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Early N400 development and later language acquisition

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Abstract

Recent developmental research on word processing has shown that mechanisms of lexical priming are already present in 12-month-olds whereas mechanisms of semantic integration indexed by the N400 mature a few months later. In a longitudinal setting we investigated whether the occurrence of an N400 at 19 months is associated with the children's language skills later on. To this end children were retrospectively grouped according to their verbal performance in a language test at 30 months. Children with later age-adequate expressive language skills already displayed an N400 at 19 months. In contrast, children with later poor expressive language skills who have an enhanced risk for the development of specific language impairment (SLI) did not show an early N400. The results imply that children who have deficits in their expressive language at the age of 30 months are already impaired in their semantic development about one year earlier.

Descriptors: Event-related potentials (ERPs), N400, Development, Semantics, Lexical priming, Specific language impairment (SLI)

By the use of the method of event-related brain potentials (ERPs) and a cross-modal picture–word paradigm it has recently been shown that in 1-year-olds acoustic-phonological word processing clearly differs depending on the children's lexical expectations that were derived from picture contexts. An enhanced negativity in the lateral frontal brain region from about 100 to 500 ms post-word onset was present on congruous words, that is, on those words that correctly named the pictures at the basic level, when compared to the same words in incongruous picture contexts (Friedrich & Friederici, 2004, 2005a, 2005b). Similar early negativities in 11- to 20-month-olds have been shown to differentiate the processing of known, unknown, and backward presented words (Mills, Coffey-Corina, & Neville, 1993, 1994), of familiar and unfamiliar words (Thierry, Vihman, & Roberts, 2003), of words that differed in their initial phoneme (Mills et al., 2004), and of phonotactically legal and illegal nonsense words (Friedrich & Friederici, 2005a). Moreover, a study with 10-month-olds showed that during the process of familiarization, the initially present frontal slow positive response on low frequency nouns decreased and a negativity emerged (Kooijman, Hagoort, & Cutler, 2005). Thus, it appears that the enhanced negative responses in fronto-temporal brain regions reflect improved phonological processing caused by the use of memory representations that have either been strengthened by some kind of familiarity or are preactivated by lexical priming. The phonological-lexical priming effect, that is, the lateral-frontal negativity on congruous word observed in the cross-modal picture–word paradigm, has been found to be present in all of the age groups of 12-, 14-, and 19-month-old children investigated so far (Friedrich & Friederici, 2004, 2005a, 2005b).

In contrast, in the same paradigm, a centro-parietal N400 effect on incongruous words was present in 14- and 19-month-olds but not in 12-month-olds. The N400 indicates semantic processing routines in both adults (e.g., Kutas & Hillyard, 1980; for a recent review, see Kutas & Federmeier, 2000) and children (Coch, Maron, Wolf, & Holcomb, 2002; Friederici & Hahne, 2001; Hahne, Eckstein, & Friederici, 2004; Holcomb, Coffey & Neville, 1992). Its amplitude reflects the effort for integrating a potentially meaningful stimulus into the current semantic context (Holcomb, 1993), such as the effort required to integrate a word into its sentence context (e.g., Friederici, Pfeifer, & Hahne, 1993) or a picture into a picture story (West & Holcomb, 2002). Pseudowords, that is, nonsense words that obey the phonetic, prosodic, and phonotactic rules of a given language, also elicit substantial N400 responses, whereas nonwords, that is, nonsense words that violate the regularities of a language, do not (Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Bentin, Mouchetant-Rostaing, Giard, Echallier & Pernier, 1999; Holcomb, 1993; Holcomb &

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Neville, 1990; Nobre & McCarthy, 1994; Rugg & Nagy, 1987). These different N400 responses to pseudo- and nonwords in adults indicate the brain's differentiation of nonsense words as being potential lexical elements of the target language and thereby potential referents for meaning or not. In 19-month-olds, the N400 occurred in response to both words and legal pseudowords that met prosodic, phonetic, and phonotactic rules of German but not in response to nonwords that violated phonotactic regularities of the target language. This suggests that even 19-month-old children consider legal pseudowords, but not phonotactically illegal nonwords, as potential words. Again, in this case, an N400 for pseudowords was not present in 12-month-olds (Friedrich & Friederici, 2005a).

As in this younger age group of 12-month-old children, the presence of the phonological-lexical priming effect indicates the existence of some initial lexical knowledge of the presented words, the absence of the N400 needs some further consideration. The data pattern suggests that although the lexical-semantic knowledge of 12-month-olds was sufficient to trigger a specific phonological expectation, semantic integration as reflected by the N400 was initiated neither for incongruous words nor for pseudowords (Friedrich & Friederici, 2005a). Thus, the N400 mechanisms appear to mature within a few months after the child's first year of life. On the psychophysiological level, the maturation of N400 integration mechanisms represents a qualitatively new stage of semantic processing.

