be related to poor formation of memory traces as a result of difficulties in encoding auditory stimuli per se, the same does not hold for infants at-risk for SLI. In the latter case, poor discrimination abilities seem to be related to impaired discrimination for the trochaic stimulus per se. Still, it is not clear whether the latter problem relates to an exclusively linguistic processing deficit or if a temporal processing deficit with respect to the processing of complex vowel duration patterns like stress patterns in German might also be involved.



## Chapter 9

### Discrimination of Vowel Length in Adults and Infants

#### 9.1 Experiment IV a: Discrimination of Vowel Length in Adults

##### 9.2 Introduction

In Experiment II a it was demonstrated that infants at the age of 5 months were able to discriminate the trochaic stress pattern when presented among iambic standards. Dependent on the filter setting used, they either displayed an adult-like MMN or a positively displaced discrimination response. Experiment III revealed that age-matched boys at-risk for SLI did display reduced MMN for the trochaic stress pattern. Similar to matched controls, no MMN in response to the iambic deviant was found. As stress pattern discrimination in German crucially depends on the ability to process complex durational patterns of vowel duration, it was hypothesized that a persistent temporal processing deficit with respect to vowel duration seen during the first half year of life in infants at-risk for dyslexia might also be present in SLI. Such a deficit would probably impair discrimination of complex vowel duration patterns, i.e. stress patterns in German (cf. Experiment III).

Experiment IV a was conducted in adult controls in order to determine the morphology and latency of the adult MMN in response to vowel length differences contained in CV-stimuli. It was hypothesized that adult listeners' brains will display a typical MMN and LDN in response to the long as well as the short syllable deviant item. Furthermore, additional deviant-alone control conditions were performed in German adults in order to verify true MMN and LDN effects.

Also, the influence of filter settings on the morphology of the MMN response was tested. It was hypothesized that no influence of filter settings on the MMN will be observed in these subjects.

##### 9.3 Methods

###### 9.3.1 Subjects

20 adult subjects (10 female) participated in the experiment. They were between 20 and 30 years old (mean: 26.7), right-handed and reported having normal hearing. All of them spoke German as their mother tongue and had no history of SLI.

### 9.3.2 Stimuli and Procedure

The short syllable /ba/ (duration: 202 ms) was infant directed spoken by a young mother who is a native speaker of standard German. After recording and digitalization (44.1 kHz, 16 bit sampling rate) the steady state part of the short syllable's vowel (202 ms) was manually lengthened (starting at 30 ms after syllable onset) to generate the second syllable /ba:/ (341 ms) (Cool Edit, 2000). Hence, the first 30 ms of both syllables were identical (Figure 11). Detailed acoustical analysis of the two syllables were done with the help of special computer software (praat 4.0, 2001).

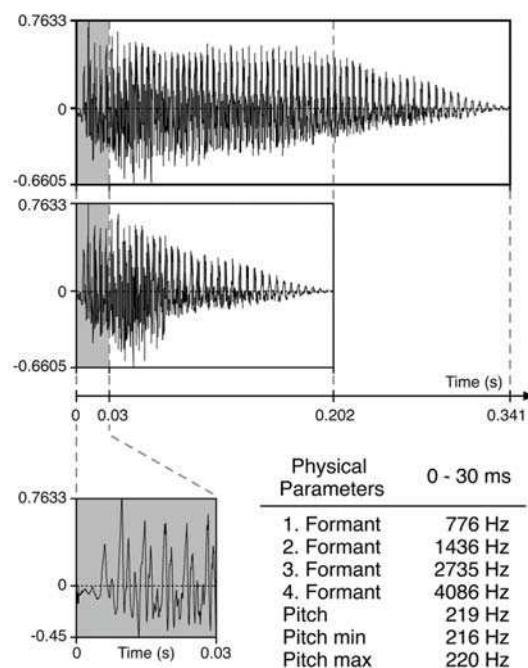


Figure 17: Illustration of the two stimuli. Physical differences start at 30 ms.

In adults, one experimental session consisted of four experimental runs which were presented in a passive oddball paradigm (standard:  $p=5/6$ , deviant:  $p=1/6$ ).

- (1) CONDITION LONG: the frequently occurring short CV-syllable /ba/ (standard) was irregularly replaced by the long CV-syllable /ba:/ (deviant);
- (2) CONDITION SHORT: the frequently occurring long CV-syllable /ba:/ (standard) was occasionally substituted by the short CV-syllable /ba/ (deviant).

### 9.3.3 Control Condition: Deviant-alone

Deviant-alone conditions are typically conducted to control for the latency and distribution of a true MMN effect. Under such a condition, all deviant stimuli are



presented with the same ISI but without any intervening standard (Näätänen et al., 1989). Hence, the subsequent two conditions were created:

- (3) DEVIANT-ALONE LONG: the deviant long CV-syllable item was presented without the intervening short standard CV-syllable but with the same ISI;
- (4) DEVIANT-ALONE SHORT: the deviant short CV-syllable was presented without the intervening standard long CV-syllable but with the same ISI.

During each experimental run 600 trials were presented with 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 (ERTS, 1997). All adult participants read a book in their native language during the recordings. Each condition was presented in a separate block. Each block lasted approximately 12 minutes. The whole experiment, including preparation and pauses, lasted about 1.5 hrs and was completely painless.

#### 9.3.4 EEG Recording

EEG recording was the same as in the previous experiments. Impedances were below 5 k $\Omega$ .

#### 9.3.5 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline (EEP 3.2.1). Trials exceeding a standard deviation of 80  $\mu$ V within a sliding window of 200 ms in any channel were rejected automatically. Individual averages included at least 65 accepted deviant items. Statistical analysis for the adult data was carried out for 2 x 4 20 ms time windows (175-255 ms, 635-715 ms) centered around the grand-average MMN and LDN peak at Fz. In adults, four-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant stimulus vs. standard stimulus), SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4), GENDER (female vs. male) and FILTER (0.3 Hz vs. 1-15 Hz) for each latency window for between-condition-comparisons (i.e. long syllable deviant item vs. long syllable standard item, short syllable deviant item vs. short syllable standard item). Hemispheric differences were tested with one-way ANOVAs for mean amplitudes of the deviant stimulus.

In the deviant-alone control condition, one-way ANOVAs with the factor MM and SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4) were conducted for mean amplitudes of the deviant stimuli (deviant-alone long syllable stimulus vs. long syllable stimulus, deviant-alone short syllable stimulus vs. deviant short syllable stimulus).

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. In the following we report uncorrected degrees of freedom and corrected probabilities.

## 9.4 Results

Figure 18 (left) shows grand-average difference waves (ERP deviant stimulus minus ERP standard stimulus) for the long CV syllable in adults after application of the 0.3 Hz highpass filter. Figure 18 (right) displays grand-average difference-waves of the same data after application of the 1-15 Hz filter.

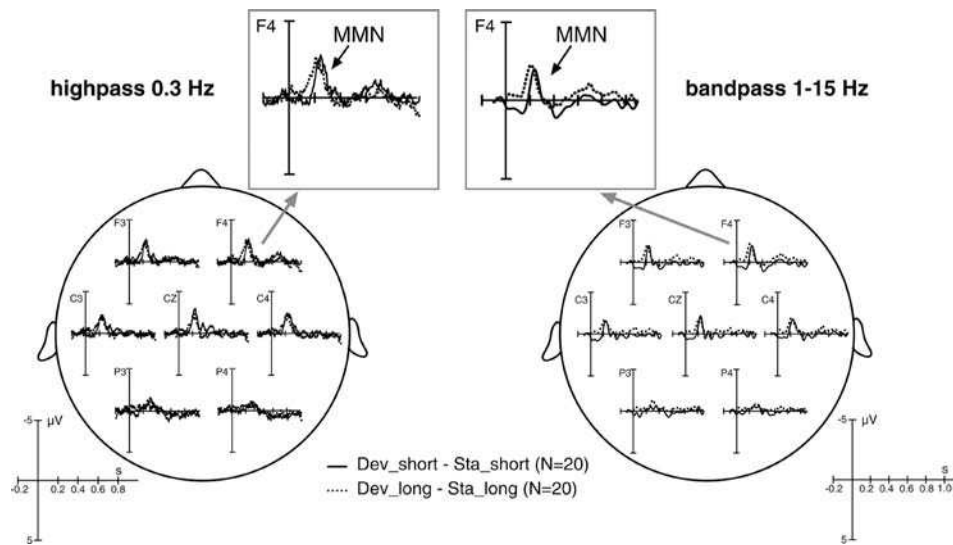


Figure 18: Grand-average difference waves (deviant minus standard) in German adults ( $N=20$ ). Left: data filtered with 0.3 Hz highpass. Right: data filtered with 1-15 Hz bandpass.

### LONG SYLLABLE

After application of the highpass 0.3 Hz filter (Figure 18, left), a prominent negative peak at fronto-central sites was seen around 220 ms. Also, a second negativity was present around 650 ms. After application of the 1-15 Hz bandpass filter (Figure 18, right). These peaks were also clearly discernible at the same latency and displayed the same distribution. Statistical analysis revealed a main effect for DISCRIMINATION at 175-255 ms, i.e. starting at 145 ms after change onset (Table 14). Additionally, significant interactions DISCRIMINATION  $\times$  SITE were present at 175-255 ms and at 655-715 ms. No further statistical significant differences were revealed.

### SHORT SYLLABLE

Difference waves for the short syllable are also presented in Figure 18. After application of the highpass 0.3 Hz filter (Figure 18, right), two prominent negativities at fronto-central sites were seen at about 220 ms and around 650 ms. After applying the band-pass 1-15 Hz filter, both negativities were discernible at the same latency. Statistical analysis revealed a main effect at 175-255 ms. Significant interactions

DISCRIMINATION x SITE were seen at 195-255 ms and at 635-715 ms. No further statistically significant effects were seen.