On the behavioral side, children begin to comprehend their first words at around 8 to 10 months of age and to produce some words around their first birthday (e.g., Bates, Thal, & Janowsky, 1992; Benedict, 1979). Within the next few months, they learn only a few new words. This phase of slow word learning is followed by a phase of very rapid acquisition of new words, the so-called vocabulary spurt (e.g., Benedict, 1979; Goldfield & Reznick, 1990; Reznick & Goldfield, 1992). When children enter into this phase they have achieved a new quality in their language development; they are now able to learn new words for new objects by only a few presentations (Mervis & Bertrand, 1995). Under appropriate experimental conditions this fast mapping ability is present in 13-, 14-, and 15-month-olds but not in 12-month-olds (Schafer & Plunkett, 1998; Werker, Cohen, Lloyd, Casasola, & Stager, 1998; Woodward, Markman, & Fitzsimmons, 1994; for a recent review, see Werker & Yeung, 2005).

The temporal co-occurrence of the fast mapping ability and N400 maturation might refer to the presence of a common neural base underlying both developmental states. It might even reflect the existence of a causal relationship between the N400 neural mechanisms and the children's learning capacity that causes success in later language acquisition. In the present study, we focus on this topic. Specifically, we asked whether the emergence of the N400 early in development is related to differences in the children's later language skills.

Although most children pass through the different phases of language acquisition in the same order, there is a great variance within individuals in the temporal occurrence of these phases (e.g., Goldfield & Reznick, 1990) as well as in the children's language outcome. Children who did not exhibit the vocabulary spurt by the age of 24 months and who have not acquired at least 50 words at that age are so-called late talkers. About half of the late talkers improve their vocabulary from ages 2 to 3, but many of them have persisting problems in their language development (Rescorla, 2002; Rescorla, Dahlsgaard, & Roberts, 2000). During the following years these problems may be manifested in specific language impairment (SLI). SLI is a disability in expressive language or in both receptive and expressive language despite normal intelligence, an adequate learning environment, and the absence of hearing, physical, or emotional problems (Bishop, 1992; Leonard, 1998). In addition to obvious linguistic deficits such as problems with phonology and inflectional morphology, children with SLI have less obvious deficits in tasks that require rapid auditory processing, transient visual processing, attention, and working memory (for a review, see Fitch & Tallal, 2003). For that reason, language problems in SLI are suggested to originate from temporal auditory processing deficits (Tallal & Piercy, 1973, 1974, 1975; Tallal & Stark, 1981), from general slower information processing (Kail, 1994), or from phonological working memory deficits such as more rapid decay or less capacity in the short-term store (Gathercole & Baddely, 1990). These processing restrictions may lead to a lower learning rate or a lack of neural simultaneousness (Fitch and Tallal, 2003; Gathercole & Baddely, 1990), and thus to limitations in the establishment or consolidation of time-dependent associations within and between different brain regions. These deficits, in turn, may disturb the process of successful language learning.

Several studies have investigated precursors of aberrant language development during infancy and early childhood (e.g., Benasich, Thomas, Choudhury, & Leppänen, 2002; Friedrich, Weber, & Friederici, 2004; Guttorm et al., 2005; Leppänen et al., 2002; Leppänen, Pihko, Eklund, & Lyytinen, 1999; Lyytinen et al., 2001; Molfese, Narter, Van Matre, Ellefson, & Modglin, 2001). Through the use of behavioral measures, it was shown that rapid auditory processing skills differ as a function of family history of SLI even in infancy, and that these processing skills are predictive for later language outcome (Benasich et al., 2002). Auditory processing deficits have also been shown to prolong the discrimination response for the long syllable/ba:/from the short syllable/ba/in the ERP of 2-month-old infants with a family history of SLI (Friedrich et al., 2004). Moreover, late enhanced ERP responses for the discrimination of the short syllable/ka/ from the long syllable/ka:/were reported for infants at risk for dyslexia (Leppänen et al., 1999). In a recent study, the ERP on the syllable/ga/measured in newborns with and without familial risk for dyslexia were shown to be associated with the children's later language and verbal memory skills. The enhanced and slower positive to negative shift within the right hemisphere was significantly related to the children's receptive language skills at 2.5 years, and the same response within the left hemisphere was correlated to children's verbal memory at 5 years (Guttorm et al., 2005). The results of these studies suggest that enhanced effort and slower auditory processing caused by weaker memory traces are among influencing factors that, genetically handed down (The SLI Consortium, 2002, 2004), may result in aberrant language development.

Most research on SLI and its precursors has focused on rapid auditory, phonological, morphological, and syntactic aspects of language processing, even though many children with SLI are also impaired in their vocabulary development and their word learning ability or they have persisting word-finding difficulties (Conti-Ramsen & Jones, 1997; Gray, 2003; Leonard, 1998; Rice, Buhr, & Nemeth, 1990; Windfuhr, Faragher, & Conti-Ramsen, 2002). Theoretically, it has been suggested that the size of the lexicon is directly related to further lexical and grammatical development. The possible relation between vocabulary increase and morphosyntactic development was addressed by simulations with an artificial neural network (Plunkett & Marchman, 1993).

With these simulations, it was shown that the vocabulary of the net necessarily had to reach a "critical mass" before it was able to make morphological generalizations. The critical mass hypothesis derived from these simulations states that after the lexicon exceeds a particular size, a qualitative shift can be observed in further lexical and morphosyntactic development. This hypothesis and its implications are supported by behavioral studies that have documented continuities in phonological, lexical, and syntactic development (e.g., Bates, Bretherton & Snyder, 1988; Marchman & Bates, 1994).

According to the critical mass hypothesis, the slower acquisition of language-related skills and even the development of SLI should be associated with weaker early lexical-semantic abilities. Similarly, the assumptions of a lower learning rate or an aberrant kind of neural simultaneousness would also predict slower early lexical-semantic development in SLI children. For that reason, in the present article we focus on the question of how the ERP correlates of very early lexical and semantic mechanisms are related to children's later language development. To this end, the ERP data of children who performed both the picture–word ERP study at the age of 19 months and the German language test SETK-2 (Grimm, 2000) at the age of 30 months were retrospectively grouped according to the children's production performance in the SETK-2. Children with later age-adequate language skills were expected to show the phonological-lexical priming effect on congruous words in their ERP at 19 months and the N400 on both incongruous words and pseudowords. Children with poor language skills later on who are at risk for the development of SLI were expected to have been delayed in their early lexical-semantic development. If these children show neither the phonological-lexical priming effect nor the N400, then we would reason that they were already impaired in their early development of lexical-semantic knowledge. If, like 12-month-olds (Friedrich & Friederici, 2005a), they do not show an N400 in their ERP but have a clear phonological-lexical priming effect, then we would conclude that the N400 maturation and thus the development of a qualitatively new semantic processing stage was impaired in these children.

Methods

Participants

The present study was part of the longitudinal German Language Development Study. Families participated in the study according to institutional signed informed consent procedures. For participation, full-term infants were chosen by pediatricians on the basis of a normal course of pregnancy and normal birth. Only healthy children with monolingual experience with German participated in the study. According to the Bayley Mental Scale (Bayley, 1993) performed at the age of 31 month, 7 children had a mild developmental delay. None of the children was significantly delayed in their mental development. The EEG recordings were taken when the children were 19 months old (± 7 days). The time of day of recordings was not systematicly related to feeding times. Prior to the experimental session, all children passed a screening assessing the integrity of their hearing. In the analyses presented here we included only those children who were looking at the pictures in at least 70% of the trials in the ERP study, met the criteria of 20 artifact-free trials per condition, and performed the language test SETK-2 at the age of 30 months. A total of 40 children entered the final analyses.

Setk-2. The German language development test SETK-2 was designed to measure both receptive and expressive language skills in 24- to 35-month-old children and to identify children with a potential risk for developmental language impairments early. In the receptive subtests, the comprehension of nine words and eight simple sentences are tested. In the expressive subtests, the production of 30 words (e.g., ball, key, cake, bear) and eight sentences (e.g., The bird is flying/The man is cleaning the window) was elicited by presenting the children objects and pictures and asking them standardized questions about these pictures and objects. The test was performed when children were 30 months old and administered by trained doctoral students. Because SLI always includes production deficits, we used the results of the expressive subtests to group the children in the present study.

At-risk group. All children with very low scores in the sentence and/or word production subtests, which were one standard deviation below the age norm, formed the at-risk group. A total of 18 children (11 male, 7 female) entered this group. Three of these children had a family history of SLI. Mean scores of the language test were 19.1 ($SD = 6.2$) for word production and 19.0 ($SD = 6.4$) for sentence production.

Control group. In the control group we included those children who successfully performed both expressive subtests of the SETK-2 and who had no family history of any developmental language disorder. This group involved 22 children (11 male, 11 female). Mean scores were 24.5 ($SD = 2.1$) for word production and 45.9 ($SD = 11.7$) for sentence production.

Possible factors that may cause group differences. The groups significantly differed in their SETK-2 scores at 30 months for both word production, $t(38) = 3.8$, $p < .001$, and sentence production, $t(38) = 8.7$, $p < .0005$. The groups also differed in the number of produced words at 24 months, $t(38) = 3.6$, $p < .001$, which was reported by parents in the questionnaire ELFRA-2 (Grimm & Doil, 2000). The groups, however, did not significantly differ with respect to their comprehension of the presented words, which was assessed by a parental questionnaire at the time of the ERP measure. Demographic variables were assessed by a separate questionnaire. The groups did not differ in any of the following demographic variables: household income, parental education, care persons, care activities, and parents' contentment with personal life circumstances.

Procedure

During the EEG recordings, the children were seated in front of a TFT-LCD screen (distance about 1–1.5 m) in a dimly lit, electrically shielded, and sound-insulated experimental room. At each trial a colored picture of a single object appeared for 4000 ms on the screen. After an interval of 900 ms from picture onset, a German indefinite article with a word length of about 700 ms was acoustically presented to refer to the pictured object in a natural way and to increase the children's attention. After a natural pause of about 300 ms, while the picture was still on the screen, the article was followed by a word or a nonsense word. Words and nonsense words were mixed within one block. The total experimental session lasted about 12 min.It was divided into two blocks with a short break between the blocks. During the whole session, children were continuously observed via a video monitor. Their behavior and their attention to the visual stimuli were rated per minute.

Stimuli

The visual stimulus material used in the present study was especially developed to be suitable for 1-year-old children. That is, pictures were simple, brightly colored illustrations that were clearly identifiable. They were selected in such a way that 1-year-old children already knew most of them. To capture the children's attention, all pictures had a bright background color.