Table 14: Differences between ERP responses to long syllable deviant and long syllable standard stimulus in German adults (N=20).

	df	t1	t2	t3	t4	t5	t6	t7	t8
		175-195	195-215	215-235	235-255	635-655	655-675	675-695	695-715
ms									
LONG									
Discrimination	1,36	22.40***	27.43***	28.28***	21.65***				
SitexDiscrimination	8,272	39.14***	36.48***	22.25***	13.96***	4.13*	7.46***	10.05***	6.72***
DiscriminationxGender	1,36								
Gender	1,36								
Filter	1,36								
DiscriminationxFilter	1,36								

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p<0.05 \*\*p<0.01 \*\*\*p<0.001

Table 15: Differences between ERP responses to short syllable deviant and short syllable standard stimulus in German adults (N=20).

	df	t1	t2	t3	t4	t5	t6	t7	t8
		175-195	195-215	215-235	235-255	635-655	655-675	675-695	695-715
ms									
SHORT									
Discrimination	1,36	9.34**	29.81***	37.07***	25.92***				
DiscriminationxSite	8,272		17.40***	46.67***	45.61***	10.84***	11.22***	8.60***	8.50***
Gender	1,36								
GenderxDiscrimination	1,36								
Filter	1,36								
DiscriminationxFilter	1,36								

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p<0.05 \*\*p<0.01 \*\*\*p<0.001

#### 9.4.1 Control Condition: Deviant-alone

##### DEVIANT-ALONE LONG

Figure 18 shows ERP waveforms for the long CV-syllable when presented in CONDITION LONG (solid line) as well as the ERP waveform for the long CV-syllable

presented in DEVIANT-ALONE LONG (dotted line). As expected, the ERP elicited by the long syllable had a higher peak amplitude and a more central distribution when presented without intervening standard stimuli. Statistical analysis (Table 16) demonstrated a main effect for MM at 175-255 ms as well as a significant interaction MM x SITE at 175-255 ms. No statistically significant difference was revealed for the second negativity emerging at the LDN latency.

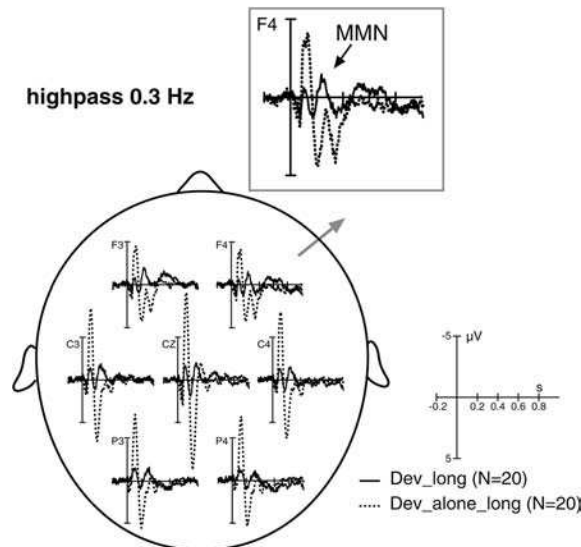


Figure 19: ERP responses to the long syllable deviant obtained for DEVIANT-ALONE LONG (dotted line) and for CONDITION LONG (solid line) in German adults (N=20).

Table 16: Differences between ERP responses to long syllable deviant in the DEVIANT-ALONE CONDITION and long syllable deviant in CONDITION LONG in German adults (N=20).

0.3 Hz highpass	df				
		t1	t2	t3	t4
ms		175-195	195-215	215-235	235-255
LONG SYLLABLE					
MM	1,19	12.93**	43.73***	44.42***	14.42**
MM x Site	1,8	6.31**	11.67***	20.78***	9.36***

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p<0.05 \*\*p<0.01 \*\*\*p<0.001.

#### DEVIANT-ALONE SHORT

In Figure 20, ERP waveforms for the short deviant presented in CONDITION SHORT (solid line) are compared to ERP waveforms for the short syllable presented in DEVIANT-ALONE SHORT (dotted line). The ERP elicited by the short syllable had a higher peak amplitude and a more central distribution when presented without

intervening standard stimuli. Statistical analysis (Table 17) demonstrated a main effect for MM at 175-255 ms as well as significant interactions MM x SITE at 175-255 ms. No statistically significant effect was revealed for the second negativity at the LDN agency.

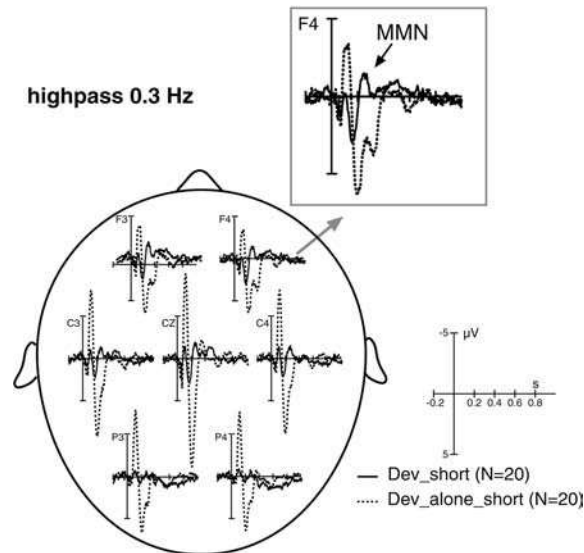


Figure 20: ERP responses to the short syllable deviant obtained for DEVIANT-ALONE SHORT (dotted line) and for CONDITION SHORT (solid line) in German adults (N=20).

Table 17: Differences between ERP responses to short syllable deviant in the DEVIANT-ALONE CONDITION and short syllable deviant in CONDITION SHORT in German adults (N=20).

0.3 Hz highpass	df				
		t1	t2	t3	t4
Ms		175-195	195-215	215-235	235-255
SHORT SYLLABLE					
MM	1,19	20.82***	57.26***	44.06***	20.40***
MM x SITE	1,8	12.06***	18.61***	18.57***	8.74***

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.

\*p<0.05 \*\*p<0.01 \*\*\*p<0.001.

## 9.5 Summary

Experiment IV a aimed at determining the MMN as well as the LDN latency to differences in vowel duration comprised in CV-stimuli. Therefore, two CV-stimuli varying in vowel duration were presented to German adults in a passive oddball paradigm. Both stimuli were presented in every position, i.e. each of them took the position of the standard

and the deviant. Then, cross comparisons were done in order to avoid interference of stimulus effects on the discrimination response.

As expected, the long as well as the short vowel CV-syllable deviant elicited a negativity at 175-255 ms, i.e. starting at 145 ms after change onset in adults. In both cases, significant differences between deviant-alone and deviant were revealed at the same latency confirming a Mismatch Negativity in adults. No influence of filter settings on the MMN morphology was observed.

In addition, a late negativity was revealed in both experimental conditions at 635-715 ms after stimulus onset. However, the latter effect was not confirmed to be a discrimination related LDN response in the deviant-alone control conditions.

Taken together, these results indicate that adults do discriminate differences in vowel duration indicated by MMN for both short and long syllable deviant. Filter settings did not have any influence on the MMN.

Yet, no LDN was observed for those stimuli. Therefore, the late negativity observed in the first conditions rather seems to be related to obligatory effects than to discrimination related effects indicating the importance of the deviant-alone control condition also for confirmation of LDN effects in adults.

## **9.6 Experiment IV b: Discrimination of Vowel Length in Infants**

### **9.7 Introduction**

In Experiment IV a the MMN pattern to long and short vowel deviant contained in CV-stimuli was determined in adults. Experiment IV b was performed in German 2-month-olds who were not-at-risk for SLI in order to determine temporal processing capacities for vowel duration as a crucial prerequisite for stress pattern discrimination before categorical knowledge is established. Thus, using the same experimental design as in Experiment IV a, the MMR pattern in normal 2-month-olds was investigated. It was hypothesized that 2-month-olds are able to discriminate long and short vowels.

Furthermore, the influence of different filter settings on the infant ERP was examined. It was hypothesized that the effect of filter settings seen on the infant MMR will be confirmed, i.e. depending on the filter settings used either the positive or the negative MMR will be prominent.

## 9.8 Methods

### 9.8.1 Subjects

The present experiment is part of the German Language Development Study (GLaD, [www.glad-study.de](http://www.glad-study.de)) established at the Children's Hospital Lindenhof, Charité, Medical Faculty of the Humboldt University Berlin. Families requested to participate in the study followed institutional informed consent procedures. One aim of the GLaD study is to determine possible processing differences of speech stimuli in infants at risk for Speech and Language Impairment (SLI). Usually, boys are at greater risk to develop SLI than girls (ICD10, 1992; Tallal, Dukette & Curtiss, 1989). With respect to future comparisons between infants at risk and infants not at risk, it is therefore of crucial importance to control for gender effects in both groups. Experiment IV b was conducted in 8-week-olds (+/- 5 days) who were not at risk for SLI. A total of 24 (12 female) full-term infants (GA: 37 to 41 +6; APGAR 1'  $\geq$  6, APGAR 5'  $\geq$  8, APGAR 10'  $\geq$  9; birth weight females:  $\geq$  2460 g, birth weight males:  $\geq$  2570 g) entered this study. They completed both runs of the experiment and had the required number of accepted deviant items. During the recordings they were either awake or in active sleep state (2 infants were awake throughout the whole experimental time, 22 infants were in mixed states). As no differences in MMR between awake infants and infants in active sleep were found at a SOA of 1.500 ms (Martynova et al., 2003), data were pooled in the present study where SOA was approximately the same. All infants were born to monolingual German families. They passed a peripheral hearing screening with evoked otoacoustic emissions (OAE). None of them had hearing problems (OAE) or a history of neurological or hearing impairment (Griffiths, 1983; Prechtel & Beintema, 1974).

### 9.8.2 Stimuli and Procedure

Stimuli were the same as in Experiment IV a. Due to limitations in infant studies, the deviant-alone control conditions were not conducted. Thus, two experimental blocks of approximately 12 minutes duration each, with occasional breaks whenever necessary were performed. Throughout the recordings, infants were sitting in a safety seat or on their parent's lap and were entertained by a puppeteer or by watching a video. Every two minutes, their alertness state was determined online according to the criteria presented in 4.3.1. Recordings took about 1.5 hours including preparation and pauses and were completely painless.