The acoustic stimuli were 44 basic level words and 44 mono- and bisyllabic nonsense words. They were spoken very slowly by a young woman, digitized at a rate of 44,100 Hz, and presented via loudspeaker with an intensity of approximately 65 dBSPL. Words were either correct basic level names of the pictured objects or basic level names of other objects, that is, either congruous or incongruous to the picture meanings. Both incongruous as well as nonsense words always differed in their first phoneme from the congruous words presented with the same pictures. That is, information about the incongruity was already available on the first phoneme. Nonsense words were either pseudowords or nonwords. Pseudowords were prosodically, phonologically, and phonotactically legal in German (e.g., *fless* or *traune*). Nonwords had a word onset that is phonotactically illegal in German (e.g., *rlink* or *sranto*). Information about the phonotactic irregularity of nonwords was available at the second phoneme, on average 174 ms after word onset. The mean word length was 1083 ms for words, 1084 ms for pseudowords, and 1085 ms for nonwords.

Each acoustic stimulus was presented twice. Each word occurred as both a congruous and an incongruous word such that the acoustic stimuli were exactly the same in the word conditions. The picture–word pairs were combined such that there was no obvious semantic relation between an object and its incongruous word or between an object and a word that is phonologically similar to its nonsense word (e.g., a rhyming word). Each picture was presented four times, once with a congruous word, once with an incongruous word, once with a pseudoword, and once with a nonword to ensure that the effect of the visual stimuli was the same in each condition. Thus, each child saw each of the 44 pictures four times, but a specific picture–word combination occurred only once. The order of these combinations was balanced by presenting a fixed randomization in which no systematic repetition effects occurred between conditions.

ERP Recording and Averaging

The EEG was continuously recorded from silver–silver chloride electrodes at sites F7, F3, FZ, F4, F8, FC3, FC4, T3, C3, C4, T4, CP5, CP6, T5, P3, PZ, P4, T6, O1, and O2 as well as left and right mastoids (according to the 10–20 International System of electrode placement) attached to an elastic electrode cap (Easy Cap; Falk Minow). During the recordings the ERP electrodes were referenced to CZ. Electrooculogram (EOG) electrodes were recorded bipolarly. Electrode impedances were mostly below 10 kΩ, at least below 20 kΩ. The EEG was amplified with PORTI-32/MREFA (Twente Medical Systems, with input impedance of $10^{12}\,\Omega$ and analogue first order low-pass filter of 5 kHz), digitized online at a rate of 500 Hz (AD converter with 22 bit, digital filter from DC to 125 Hz), and stored on hard disk. Further analyses were processed off-line.

The EEG was algebraically re-referenced to the average of left and right mastoids (A1, A2). A zero-phase digital band-pass filter ranging from 0.3 to 20 Hz (-3dB cut off frequencies of 0.43 and 19.87 Hz) was applied to increase the signal-to-noise ratio by removing slow drifts and muscle artifacts. All trials were individually checked for artifacts. Blinks and horizontal eye movements were corrected by a PCA-based computer algorithm. All other artifacts were rejected manually. The mean number of accepted trials was 25.3 for congruous words, 25.4 for incongruous words, 25.9 for pseudowords, and 25.0 for nonwords. Standard deviations varied from 5.2 to 5.5. The numbers of accepted trials differed neither between groups nor conditions. Epochs of 1600 ms from word onset were averaged relative to a 200 ms prestimulus baseline.

Data Analyses

To investigate the early phonological-lexical priming effect and the effect of phonotactic familiarity, mean amplitudes were calculated within two time windows: from 150 to 250 ms and from 250 to 400 ms. For the semantic effect occurring later, mean amplitudes within consecutive time windows of 100 ms duration were analyzed from 400 to 1200 ms. This kind of analysis was chosen for two reasons: First, it makes the results comparable to previously published data, and second, this type of analysis estimates temporal aspects, especially the onsets and offsets of the effects for the two groups.

To assess differences between the groups, their different processing of the conditions, and topological aspects of these differences, three-way ANOVAs with word Condition (incongruous vs. congruous words; pseudo- vs. nonwords), Hemisphere (left vs. right), and Region (lateral frontal [F7/8], frontal [F3/4], fronto-central [FC3/4], temporal [T3/4], central [C3/4], centro-parietal [CP5/6], parietal [P3/4], and lateral parietal [T5/6]) as within-subject factors and Group (at-risk vs. control) as the between-subject factor were conducted. For midline sites two-way ANOVAs with word Condition (incongruous vs. congruous words; pseudo- vs. nonwords) and Region (frontal, central, parietal) as within-subject factors and Group (at-risk vs. control) as the between-subject factor were performed. Subsequent to Group main effects or interactions of Group and Hemisphere, t-tests for independent samples were used to separately check group differences for each hemisphere and each condition. To investigate the processing of the different conditions within at-risk and control groups, three-way ANOVAs with word Condition, Hemisphere, and Region as well as two-way ANOVAs with word Condition and Region were carried out for each group separately. Within groups, significant interactions including the factor Condition were further analyzed by one-way ANOVAs for single electrode sites. In all ANOVAs the Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) was applied whenever there was more than one degree of freedom in the numerator. Here, we report uncorrected degrees of freedom, ε values, and adjusted p values. To explore systematic differences between the nonsense word conditions within the at-risk group, correlations between SETK language test scores and mean amplitudes of the difference waves were performed.

Results

Incongruous Words versus Congruous Words

Group differences between at-risk and control group. The ERPs for both groups to congruous and incongruous words are shown in Figure 1. For the word stimuli, group main effects were present from 700 to 1000 ms, $F(1,38) = 4.4$–6.3, $p < .05$. In addition, an interaction between Group and Hemisphere occurred from 400 to 900 ms, and from 1000 to 1100 ms (Table 1).

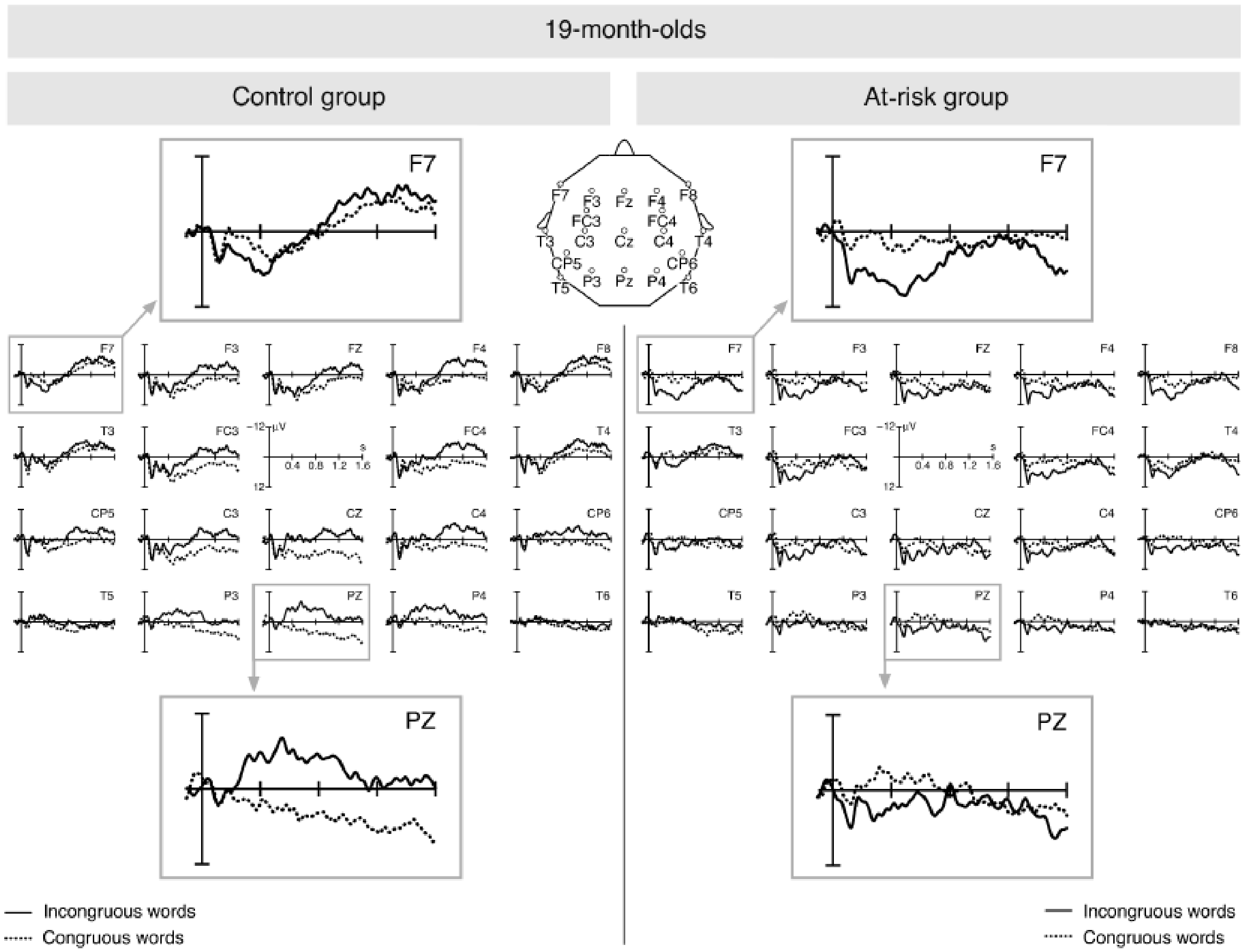

Figure 1. ERPs for congruous and incongruous words for the 19-month-old control and at-risk groups. Solid lines represent incongruous words and dotted lines congruous words. Negativity is plotted up.

Subsequent analyses indicated that in the right hemisphere incongruous words elicited more negative responses in the control group than in the at-risk group from 400 to 1200 ms, $t(38) = -4.0$ to -2.9, $p < .05$. In the left hemisphere, the response to congruous words was more positive from 500 to 700 ms, $t(38) = 2.2$–2.3, $p < .05$, and more negative from 900 to 1000 ms, $t(38) = -2.4$, $p < .05$, for the control group as compared to the at-risk group. Interactions including Group and Condition were observed during all time windows from 250 to 1200 ms (Table 1).