### 9.8.3 EEG Recording

EEG recording was analog to all previous experiments. Impedances were below 10 k $\Omega$ .

### 9.8.4 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline (EEP 3.2.1). Trials exceeding a standard deviation of 80  $\mu$ V within a sliding window of 200 ms in any channel were rejected automatically. Statistical analysis of the discrimination effect in the infant data were carried out for 3 x 2 consecutive time windows of 40 ms. The first time window (160-240 ms) was centered at the MMN latency determined in Experiment IV a. The second one was centered around the first positive peak to appear at the latency of of a discrimination related positivity, i.e. in this case at 400-480 ms after stimulus onset. Also, the infant late negativity was examined (720-800 ms).

Three-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant vs. standard), SITE (F3/ Fz/ F4/ C3/ Cz /C4 / P3 /Pz /P4) and GENDER (female vs. male) for each latency window (i.e. long-syllable deviant vs. long-syllable standard, short-syllable deviant vs. short-syllable standard). Hemispheric differences were tested with one-way ANOVAs for mean amplitudes of the deviant at fronto-central sites.

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. Below, we report uncorrected degrees of freedom and corrected probabilities.

## 9.9 Results

Figure 21 displays grand-average difference waves for the long and the short syllable deviant obtained in 2-month-olds who were not at-risk for SLI.

### LONG SYLLABLE

*Filter: highpass 0.3 Hz*

Figure 21 (left, dotted line) shows grand-average difference waves for the long syllable deviant after applying the highpass 0.3 Hz filter. At fronto-central sites a pronounced positivity peaking around 400 ms was seen. Additionally, starting at about 700 ms, a negativity was discernible. Statistical analysis (Table 18) revealed significant interactions DISCRIMINATION x SITE at 400-480 ms. No further significant effects were observed.

*Filter: bandpass 1-15 Hz*

In Figure 21 (right, dotted line) the same data is presented after applying the 1-15 Hz



filter. A prominent negativity peaking at around 200 ms was observed. Although not as prominent as after application of the 0.3 Hz highpass filter, a positivity peaking at 400 ms was discernible. Furthermore, a negativity around 700 ms was seen at fronto-central sites. Statistical analysis revealed a significant interaction between the factors DISCRIMINATION and SITE at 160-240 ms (Table 19). Significant interactions DISCRIMINATION x SITE were found again at 400-480 ms, i.e. for the positivity starting at 370 ms after change onset. Significant interactions DISCRIMINATION x SITE were also seen at 720-800 ms, i.e. for the late negative response. No further significant differences were observed. No hemispheric differences were seen.

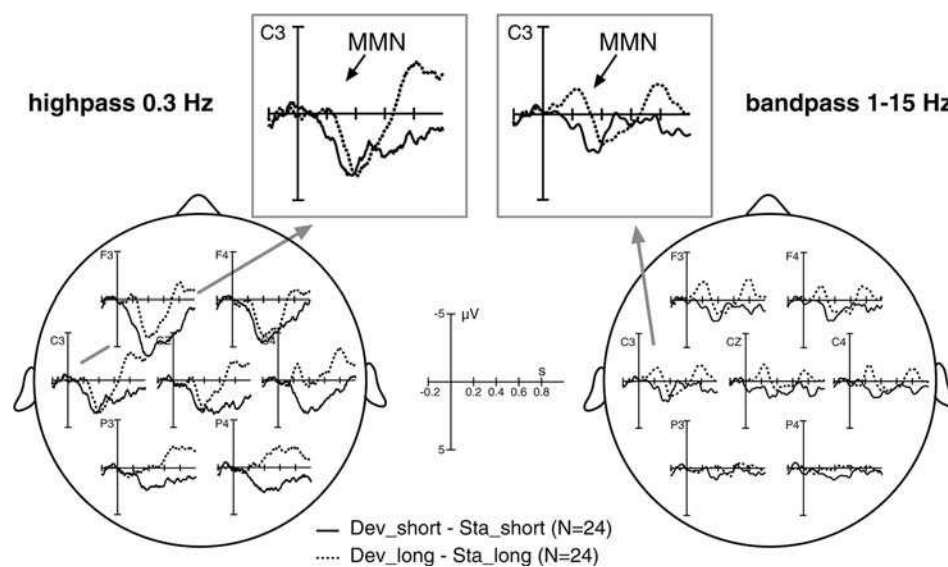


Figure 21: Grand-average difference waves (deviant minus standard) in German infants (N=24). Left: data filtered with 0.3 Hz highpass. Right: data filtered with 1-15 Hz bandpass.

Table 18: Differences between ERP responses to deviant and standard in German infants (2 months old, N=24) after application of the 0.3 Hz highpass filter.

0.3 Hz highpass	df	0.3 Hz					
		t1	t2	t3	t4	t5	t6
ms		160-200	200-240	400-440	440-480	720-760	760-800
LONG							
Discrimination	1,22						
Discrimination x Site	8,168			3.40*	3.32*		
Gender	1,22						
Gender x Discrimination	1,22						

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.  
\*p<0.05 \*\*p<0.01 \*\*\*p<0.001.

Table 19: Differences between ERP responses to deviant and standard in German infants (2 months old, N=24) after application of the 1-15 Hz bandpass filter.

1-15 Hz bandpass	df						
		t1	t2	t3	t4	t5	t6
ms		160-200	200-240	400-440	440-480	720-760	760-800
LONG							
Discrimination	1,22						
Discrimination x Site	8,168	3.47**	3.19*	3.36*	3.30*	2.86*	4.5**
Gender	1,22						
Gender x Discrimination	1,22						

Note: Time windows (t) in ms relative to stimulus onset. Only significant F-values are reported.  
\*p<0.05 \*\*p<0.01 \*\*\*p<0.001.

#### SHORT SYLLABLE

Filter: *highpass 0.3 Hz*

Figure 21 (left, solid line) also displays difference waves for the short syllable deviant after applying the highpass 0.3 Hz filter. Again, at fronto-central sites a positive deflection around 400 ms was seen. No statistical significant effects were revealed.

Filter: *bandpass 1-15 Hz*

After the 1-15 Hz bandpass filter was applied, the main feature of the difference wave still was the positive going deflection occurring at fronto-central sites. No statistical significant effect was seen.

## 9.10 Summary

In Experiment IV b ERPs to long and short vowels contained in CV-items were recorded in 2-month-olds not-at-risk for SLI. Moreover, the possible impact of different filter settings on the MMR morphology was investigated.

It was demonstrated that 2-month-olds displayed a positive as well as a negative MMR in case the long syllable deviant was presented among short standards. Also, a late negativity was revealed for the long syllable deviant. However, when the short syllable deviant was presented among long syllable standards, no discrimination related responses were observed.

Furthermore, the impact of different filter settings on the infant MMR and late negativity was confirmed in Experiment IV b, i.e. in 2-month-olds, a negative MMR and late negativity was only statistically discernible when the bandpass 1-15 Hz filter was used. The MMN appeared at about the same latency as in adults, i.e. starting around 130 ms after change onset. However, the statistical discernibility of the positive discrimination related response was not a function of the filter settings used, i.e. it was present after application of both filters starting around 370 ms after change onset.

## 9.11 Discussion

Throughout the present experiments, evoked responses to CV-syllables varying in vowel duration were measured in German adults as well as in German 2 months old infants not-at-risk for SLI.

In adults, a typical Mismatch Negativity starting at 145 ms after change onset was present in response to the long as well as the short syllable deviant (Experiment IV a). As previously seen, filter settings did not have any impact on the morphology of the adult MMN.

When the long syllable functioned as the deviant item, the 2 months old infants not-at-risk for SLI displayed a negative as well as a positive discrimination related brain response. No hemispheric differences were observed. Also, a late negativity was present in case the long syllable deviant was presented as the deviant item. However, infants at the age of 2 months were not able to discriminate the short syllable deviant when presented among long syllable standards. From the visual domain it is known that infants at the age of 3 months are able to discriminate big circles among small ones but not vice versa (Sireteanu, 2002). This result was suggested to reflect the higher saliency of the big circles when presented among small ones. Taking these results into

account, it is suggested, that in the auditory domain 2-month-olds might profit from the higher saliency of the long vowel syllable when presented among short vowel syllables.

*Comparison between Highpass and Bandpass filtering*

Whereas the early negative discrimination response was only present in case the bandpass 1-15 Hz filter was used, the positivity and the late negativity were seen with both filters. Thus, the discernibility of the negative MMR was again dependent on the filter settings used, i.e. it was only significant in case the bandpass 1-15 Hz filter was applied. As the negativity appeared at about the same latency as in adults, it can be considered a typical Mismatch Negativity which is established in infants (cf. chapter 5). Hence, the hypothesis concerning the significant overlap of infant slow wave activity obscuring the fast wave related infant discrimination response was confirmed again (Experiment II a).

The positivity seen in the present experiments started at around 370 ms after change onset. This latency corresponds to the positive discrimination related responses obtained in infants when investigating their discrimination abilities for vowel duration in 6-month-olds (Leppänen et al., 1999), stress pattern discrimination in 5-month-olds (Experiment II a) and consonant discrimination in 3-4 months old infants (Dehaene-Lambertz, 2000). As it was present after application of each filter, the positive discrimination related response does not involve fast wave activity above 15 Hz. Rather, it must be related to slow wave activity below 1 Hz and above 1 Hz as it was present after application of both filters in 2-month-olds. The fact, that the positive MMR was more pronounced in 2-month-olds than in 5-month-olds points to maturational changes of the latter component, i.e. it seems to diminish with age (cf. Morr, Shafer, Kreuzer & Kurzberg, 2002).

In 2-month-olds, also a late negativity was seen in the grand-average difference wave in response to the long vowel deviant. Similar to the late negativity seen in Experiment II a, it started around 700 ms after change onset. In both experiments it was only significant in case a MMR was seen before. Therefore, it rather seems to indicate discrimination related further processing of the deviant stimulus than simple novelty detection (cf chapter 5.2.2.3).

## Chapter 10

### Discrimination of Vowel Length in Infants at Risk for SLI

#### 10.1 Introduction

For German-learning infants, discrimination of differences in vowel duration is a crucial prerequisite for computing stress patterns in bisyllabics. In Experiment IV a and IV b it was demonstrated that infants at the age of 2 months are able to discriminate vowel length increment as indicated by their MMN brain responses.

Experiment V will be performed in order to investigate discrimination abilities for varying vowel duration in 2-month-olds at-risk for SLI. Using a MMN paradigm in infants at-risk for dyslexia, a persistent deficit with respect to processing of vowel duration has been demonstrated during the first 6 perinatal months (Leppänen et al., 1999). As the same temporal processing deficit is assumed to underly dyslexia as well as SLI it is hypothesized that 2-month-olds at-risk for SLI will display reduced discrimination abilities for vowel duration as compared to matched controls.

Due to the fact that MMN was only seen in case the bandpass 1-15 Hz filter was applied, only data obtained after application of the latter filter settings will be analyzed in the following.

#### 10.2 Methods

##### 10.2.1 Subjects

The present experiments are also part of the German Language Development Study. They were conducted in 8-week-olds (+/- 5 days) who turned out to be at risk for SLI according to their word production scores at the age of 18 months (Grimm & Doil, 2000). At this point of data evaluation, a much higher percentage of male participants of the GlAD-study turned out to be at risk. Therefore, a total of 10 male full-term infants (GA: 37 to 41 +6; APGAR 1'  $\geq$  6, APGAR 5'  $\geq$  8, APGAR 10'  $\geq$  9; birth weight females:  $\geq$  2460 g, birth weight males:  $\geq$  2570 g) entered this study. A subgroup of 10 not-at-risk infants recruited from Experiment IV b was also included. The subgroup consisted of 5 male and 5 female infants. All infants completed both runs of the experiment and had the required number of accepted deviant items (i.e. 80). During the recordings they were either awake or in active sleep state (2 awake, 8 mixed states). All infants were born to monolingual German families. They passed a peripheral hearing screening with evoked otoacoustic emissions (OAE). None of them had hearing problems (OAE)

or a history of neurological or hearing impairment (Griffiths 1983, Prechtl & Beintema 1974).

### 10.2.2 Stimuli and Procedure

Stimuli and Procedure were the same as in Experiment IV a and IV b.

### 10.2.3 EEG Recording

EEG recording was the same as all previous experiments. Impedances were below 10 k $\Omega$ .

### 10.2.4 Data Analysis

Epochs of 1200 ms from stimulus onset were averaged separately for each condition, electrode and participant according to a 200 ms pre-stimulus baseline (EEP 3.2.1). Trials exceeding a standard deviation of 80  $\mu$ V within a sliding window of 200 ms in any channel were rejected automatically. Statistical analysis of the discrimination effect in the infant data were carried out for 2 consecutive time windows of 40 ms (160-240 ms). It was centered at the MMN latency determined in Experiment IV a. The MMN is prominent at fronto-central sites. Therefore, only those sites entered statistical analysis for the discrimination effect in the smaller subgroups.

In the not-at-risk subgroup three-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant vs. standard), GENDER (female vs. male) and SITE (F3/ F4/ C3/ C4) for each latency window (i.e. long-syllable deviant vs. long-syllable standard, short-syllable deviant vs. short-syllable standard). In the at-risk group, two-way analysis of variance (ANOVA) for repeated measures were conducted with the factors DISCRIMINATION (deviant vs. standard), GENDER (female vs. male) and SITE (F3/ F4/ C3/ C4) for each latency window (i.e. long-syllable deviant vs. long-syllable standard, short-syllable deviant vs. short-syllable standard). Hemispheric differences were tested with one-way ANOVAs for mean amplitudes of the deviant at fronto-central sites. Group differences regarding the discrimination effect were examined conducting T-tests with the group variable RISK for individual negative maxima at the MMN latency at fronto-central sites (F3, F4, C3, C4).

Processing differences in the obligatory ERP to each standard response between infants at-risk and infants not-at-risk were carried out for 20 consecutive time windows of 40 ms starting at stimulus onset until 800 ms. These differences were examined for data obtained after application of the highpass 0.3 Hz filter to preserve most of the signal involved in stimulus encoding. Two-way analysis of variances (ANOVA) for repeated measures were carried out with the factors GROUP (standard long infants

at-risk vs. standard long infants not-at-risk, standard short infants at-risk vs. standard short infants not-at-risk) and SITE (F3/ Fz/ F4/ C3/ Cz /C4 /P3 /Pz /P4).

The Greenhouse-Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator. Below, we report uncorrected degrees of freedom and corrected probabilities.

### 10.3 Results

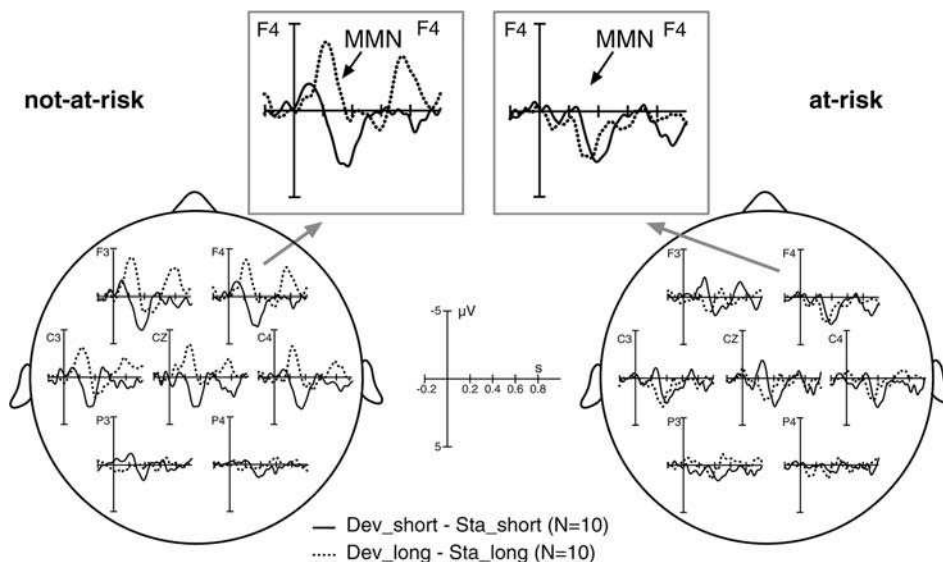


Figure 22:  
Grand-average difference waves (deviant minus standard) in 2 months old infants at-risk for SLI (right) and in 2 months old infants not-at-risk for SLI (left).

#### LONG SYLLABLE

##### *Infants not-at-risk*

In the subgroup of 10 not-at-risk-infants (Figure 22, left) a prominent negativity peaking around 220 ms was observed. Statistical analysis revealed a main effect for DISCRIMINATION at 160-240 ms [160-200 ms:  $F(1,9)=7.39^*$ ,  $p<.05$ ; 200-240 ms:  $F(1,9)=11.34^*$ ,  $p<.05$ ].

##### *Infants at-risk*

Infants at-risk for SLI displayed a small negativity peaking around 220 ms (Figure 22, right). However at the MMN latency no statistical significant effect was revealed.

##### *Comparison between Infants at-risk and Infants not-at-risk*

Single subject peak analysis revealed a significant difference of negative maxima at the MMN latency between groups in response to the long syllable deviant at F4 ( $T=2.381$ ,  $p<.05$ ) and C3 ( $T=2.726$ ,  $p<.05$ ).

#### SHORT SYLLABLE

##### *Infants not-at-risk*

In Figure 22 (left, solid line) difference waves for the short syllable deviant obtained in the not-at-risk group are presented. No negative deflection was seen. Statistical analysis revealed a significant interaction GENDER x DISCRIMINATION at 200-240 ms [ $F(1,9)=5.79$ ,  $p<.05$ ]. However, separate ANOVAs for boys and girls did not confirm the latter effect.

##### *Infants at-risk*

Infants at risk for SLI displayed a similar response consisting of a prominent fronto-centrally distributed positivity (Figure 22, dotted line). However, also a negativity was observed. Statistical analysis did not reveal a statistically significant effect at the MMN latency.

### 10.4 Summary

Experiment V was conducted in order to investigate discrimination abilities for varying vowel duration in infants at-risk and infants not-at-risk for SLI. Processing of different vowel duration is a crucial prerequisite for computing different stress patterns in German bisyllabics.

It was demonstrated that age-matched controls displayed the same mismatch pattern as the larger group investigated in Experiment IV b. Thus, 2-month-olds not-at-risk for SLI displayed a negativity at the MMN latency for the long syllable deviant, i.e. starting around 130 ms after change onset. However, no discrimination related negativity was elicited by the short syllable deviant.

2 months old boys at-risk for SLI did not display any discrimination related brain response to either deviant item. Individual peak analysis of the negative maxima at the MMN latency revealed significant differences in amplitude between groups at left temporal sites (C3). Also, significant amplitude differences were detected at right frontal sites (F4).

Hence, a discrimination deficit with respect to the long syllable deviant can now be suggested in 2-month-olds at-risk for SLI. Still, in order to determine whether the missing mismatch response is related to impaired discrimination abilities or rather results from deficits in auditory stimulus encoding, processing of standards needs to be investigated in both groups.



## 10.5 Processing of Standards

In Figure 23 the ERPs obtained for the long (right) and the short (left) syllable when presented as standards are displayed.