Condition effects for the control group. Children in the control group displayed the earliest differences between their responses on congruous and incongruous words in the lateral frontal brain

Table 1. *Group Effects for the Comparison of Congruous versus Incongruous Words*

Time window (ms)	Hemi × Group, $F(1,38)$	Cond × Group, $F(1,38)$	Cond × Reg × Group, $F(7,266)$ (ε)	Midline sites: Cond × Group, $F(1,38)$	Midline sites: Cond × Reg × Group, $F(2,76)$ (ε)
250–400		8.7***	2.8** (.60)	17.5***	5.2*** (.96)
400–500	8.2***	13.3***	2.7** (.55)	13.6***	
500–600	8.9***	11.5***	2.1* (.59)	15.4***	5.4*** (.85)
600–700	8.0***	11.9***	2.9* (.52)	11.2***	2.5* (.95)
700–800	6.9**	4.4**		6.7**	2.8* (.86)
800–900	7.8**	6.4**	2.3* (.49)	9.2***	
900–1000		7.8***	2.6** (.50)	13.0***	
1000–1100	8.2***	3.1*		4.4**	
1100–1200		4.6***		5.4**	

*$p < .1$, **$p < .05$, ***$p < .01$.

Table 2. *Condition Effects for the Control Group for the Comparison of Congruous versus Incongruous Words*

Time window (ms)	Condition, $F(1,21)$	Cond × Region, $F(7,147)$ (ε)	Midline sites: Condition, $F(1,21)$	Midline sites: Cond × Region, $F(2,42)$ (ε)
150–250		3.4*[a]		
250–400		5.2*** (.57)	6.2**	7.9*** (.98)
400–500	3.8*	2.8** (.44)	13.9***	4.6** (.79)
500–600	4.5**	2.5* (.46)	18.2***	13.2*** (.95)
600–700	5.4**		10.0***	6.8*** (.99)
700–800	6.2**	2.2* (.44)	11.7***	7.5*** (.87)
800–900	15.0***	3.5** (.39)	17.3***	
900–1000	18.2***	3.4** (.38)	17.7***	
1000–1100	13.1***	3.4** (.48)	12.4***	
1100–1200	20.0***	3.1** (.44)	13.2***	

Nonshaded cells: N400 semantic effect: incongruous words more negative than congruous words; shaded cells: lexical priming effect: congruous words more negative than incongruous words.
[a]Condition × Hemisphere instead of Condition × Region.
*$p<.1$, **$p<.05$, ***$p<.01$.

region (Figure 1). These differences were indicated by a significant interaction between Condition and Region from 250 to 400 ms as well as a marginal interaction between Condition and Region from 150 to 250 ms (Table 2). Within both time windows, congruous words elicited more negative responses than incongruous words over the left lateral frontal brain region, although this difference did not reach significance at the .05 level ($p<.08/.07$). From about 250 ms, incongruous words were processed more negatively than congruous words, particularly over centro-parietal midline sites. This difference was indicated by Condition effects and/or interactions between Condition and Region during all time windows from 250 to 1200 ms (Table 2). The effect started in the centro-central, parieto-central, and right parietal brain regions ($p<.05$). During the following time windows it spread out to all other brain regions except the lateral frontal, lateral parietal, and temporal regions.

To summarize, 19-month-old children in the control group displayed both a more negative response to congruous words from 150 to 400 ms, which was restricted to the left lateral frontal region, and a broadly distributed more negative response to incongruous words from 250 to 1200 ms, which had a maximum over centro-parietal midline sites.

Condition effects for the at-risk group. Children of the at-risk group also displayed differences between their responses to congruous and incongruous words that started early (Figure 1). They were indicated by Condition main effects as well as interactions between Condition and Region from 150 to 700 ms (Table 3). Within all of these time windows congruous words elicited more negative responses than incongruous words. The effect started at 150 to 250 ms in left and right lateral frontal as well as in right fronto-central and right temporal brain regions. From 250 to 400 ms it included virtually all brain regions. During the following time windows, lateral frontal and fronto-central regions were mainly involved in this effect.

Thus, 19-month-old children of the at-risk group displayed a more negative response to congruous words only. This broadly distributed effect started at about 150 ms and lasted until 700 ms.

Table 3. *Condition Effects for the At-Risk Group for the Comparison of Congruous versus Incongruous Words*

Time window (ms)	Condition, $F(1,17)$	Cond × Region, $F(7,119)$ (ε)	Midline sites: Condition, $F(1,17)$
150–250	3.8*	5.2*** (.44)	3.2*
250–400	14.1***	3.1** (.39)	11.2***
400–500	9.8***	2.8** (.58)	3.6*
500–600	8.7***	2.2* (.56)	
600–700	7.1**	2.7** (.57)	

Shaded cells: lexical priming effect; nonshaded cells: congruous words more negative than incongruous words.
*$p<.1$, **$p<.05$, ***$p<.01$.

Legal Pseudowords versus Phonotactically Illegal Nonwords

Group differences between at-risk and control groups. The ERPs for both groups on legal pseudo- and phonotactically illegal nonwords are shown in Figure 2. For these nonsense words, group main effects occurred from 900 to 1000 ms, $F(1,38)=5.3$, $p<.05$. Interactions between Group and Hemisphere were present from 400 to 900 ms, and from 1100 to 1200 ms (Table 4). Analyses of single hemispheres indicated that in the right hemisphere pseudowords elicited more negative responses in the control group as compared to the at-risk group from 600 to 1200 ms, $t(38)=-3.4$ to -2.7, $p<.05$. Moreover, interactions including Group and Condition were observed from 600 to 1000 ms (Table 4).