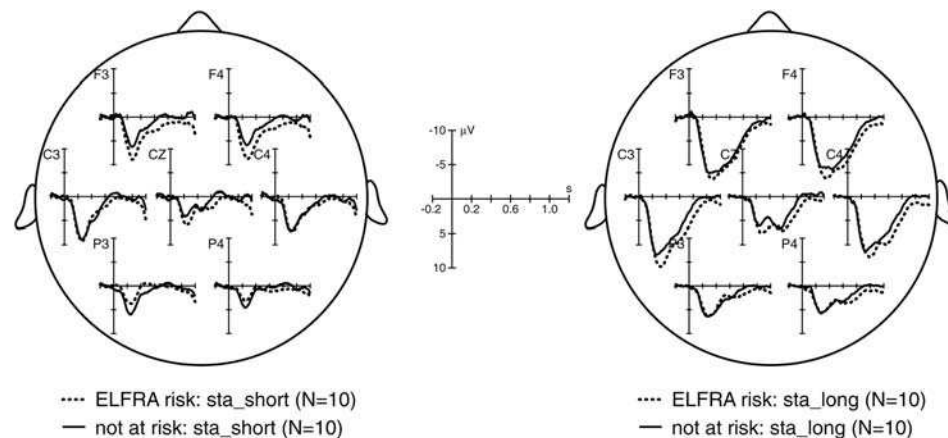


Figure 23: ERP standard response for the long syllable (right) and the short syllable (left) obtained in infants at-risk ( $N=10$ , red line) and infants not-at-risk ( $N=10$ , blue line).

### LONG SYLLABLE

Figure 23 (right) displays ERPs to the long syllable when presented as standard stimulus to infants at risk for SLI (dotted line) and infants not-at-risk (solid line). In both groups, a obligatory P350-N450 complex was observed. At fronto-central sites, the ERPs of infants at risk for SLI were larger in amplitude and more extended. However, no statistical significant differences between both groups were revealed.

### SHORT SYLLABLE

In Figure 23 (left) ERPs to the short standard syllable are shown for both groups. In both infants at risk for SLI and infants not at risk for SLI, a P350-N450 complex was seen. Again, at frontal sites, the obligatory waveform was more pronounced and more extended in the at-risk group. However, no statistically significant differences were observed.

## 10.6 Summary

Additional analysis of standard processing did not reveal any significant differences between groups. Obviously, auditory stimulus encoding does not differ between infants at-risk for SLI and infants not-at-risk for SLI at the age of 2 months.

## 10.7 Discussion

In Experiment V it was investigated whether discrimination abilities for varying vowel length differs in 2-month-olds at-risk for SLI as compared to age-matched controls. It was hypothesized that infants at-risk for SLI will display reduced discrimination abilities for vowel duration due to the fact that difficulties with respect to vowel length discrimination have been found in newborns as well as in 6-month-olds at-risk for dyslexia. The same temporal processing deficit is assumed in SLI and dyslexia.

Infants not-at-risk for SLI displayed the same discrimination pattern as the larger group investigated in Experiment IV b, i.e. they discriminated the long vowel deviant but did not display a negative MMR for the short vowel deviant syllable. On the contrary, boys at-risk for SLI did not display a significant discrimination response to either deviant item. Individual analysis of the negative peak maxima at the MMN latency revealed significant amplitude differences at left temporal and right frontal sites.

Furthermore, separate analysis of the processing of standard items were performed in both groups. As no differences between infants were seen, reduced discrimination abilities in infants at-risk and infants not-at-risk for SLI are not related to poor encoding of auditory stimuli per se, but rather indicate a discrimination problem for differences in vowel duration in SLI.

Taken together, the data obtained in 2-month-olds at-risk for SLI are in line with those seen in Experiment III. In both experiments, it was demonstrated for the first time that infants at-risk for SLI display reduced discrimination abilities for speech sounds when compared to age matched controls. This was previously reported for older children with SLI (Uwer, Albrecht & von Suchodoletz, 1998). The results also parallel findings of reduced discrimination abilities for vowel duration in neonates at-risk for dyslexia as well as reduced processing of consonant duration in 6-month-olds at-risk for dyslexia (cf. chapter 5.2.3). Similar to the data obtained in Experiments V and III, reduced MMN was mainly seen at left hemispheric sites. Hence, reduced temporal processing for vowel duration can be seen in infants at-risk for SLI as well as in infants at-risk for dyslexia suggesting the same deficit for both groups at this early age. Still, differences in obligatory processing between both groups were consistently found. Whereas reduced discrimination abilities in SLI do not seem to relate to differences in encoding of auditory stimuli per se obligatory processing was different in infants at-risk for dyslexia as compared to controls. These differences, in turn, were mainly located in the right hemisphere.

Taken together, a persistent deficit with respect to vowel duration processing during the first half year of life can be assumed in SLI as well. Yet, whether it relates to difficulties in processing of complex durational patterns of vowel length needs to be determined by future research.

## Chapter 11

### Summary and Conclusions

The present set of experiments focuses on discrimination abilities for suprasegmental phonological features in German infants with and without risk for Specific Language Impairment (SLI) as well as on the morphology of the infant brain discrimination response. Within the 'prosodic bootstrapping account', it is assumed that infants learning a stress-timed language acquire considerable information about possible word boundaries in their native language through different types of perceptual cues provided by the speech signal, e.g. stress patterns in bisyllabics (Gleitman & Wanner, 1982). Children with SLI, however, demonstrate reduced prosodic knowledge (Penner et al., 1998; Penner et al., 1992). It was suggested that this might be due to reduced prosodic bootstrapping capacities, i.e. less efficient detection of relevant cues to trigger prosodic development (Penner et al., 1998). Furthermore, reduced bootstrapping capacities, in this case less efficient detection of prosodic cues like, for example, syllable stress might relate to differences in basic temporal auditory information processing underlying language problems like SLI and dyslexia (Benasich & Tallal, 2002; Tallal, 2000). Note that stress pattern processing in German is crucially related to the computation of complex vowel duration patterns (Jessen et al., 1995). In fact, electrophysiological evidence in favor of deviant vowel duration discrimination abilities in newborns and 6-month-old infants at-risk for dyslexia has been presented by Leppänen and colleagues (Leppänen et al., 1999; Pihko et al., 1999).

Pertaining to word segmentation, results of previous behavioral research suggested word segmentation strategies based on the native-language prosodic pattern of two syllable content words, i.e. the trochee, for both adults and 6 to 9 months old German and American infants (Jusczyk, 1997; Jusczyk et al., 1993; Cutler, 1994; Echols et al., 1997; Jusczyk et al., 1999; Hoehle, 2002). This finding is generally referred to as 'trochaic bias'. With respect to the trochaic bias in American and German infants, however, it remained unclear whether it is related to language-specific linguistic knowledge or rather to a general perceptual/processing advantage of the trochaic item.

Still, as behavioral measures mostly rely on infants' motoric and attentional abilities, the earliest timepoint of infants' discrimination capacities for suprasegmental prosodic features like stress pattern and vowel duration can be better determined using a neurophysiological paradigm like the Mismatch paradigm. The infant Mismatch Response (MMR) is well established although there is considerable debate with respect to its morphology (Čeponienė et al., 2002; Cheour et al., 1998a; Cheour et al., 1998b; Dehaene-Lambertz, 2000; Dehaene-Lambertz & Baillet, 1998; Dehaene-Lambertz & Dehaene, 1994; Dehaene-Lambertz & Pena, 2001; Kushnerenko et al., 2001).

In the present work, the empirical behavioral results on stress pattern discrimination in infants were used to design electrophysiological paradigms in order to determine the earliest developmental timepoint of stress pattern discrimination in German infants. After determining it, it was investigated whether prosodic bootstrapping capacities with respect to stress pattern processing were different in age-matched infants at-risk for SLI. As stress pattern discrimination in German is also related to vowel duration processing, this capacity was additionally explored in German infants with and without risk for SLI. Throughout all experiments the influence of filter settings on the morphology of the infant MMR was investigated.

The results of **Experiment I a** reveal that adult controls display a typical MMN response when presented with trochaic (initially stressed) and iambic (not initially stressed) two syllable pseudowords. Furthermore, a second discrimination related response (LDN) appears for both items indicating further automatic processing of the discriminated stimuli. In a cross-linguistic study including German and French adults, i.e. **Experiment I b** it was demonstrated for the first time that – in case of the iambic stress pattern – MMN and LDN vary as a function of language-specific frequency. In contrast, no such influence can be seen for the trochaic item. This might be caused by some perceptual advantage, e.g. higher saliency of the trochaic item.

In **Experiment II a and II b** it was demonstrated for the first time that stress pattern discrimination in the form of a trochaic bias is only present at the age of 5 months in German infants without risk for SLI: In the latter age group, a MMR as well as a late negativity emerges only for the trochaic item. Due to the results obtained in Experiment I b, however, it is still not clear whether the trochaic bias is related to infants' language specific knowledge about the regular stress pattern in German or either to a possible perceptual advantage of the trochaic stress pattern. In contrast to adult data, the morphology of the MMR response varies as a function of filter settings applied on the data.

**Experiment III** reveals reduced discrimination abilities for the trochaic pseudoword in German 5-month-olds at-risk for SLI mainly at left temporal sites. However, contrary to similar data obtained in 6-month-olds at-risk for dyslexia, auditory encoding per se, i.e. the built-up of the sensory memory trace is not affected in infants at-risk for SLI. Prosodic bootstrapping capacities in terms of word segmentation seem to be reduced at the age of 5 months in German infants at-risk for SLI.

In **Experiment IV a and IV b** processing of differences in vowel duration as a crucial prerequisite for stress pattern computation in German was investigated in adults and 2 months old infants not-at-risk for SLI. German adults (Experiment IV a) expose vowel length discrimination abilities for short and long vowel syllables as indicated by MMN.

Contrary to Experiment I a and I b, no adult LDN was seen here. In Experiment IV b, 2 months old German infants without risk for SLI display a MMR to the long vowel syllables but not to short vowel deviants. This result parallels findings in the visual domain of infants pointing to differences in saliency. Again, the major influence of filter setting only on the infant MMR is present.

Results of **Experiment V** reveal reduced discrimination abilities for vowel duration differences as a crucial prerequisite for stress pattern processing in German 2-month-olds at-risk for SLI. Once more, reduced discrimination abilities do not relate to difficulties in encoding auditory stimuli as was previously seen in infants at-risk for dyslexia (cf. Experiment III). However, as the same temporal processing deficit is assumed to underlie SLI as well as dyslexia it might well be the case that reduced vowel duration processing capacities in dyslexia and SLI during the first half year of life interact with reduced stress pattern discrimination capacities at the age of 5 months and, consequently, reduced prosodic bootstrapping abilities at this age. At any rate, reduced vowel discrimination abilities are likely to affect the development of categorical knowledge related to vowel length in 2-month-olds.

In the following, I will discuss the major aspects of the present thesis, that is, the morphology of the infant MMR as well as the normal and at-risk infants' ability to process differences in vowel duration and stress pattern as a correlate of their prosodic bootstrapping ability.

## 11.1 The Infant Brain Discrimination Response

One main goal of the present thesis was to contribute to the debate about the morphology of the infant MMR. It is known that the major frequency range present in the adult MMN is theta activity (Başar, 1999). As the infant EEG is characterized by a very high portion of slow wave activity, faster theta wave activity related to MMN might be obscured in infants (Niedermeyer, 1998). In fact, studies applying a bandpass filter of 1-15 Hz always report a negative infant MMR (Čeponienė et al., 2002; Kushnerenko et al., 2001) whereas studies using a highpass 0.3 or 0.5 Hz filter mostly report positive infant MMRs (Dehaene-Lambertz & Dehaene, 1994; Friederici et al., 2002; Leppänen et al., 1999). Therefore, I investigated the infant MMR's variation due to different filter settings, i.e. a bandpass 1-15 Hz filter and a highpass 0.3 Hz filter (cf. chapter 5). The major finding in this respect was that depending on the filter settings applied on the data, a negative (bandpass 1-15 Hz) or a positive (highpass 0.3 Hz) MMR was prominent in infants. The same did not hold for adults. In the following, the morphology of the infant discrimination response will be discussed for infants without risk for SLI.

### 11.1.1 Early negative MMR

Results of Experiments II a, II b and IV b clearly indicate that already infants as young as 2, 4 and 5 months of age who are not in quiet sleep display an adult-like MMN for highly salient speech stimuli like long vowel syllables or trochaic pseudowords in case a bandpass 1-15 Hz filter is used. The finding of an adult-like MMN in infants to vowel differences and complex CVCV-stimuli is in line with previous findings (Cheour 1998a, 1998b; Kushnerenko et al., 2001; Leppänen et al. 2002). Note that in the studies conducted by Cheour the bandpass 1-15 Hz filter was not always applied. However, besides filter settings, another important methodological difference seen in the infant MMR literature relates to the required number of accepted deviants improving the signal to noise ratio. Whereas in the present work at least 65 (respectively 80) accepted deviants were mandatory, in the studies conducted by Cheour usually at least 100 accepted deviants were required.

Importantly, it is not the case that the application of the bandpass 1-15 Hz filter automatically reveals a negative MMR response in infants suggesting that the latter effect does not arise from some sort of technical artefact. Similar to results obtained in a study in 1-12 months old infants (Morr et al., 2002), in Experiments II a, II b and IV b a negative MMR was only obtained in case the difference between standard and deviant was large enough. Morr and coworkers (2002) suggested a masking effect for the negative MMR through a large positive component appearing at the same latency. However, parallels to the latter study need to be carefully drawn as age range for one group comprised 5 months as compared to 5 days in the present work.

Besides filter settings, the prominence of the negative MMR might also be influenced by the alertness state of the examined subjects as it was reported to be more prominent in awake 2 months old infants as compared to sleeping subjects (Friederici et al., 2002; Friedrich, Weber & Friederici, in press). However, in the present studies infant data obtained during quiet sleep was excluded. Lacking negative MMR might also relate to the fact that single subject analysis reveal that the negative MMR cannot be reliably recorded in up to 50 % of healthy newborns (Čeponienė et al., 2002; Kurtzberg, Vaughan, Kreuzer & Fliegler, 1995; Leppänen et al., 1997). Still, in the present thesis the same data entered analysis suggesting that the latter argument cannot account for the differences in results seen here.

Hence, according to the functional significance underlying MMN, it can be concluded that 2-month-olds as well as in 5-month-olds who are not at-risk for SLI are capable to encode specific auditory information, build a transient central sound representation, automatically compare a new stimulus to the latter representation in sensory memory and detect a change at about the same latency as adults. However, as MMN was not

elicited in all conditions, it needs to be determined yet to what extent this process is dependent on the structure and complexity of the auditory stimulus (e.g. tones vs. speech). Moreover, the influence of methodological differences like filter settings and minimum number of accepted deviants on the discernibility of the negative MMR in different age groups has to be further investigated (Weber, Hahne, Friedrich & Friederici, 2004).

### 11.1.2 Positive MMR

Results of Experiments II a and IV b show that infants as young as 2 and 5 months of age who are not in quiet sleep display a positive MMR for highly salient speech stimuli like long vowel syllables or trochaic pseudowords in case the highpass 0.3 Hz filter is used.

A positive discrimination related response for vowel duration differences contained in CV-stimuli elicited in a passive oddball design was demonstrated before using similar filter settings (Leppänen et al., 1999; Pihko et al., 1999). Several researchers suggested the latter positivity to relate to orienting or other automatic attentional responses like, for example, the P3a (Cheour et al., 1998; Cote, 2002). However, due to the fact that the positivity has been reported in 2-month-olds who were in quiet sleep stage it is unlikely to be related to a P3a kind of response (Friederici et al., 2002). An alternative explanation for the increase in positivity in response to the new deviant stimulus could be an enhancement of the obligatory response which is positive in polarity in infants. However, given the fact that infants also display a positive response when presented with short vowel deviants among long vowel standards this explanation seems unlikely due to the fact that the shorter vowel cannot elicit additional afferent activity necessary for an increase in obligatory response (Leppänen et al., 1999). Still, it is known, that the exogenous components contribute to the deviant response also in adults (Näätänen & Picton, 1987). Thus, in order to finally rule out such obligatory effects in infants, it is mandatory to conduct a deviant-alone control condition in infants (for adults, cf. Experiment I a and Experiment IV a). Actually, a deviant-alone control study has been conducted for tones in newborns (Leppänen et al., 1997a). The authors suggested that the discrimination response to tone differences in infants might appear as a reduction of the obligatory positivity response in the deviant response. Still, a similar control for speech stimuli is lacking in the literature.

However, if one adopts the view of a positive discrimination MMR, its functional significance remains to be explained. Trying to separate both components which are observable together in grand-average ERPs, it has been proposed that the positivity might relate to bottom-up categorization of new incoming stimulus features as opposed to a top-down discrimination process related to MMN on the basis of a deviance



detection in expected stimulus features (Friedrich et al., in press). Alternatively, one might suggest that the positivity represents a genuine 'immature' infantile discrimination response contained in slow wave activity which is present in infancy, e.g. due to immature myelination slowing down brain responses. Following this logic, it can be assumed that some subjects entering the grand-average might be more mature, i.e. they display a negative MMR. Taking the difference in prominence of the positive MMR at the age of 2 and 5 months into account (Experiment II a and Experiment IV b) maturational changes in the form of diminishing positive discrimination activity can indeed be seen (cf. also Morr et al., 2002). Therefore, in order to determine the separability of both components it is necessary to examine them on a single-subject level. Due to the fact that MMN is not always elicitable in infants as well as the fact that the influence of sleep on the MMN has not been determined in the same subjects, the functional separation of both components is not established yet.

Overall, future research needs to address several remaining problems. First, the contribution of obligatory positive activity to the positive MMR in infants has to be determined for speech stimuli. Second, the functional significance of the positive response as compared to the MMN needs to be separated in the same subjects, e.g. during different alertness states. Also, the maturational course of both components needs to be verified.

### 11.1.3 Late Negativity

Results of Experiments II a and IV b demonstrate that infants as young as 2 and 5 months of age who are not in quiet sleep display a late negativity around 700 ms after change onset in a passive oddball design. It was more prominent in case the band-pass 1-15 Hz filter was used. As it only occurred for the discriminated stimuli the late negativity seen in the present thesis relates to the discrimination process in infants.

So far, only a few studies have reported late negativities in infants and/or LDN in adults. The main reason is probably that in a typical oddball paradigm the ISI is usually too short for a reliable late negative response of any kind. However, several researchers found a late negative shift when presenting auditory deviant stimuli in a passive oddball design to infants (Dehaene-Lambertz & Dehaene, 1994; Friederici et al., 2002; Pihko et al., 1999). Some authors interpreted this response to be related to an obligatory offset response to the deviant stimulus (Pihko et al., 1999). As in infants obligatory responses are usually positive in polarity, this explanation is unlikely (cf. chapter 5). Others proposed it to be related to novelty (Dehaene-Lambertz & Dehaene, 1994). Moreover, the latter response was suggested to be an indication of cognitive aspects of mismatch discrimination as its amplitude depends on the alertness state of the child, i.e. it is more prominent in awake infants (Friederici et al., 2002). This interpretation is well in line with



the possibility that the latter component might parallel the infant Nc component which is well known in the visual domain but has also been reported for the auditory domain (Kurtzberg & Vaughan, 1985). The Nc component is a frontally dominant negativity which has been suggested to be a manifestation of attention to a recently presented stimulus. The more deviant, new or surprising the deviant stimulus is, the larger the Nc amplitude seems to be (Courchesne, 1977; 1978; 1981). It has also been implied that to obtain a prominent Nc, the deviant stimulus has to be important enough to require further, more detailed processing. The Nc latency decreases during development, being approximately 1000 ms in newborns, 700 ms in 6-month-olds and reaches the adult level, that is, about 400 ms, by the age of 7 years (Courchesne, 1981).