Condition effects for the control group. Children in the control group displayed clear differences between phonotactically legal pseudowords and phonotactically illegal nonwords (Figure 2). Condition main effects and/or interactions of Condition with Region occurred from 250 to 500 ms as well as from 600 to 1100 ms (Table 5). Although both effects are relatively broadly distributed, they could be divided into two separate effects according to their temporal occurrence. From 250 to 500 ms left and right lateral frontal, centro-frontal, fronto-central, centro-central, parieto-central, right temporal, and left frontal brain regions were involved ($p<.05$). Between 600 and 800 ms, interactions of Condition with Region were not present, which suggests a broad spatial distribution of the effect. From 800 to 900 ms, all except lateral parietal regions, and from 900 to 1000 ms, all except lateral parietal, lateral frontal, and centro-frontal regions were involved in the effect.

To summarize, 19-month-old children of the control group displayed a negativity in response to legal pseudowords when compared to phonotactically illegal nonwords that started early and was strongly present over lateral frontal and temporal

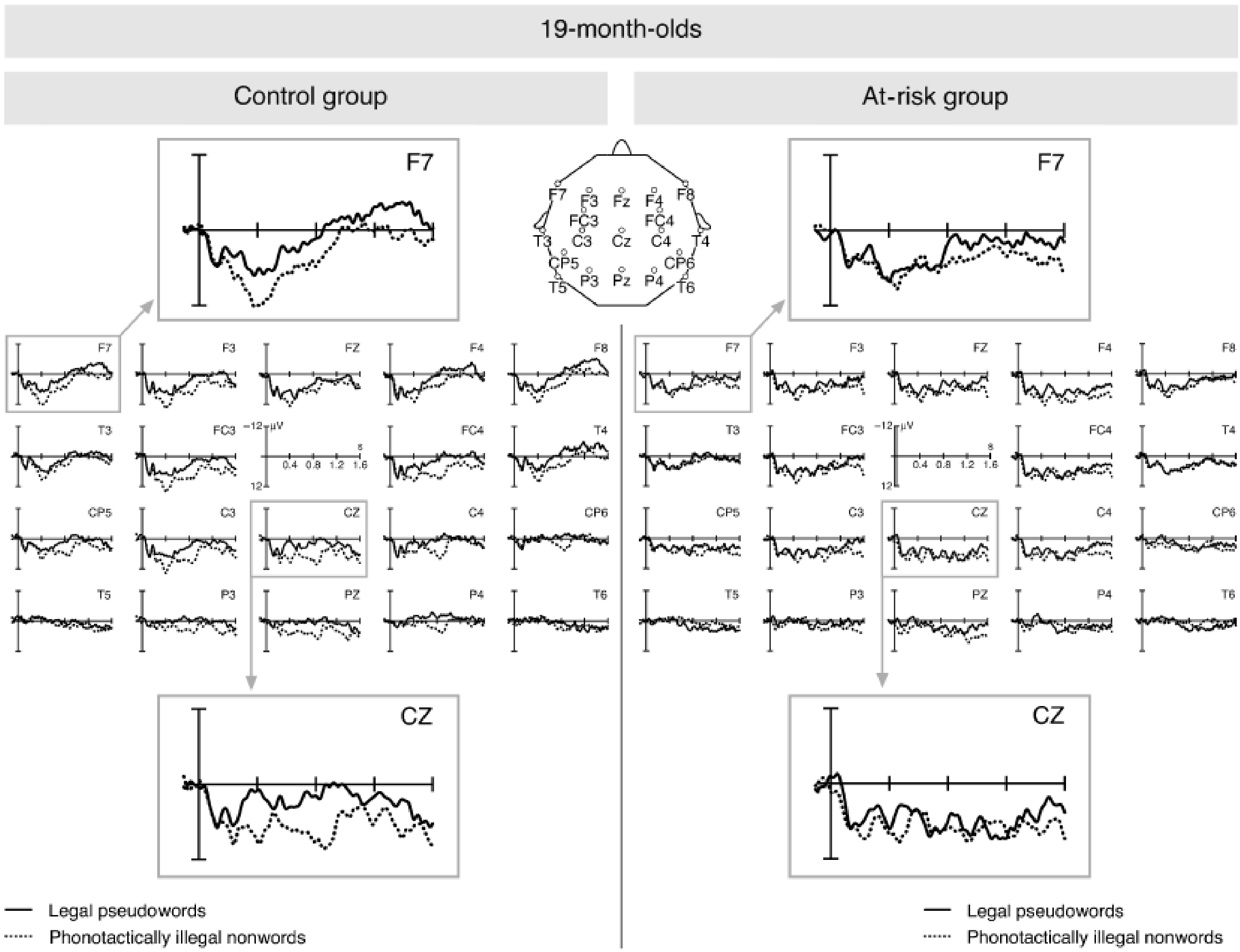

Figure 2. ERPs for legal pseudowords and phonotactically illegal nonwords for the 19-month-old control and at-risk groups. Solid lines represent legal pseudowords and dotted lines phonotactically illegal nonwords. Negativity is plotted up.

regions. A second negativity followed that was distributed over centro-parietal midline sites and was more long-lasting than the first negativity.