Cheour and colleagues (Cheour et al., 2001) proposed that the late negativity observable in infants and children in the auditory domain resembles the Late Discriminative Response (LDN) seen in children and adults. Both components are observable in a passive oddball design. The LDN was suggested to reflect automatic processing of previously discriminated stimuli, possibly even linguistic stimuli in children (Korpilahti, 1996). Yet, it has been shown that LDN can also be obtained in response to changes in sinusoidal tones in adults and infants (Čeponienė et al., 2002; Čeponienė et al., 1998). However, with respect to the results seen in the present thesis, that is, a late infant negativity in response to vowel duration differences as well as in response to stress pattern differences (Experiments II a and IV b) as opposed to an adult LDN in response to stress pattern discrimination differences (Experiments I a and I b) but not in response to vowel duration (Experiment IV a), it seems unlikely that the late infant negativity is analogous to the LDN. This is due to the fact that higher automaticity of further processing cannot be expected in infants as compared to adults. Therefore, the late infant negativity rather appears to indicate attention related further processing as suggested above instead of a LDN. However, it is not clear why the adult LDN is lacking in response to vowel duration discrimination. One possibility relates to the fact that the criteria for adult LDN in the present case might have been too strict: In most studies reporting adult LDN deviant-alone conditions to control for true discrimination effects as opposed to mere obligatory effects were not conducted. The same argument does not hold for the infant late negativity though as a possible negative offset response is unlikely during infancy. Furthermore, assuming some kind of obligatory effect only visible in half of the experimental conditions is not convincing.

However, from the present data it can be concluded that the infant negativity is not analogous to the LDN. Still, to my knowledge, no studies have tried to separate both components in order to investigate their functional significance during development. Therefore, future research should address this question, e.g. by presenting the same paradigm to different age groups. Here, also deviant-alone control conditions should be conducted to definitely rule out obligatory effects.

Taken together, the infant discrimination response seen in the difference wave consists of an early negativity at the MMN latency, i.e. at 100-200 ms after change onset. Alternatively, an immature infantile positive discrimination response emerging around 300 ms after change onset can be seen. Still, this component might also have a different functional significance, i.e. bottom-up categorization of the deviant stimulus. At around 700 ms after change onset, a second negative deflection is visible probably indicating cognitive aspects of the mismatch response which might relate to alertness and possibly to attention. All components can be clearly discerned when using a bandpass 1-15 Hz filter. If a highpass 0.3 Hz filter is applied, the negativities are less pronounced.

## 11.2 Neurophysiological Indication of a ‘Trochaic Bias’ in German Infants with and without risk for SLI

The second main objective of the present thesis is to determine the earliest developmental timepoint of stress pattern discrimination in German infants and to investigate whether prosodic bootstrapping capacities with respect to stress pattern processing is different in age-matched infants at-risk for SLI. In the following, the obtained results will be discussed in the light of this question.

### 11.2.1 Vowel Length Discrimination in Infants

The ability to discriminate vowels of different duration is crucial for German-learning infants. This relates to the fact that it is an important prerequisite for computing complex temporal patterns of vowel duration present in stress patterns of German bisyllabics. Furthermore, it also is a categorical phoneme feature in segmental phonology (e.g. /lam/ *sheep* vs. /la:m/ *lame*).

#### *Infants not-at-risk*

Results of Experiment IV b indicate that German 2 months old infants discriminate long vowel deviants contained in CV-stimuli when presented among short vowel standards but not vice versa. This result contrasts with data obtained in Finnish newborns who were able to discriminate a short vowel deviant from long vowel standards (Pihko et al., 1999). Finnish bisyllabics also follow the trochaic stress pattern. In both studies, duration differences between stimuli were 140 ms indicating the same discrimination difficulty in both cases. However, the stimuli differed in total length being generally longer in Experiment IV b. Still, as encoding abilities for longer and more complex stimuli are obviously in place at birth (Kushnerenko et al., 2001) this fact neither can account for the differences in result. Also, the number of subjects which always improves the signal to noise ratio was not smaller in Experiment IV b as compared to the Finnish study. Still, another factor influencing the signal to noise ratio is the required number of accepted deviants which was higher in the Finnish study.

However, if differences in results indeed result from different sensitivity to factors like signal to noise ratio it is assumed that MMN to short vowel deviants is present but smaller than MMN to long vowel deviants. The fact that, even in adults, omission of a stimulus element usually elicits a smaller and later MMN than does inclusion of the same element, however, supports this view (Nordby, Hammerborg, Roth & Hugdahl, 1994).

Thus, the result obtained in Experiment IV b is an indication of sensitivity to differences in saliency relevant for auditory processing in 2-month-olds. This parallels results obtained in 3-month-olds in the visual domain. Using a behavioral paradigm, Sireteanu (2002) demonstrated that infants are able to discriminate big circles from smaller ones but not vice versa.

In order to address temporal processing abilities for vowels in infants more specifically, future research has to address the contribution of single physical features like pitch and intensity which were not held constant in the present stimuli due to the fact that natural speech sounds were used. However, digital manipulation of natural speech sounds often implies a more artificial sound quality. This, in turn, causes specific ERP effects even in adults as demonstrated by Steinhauer and Friederici (2001). Moreover, in order to address possible specificity of language processing, it has to be investigated whether temporal processing differs as a function of the speechness of the stimuli, e.g. between tones and speech stimuli. With respect to comparisons between infant studies, another important methodological difference possibly relating to differences in results, i.e. number of accepted deviants needs to be investigated.

#### *Infants at-risk*

Experiment V and IV b reveal that infants at-risk for SLI are not able to process differences in vowel duration as efficiently as controls. In general, the discrimination pattern did not differ between infants at-risk for SLI but only seemed to be less pronounced in infants at-risk for SLI, i.e. MMN to the long vowel CV-stimulus was reduced, MMN to the short vowel syllable deviant was absent. Note that the required number of accepted deviants was considerably higher in these experiments.

Similar to results obtained during the first half year of life in infants at-risk for dyslexia, discrimination abilities in infants at-risk were less elaborate than in infants not-at-risk (Guttorm et al., 2003; Leppänen et al., 1999; Leppänen et al., 2002). However, whereas in infants at-risk for dyslexia encoding of stimuli also differed between groups, this was not the case in Experiment V indicating that the built-up of the sensory memory trace for the frequent standard stimulus is not affected by being at-risk for SLI.

Data reported for school children exhibiting SLI also point to reduced discrimination abilities for native language phonemes (Uwer, Albrecht & v. Suchodoletz, 1998). One

possibility to account for reduced discrimination capacity in SLI is less effective encoding of the deviant stimuli, i.e. in SLI a higher presentation rate of auditory stimuli might be necessary for precise memory encoding. This view is supported by the fact that long term memory traces which also might influence MMN amplitude are not likely to be responsible for smaller MMN in school children exhibiting SLI, long term memory for native language phonemes is not supposed to differ between groups. However, in order to investigate this question, an MMN experiment varying the number of deviants in SLI and controls should be conducted.

Comparisons between groups indicate that amplitude differences are most prominent at electrode F4, i.e. at right frontal sites and at electrode C3, i.e. at left temporal sites. In adults, a subcomponent of the MMN generator is assumed to be located near F4 (Giard et al., 1990). Therefore, differences in amplitude at this site might point to different generator activity for the discrimination response. In turn, left temporal sites are assumed to be involved in language processing during adulthood. Thus, less efficient discrimination abilities for vowel duration at the age of 2 months in these particular regions might involve reduced language specific processing abilities for such contrasts. However, it is not clear whether there is a left-hemispheric advantage for language processing in infants. Still, the latest fMRI results support the notion of a strong left lateralization of language already by the age of 2-3 months (cf. section 5.3).

Taken together, comparisons between results obtained in Experiment IV b and V indicate that infants at-risk for SLI are delayed with respect to vowel duration processing as compared to controls: they do not have difficulties in laying down a sensory memory trace for the frequently presented standard. Still, their general discrimination response pattern is less pronounced. However, less efficient encoding as a function of presentation rate may relate to less elaborate discrimination in SLI. Hence, at the age of 2 months already, infants can be at-risk to display difficulties in building up categorical knowledge involving the feature vowel duration as well as in processing of complex temporal patterns of vowel duration.

Future research has to address the question when this problem resolves as it is not present in older children with SLI (Tallal, 1975). Still, as the same temporal processing deficit is assumed to underlie SLI and dyslexia (Habib, 2000), it is well possible that deviant vowel duration processing abilities seen during the first half year of life in infants at-risk for dyslexia affects infants at-risk for SLI during the same period.

### **11.2.2 Stress Pattern Discrimination in Infants**

A large body of behavioral infant studies investigated stress pattern processing in bisyllabics (cf. section 2.2.2). In German 6-month-olds, a preference of the trochaic

stress pattern was confirmed (Hoehle, 2002). Behavioral evidence varying duration as a function of word stress in bisyllabics found evidence in favor of a 'trochaic bias' in 9 months old American infants. However, in the same study it was demonstrated that 6 months old American infants do not display a trochaic bias yet (Morgan, 1996). Differences with respect to the developmental course of the trochaic biases development might be clarified using a neurophysiological design built on the previous results. Therefore, the electrophysiological mismatch account usually applied to investigate aspects of segmental phonology was extended to explore developmental aspects of suprasegmental phonology tapping general language acquisition.

#### *Infants not-at-risk*

Results of Experiment II b reveal that stress pattern discrimination in single subjects is already present at the age of 4 months. In the latter experiment more infants were able to discriminate the trochaic deviant as compared to the iambic one. A trochaic bias is visible on the group level in the neurophysiological paradigm indicating a developmental change in discrimination abilities the age of 5 months. At this age, the iambic stress pattern was not discriminated on a group level. Hence, neurophysiological evidence suggests that the trochaic bias is already present at the age of 5 months in German infants. However, in order to finally determine whether neurophysiological paradigms can better determine the developmental course of stress pattern discrimination abilities in infants than behavioral measures, a similar behavioral paradigm has to be conducted in age-matched controls.

Nevertheless, on the neurophysiological level, these findings confirm the results of the two existing mismatch studies investigating the processing of complex stimuli varying in phoneme duration in newborns (Kushnerenko et al., 2001) and 6 months old infants (Leppänen et al., 2002). Interestingly, Kushnerenko and coworkers (2001) found consonant duration discrimination in complex speech stimuli already in newborns. This result, though, might relate to the fact that phoneme discrimination is present earlier in development than stress pattern discrimination. Still, in the present study, stress pattern realization involves changes in vowel length on the segmental level. Therefore, another possible explanation to account for differences in results might be the fact that in the present study, stimuli were considerably longer implying more processing load for the encoding of the rare deviant item which is necessary for the discrimination process.

Taking the results of Experiment I b and Experiment IV b into account, in the following, some arguments concerning the question of how infants come to adopt a trochaic bias will be discussed. In Experiment I b it was demonstrated that, in contrast to the iambic stress pattern, the trochaic one seems to have a perceptual processing advantage. As onsets of auditory stimuli constitute particularly salient transients and are, furthermore,

behaviorally relevant, the fact that the trochaic item is more easily discriminated than the iambic one might arise from differences in onset saliency for both stress patterns. Whereas the trochaic one starts with a long vowel syllable, the iambic one starts with a short vowel syllable. In Experiment IV b infants' higher sensitivity to the saliency of a long vowel CV-item was revealed. Therefore, sensitivity to the saliency of long and short vowel stimuli at the beginning of two syllable items might account for better discrimination of the trochee in infants.

However, if a strong perceptual bias towards the trochaic items existed, it should be visible in the single subject analysis performed in 4-month-olds, too (Experiment II b). Yet, the fact that Experiment II b revealed that 13 4-month-olds displayed MMN to the trochaic item as compared to 9 4-month-olds exposing MMN to the iambic one can only be interpreted as a trend towards such a perceptual advantage of the trochee. Still, the existence of this trend makes it worthwhile to investigate this question more detailed in future research in infants younger than 5 months.

Importantly, at the age of 4 months, infants did also discriminate the iambic deviant item indicating sensitivity to the non-regular ambient language stress pattern. The developmental change towards a clear trochaic bias at the age of 5 months, however, points either to a decrease in sensitivity to the iambic pattern or to an increase of sensitivity to the trochaic pattern. In both cases an influence of the stress pattern frequency contained in the mother tongue can be assumed. Therefore, a distributional analysis of the native language with respect to stress patterns in bisyllabics appears to be involved in the developmental process seen in Experiments II a and II b.

With respect to the question of how German infants develop a trochaic bias, the results of Experiment I b, Experiments II a and II b as well as Experiment IV b point to a possible perceptual advantage through higher saliency of the trochaic item's onset which might interact with effective distributional analysis of the native language input and/or trigger innate prosodic learning mechanisms. Conducting an electrophysiological cross-linguistic study in age-matched infants using a language with opposite stress pattern distribution might further clarify the influence of language specific knowledge on prosodic development in infants. In sum, the electrophysiological account seems to be a promising tool to investigate the course of developmental changes in sensitivity to different aspects of phonological development.

#### *Infants at-risk*

In the present thesis it was for the first time explored whether infants at-risk for SLI display the same discrimination abilities for relevant suprasegmental features contained in bisyllabics as age-matched controls. Experiment III reveals that infants at the age of 5 months display less effective discrimination abilities for the trochaic item. However,

the discrimination pattern was the same as in controls (Experiment II a). Additional comparisons of standard stimulus encoding between groups indicate that the built-up of the sensory memory trace does not differ as a function of being at-risk for SLI. Thus, less elaborate discrimination abilities for the trochee are present in 5-month-olds at-risk for SLI and might be suggested to impair prosodic bootstrapping capacities in terms of word segmentation at this age.

With respect to the temporal processing deficit assumed to underlie SLI as well as dyslexia it is interesting to note that electrophysiological evidence in 6-month-olds at-risk for dyslexia points to reduced discrimination abilities for differences in consonant duration contained in complex CVC-stimuli (Leppänen et al., 2002). The same obviously holds for stress pattern differences mainly realized as vowel duration differences in CVCV-stimuli computed by 5-month-olds at-risk for SLI. Similar to results seen in Experiment V, however, no differences emerge at the level of building up the sensory memory trace in SLI. Thus, in contrast to infants at-risk for dyslexia, infants at-risk for SLI do not differ from controls in this respect suggesting intact auditory sensory memory functions in SLI as opposed to dyslexia.

However, it cannot be excluded that in SLI, stimulus encoding differs as a function of presentation rate of the stimulus to encode. In fact, one possibility to account for reduced discrimination capacities in SLI is more effortful encoding of rarely presented deviant stimuli. Therefore, a possible distinction between SLI and dyslexia during the first half year of life might either be the degree of auditory encoding difficulties or auditory encoding capacities per se.

Experiment I b reveals that long term memory traces for stress patterns in bisyllabics enhance MMN amplitude. However, taking into account that 6-month-olds do not have language specific long term memory traces for native language phonemes (Cheour et al., 1998b), the assumption of long term memory traces for complex stress patterns enhancing MMN in 5-month-olds not-at-risk for SLI is rather unlikely.

Taking the results of Experiment V into account, it seems that speech stimulus discrimination involving differences in vowel length is rather delayed than deviant in infants at-risk for SLI. In both studies, the same processing pattern emerges, i.e. reduced discrimination abilities in infants at-risk for SLI but intact encoding of the frequently presented auditory stimulus in sensory memory. Still, whether the deficit relates to precision of auditory encoding as a function of presentation rate remains to be investigated.

Also similar to the results seen in Experiment V, amplitude differences of the MMN in Experiment III were largest at left temporal sites. This, in turn, might point to a central



role of left temporal sites for the processing of durational differences at least in complex speech stimuli. Note that the same site was revealed to be affected in 6 months old infants at-risk for dyslexia when processing complex speech sounds (Leppänen et al., 2002).

### 11.3 Implications for Theory

Infants are successfully acquiring complex and language-dependent phonological concepts although they cannot necessarily be expected to have specific knowledge about the language to be learned. However, different languages follow certain rhythmic organization principles which are realized by different acoustic-phonetic cues contained in the input. Those, in turn, are suggested to trigger further prosodic development (cf. chapter 2).

Mehler and coworkers (1996) put forward the idea that infant speech perception is centered on vowels which were demonstrated to be more salient in the speech signal (cf. TIGRE, section 2.1.1, 2.2.1). Following this account, Ramus and colleagues (1999) showed that infants and adults could indeed rely on the computation of the vowel/consonant temporal ratio %V when categorizing the rhythmic organization type of languages. Certainly, the TIGRE account has to be confirmed investigating more languages as only data from 8 languages was investigated. Also, the definition of the variable %V is arbitrary but, at the same time, it is also very straightforward due to its simplicity.

#### *Infants not-at-risk*

Integrating the results of the studies conducted in infants not-at-risk (Experiments II a, II b and IV b), the TIGRE proposal might be extended. Perceptual cues demonstrated to be relevant for rhythmic language organization, i.e. the computation of relational temporal aspects of speech sounds might well be used by infants to further explore rhythmic properties on the word level of a given stress-timed language. Thus, in German-learning infants, the saliency of long vowel syllables onsets could be of help to find out about rhythmical regularities on the word level. As previously pointed out, long vowel deviants are more easily processed in infants and probably also in adults (Experiment IV a & IV b). The cross-linguistic adult study (Experiment I b) as well as infant studies (Experiment II a & III) reveal that trochaic bisyllabics starting with a long vowel syllable are more easily processed than iambic bisyllabics starting with a short syllable. In the latter stimuli, word stress was mainly realized as increased vowel duration due to the fact that duration is its most critical feature of word stress in German (cf. section 2.1.2). Therefore, long vowel sounds might serve as an anchorpoint for finding out about saliency patterns, i.e. stress patterns in bisyllabics realized as complex patterns of vowel duration.



*Infants at-risk*

Integrating the TIGRE account with the evidence in favour of reduced vowel length discrimination in infants at-risk for SLI (Experiments III and V), a possible link of temporal processing deficits (cf. section 3.3) to reduced prosodic bootstrapping capacities in German infants will be presented in the following.

In order to be able to compute the temporal vowel/consonant ratio relevant for prosodic bootstrapping with respect to language rhythm, at least two prerequisites have to be in place in newborns or infants. First, it is necessary to separate single speech qualities like vowels, i.e. steady-state formant frequencies of longer duration and consonants, i.e. rapidly changing transient frequency information. Here, sensitivity to the general perceptual saliency of vowels as demonstrated behaviorally is of advantage (cf. section 2.2.1). The present results additionally indicate different degrees of infants' sensitivity to saliency, e.g. to vowels of long duration. In infants at-risk for SLI, this sensitivity is less pronounced.

A second prerequisite for successful computation of the vowel/consonant ratio is the processing of differences in duration of consonant and vowel speech sounds. Behavioral results indicate that infants Rapid Auditory Processing (RAP) abilities for tones and consonants were predictive for later language outcome (cf. section 3.3.2). Electrophysiological evidence in infants up to 6 months suggests discrimination of vowel duration. However, during that same period of life, infants at-risk for SLI and infants at-risk for dyslexia display reduced discrimination of differences in vowel length (cf. Experiment V, section 5.2.2).

Reduced temporal processing abilities in infants at-risk for SLI are likely to influence prosodic development in those infants, i.e. diminish their prosodic bootstrapping capacities due to reduced exploitation of available cues in the language input. Furthermore, in German infants, this might also affect their ability to use salient prosodic cues for word segmentation.

Taken together, the extension of the temporal processing account on vowel duration processing as an important feature of prosodic bootstrapping capacity in early infancy is a promising account. It provides an explanation of how temporal processing abilities often seen on the segmental phonological level might affect general language acquisition in SLI. Furthermore, the investigation of language processing in infants at-risk for SLI might, similar to the aphasia account, shed light on decisive prerequisites as well as sensitive periods of normal language acquisition. However, especially in SLI, sample sizes should be increased in the future.



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