Condition effects for the at-risk group. In the at-risk group, no significant differences between the ERP responses to the nonsense word conditions were observed (Figure 2). However, significant negative correlations between SETK-2 scores and mean amplitudes of the difference between pseudo- and nonwords were present at frontal and temporal sites from 250 to 500 ms, at left parietal sites from 500 to 700 ms, and at parieto-central and right parietal sites from 900 to 1100 (Table 6). These correlations indicate that the better the children performed in the language test, the stronger the negative difference between pseudo- and nonwords in the ERP was.

Thus, the at-risk group as a whole did not show any significant difference between the processing of legal pseudowords and phonotactically illegal nonwords. Within the at-risk group,

Table 4. *Group Effects for the Comparison of Legal Pseudowords versus Phonotactically Illegal Nonwords*

Time window (ms)	Hemi × Group, $F(1,38)$	Cond × Group, $F(1,38)$	Midline sites: Cond × Group, $F(1,38)$	Midline sites: Cond × Reg × Group, $F(2,76)$ (ε)
400–500	18.2***			
500–600	6.2**			
600–700	14.2***	6.5**	4.7**	
700–800	7.7***	10.6***	4.1**	
800–900	9.0***	5.2**		2.7* (.86)
900–1000				3.3** (.96)
1100–1200	4.3**			

*$p<.1$, **$p<.05$, ***$p<.01$.

Table 5. *Condition Effects for the Control Group for the Comparison of Legal Pseudowords versus Phonotactically Illegal Nonwords*

Time window (ms)	Condition, $F(1,21)$	Cond × Region, $F(7,147)$ (ε)	Midline sites: Condition, $F(1,21)$	Midline sites: Cond × Region, $F(2,42)$ (ε)
250–400	11.2***	2.8* (.32)	9.4**	
400–500	11.7***	2.6* (.40)	7.8**	
600–700	9.7***		8.4***	
700–800	18.4***		19.9***	
800–900	24.6***	3.1** (.46)	25.9***	2.9* (.90)
900–1000	18.1***	2.4* (.46)	12.2***	3.1* (.96)
1000–1100	5.3**			

Shaded cells: phonotactic familiarity effect; nonshaded cells: N400 semantic effect.
*$p < .1$, **$p < .05$, ***$p < .01$.

however, more negative responses on pseudo- as compared to nonwords were present for those children who had better scores in the later language test.

Discussion

The present study investigated whether children's expressive language skills at the age of 30 months are associated with their lexical-semantic development at the age of 19 months. In particular, we tested whether the phonological-lexical priming abilities indexed by a lateral frontal negativity to congruous words or the maturation of semantic integration mechanisms indexed by the N400 to incongruous and legal pseudowords or even both developmental states are impaired early in children with poor later language outcome. To this end, the ERP data of 19-month-old children obtained in a cross-modal picture–word paradigm were retrospectively grouped according to the children's expressive language skills in the language test SETK-2 performed at the age of 30 months. As a result, specific differences could be observed between children with later age-adequate language skills and children with poor expressive language skills later on who have an enhanced risk for the development of SLI. In the following, we discuss these effects separately.

The Phonological-Lexical Priming Effect

Although both groups displayed the phonological-lexical priming effect, that is, an early enhanced negativity for congruous words as compared to incongruous words, this effect differed in its spatio-temporal characteristics between the groups. In children with age-adequate expressive language skills at 30 months, the phonological-lexical priming effect registered at 19 months was spatially restricted to the left lateral frontal region and temporally limited to 150 to 400 ms after word onset. In the at-risk children, the phonological-lexical priming effect was more broadly distributed and temporally more extended. This finding for the at-risk group has crucial implications. First, the presence of any phonological-lexical priming effect indicates that these children already have an implicit vocabulary of the stimuli presented. It seems that their acoustic-phonological processing of the target word benefited from the contextual information given by the picture, and this facilitation was effective at the same time after word onset as in the control group. Note, that this result does not contradict the slower speed of auditory processing observed in SLI children (e.g., Tallal & Piercy, 1973, 1974, 1975; Tallal & Stark, 1981), because semantic assignment, lexical choice, and preactivation of the expected phonological forms triggered by the picture context had most likely already occurred before the word was presented. That means that children had enough time to prepare phonological processing and generate a phonological expectation. This expectation, then, facilitated the processing of incoming congruous words immediately after word onset.

Second, the strong phonological-lexical priming effect that was extended in its duration in the at-risk group as compared to the control group indeed points to a delayed processing mechanism in some respects in children at risk for SLI as compared to children of the control group. In particular, the facilitation effect for primed congruous words was prolonged in this group, indicating that children at risk for SLI rely longer and more extensively on the picture context than children with later age-adequate language skills. This, in turn, suggests that without facilitating context children at risk for SLI may need more effort to process words adequately.

An alternative explanation might view the longer duration of the phonological-lexical priming effect and its broader distribution to be caused by the missing overlap with the centro-parietal distributed N400 starting at about 250 ms in control children. This is unlikely, as a younger group of 12-month-old children without family history of SLI showed, despite a missing N400, a phonological-lexical priming effect that was about 200 ms shorter in its duration and spatially more restricted (Friedrich & Friederici, 2005a) than that of 19-month-olds in the at-risk group in the present study, Thus, differences in the phonological-lexical priming effect seem to be at least partly independent of the presence of an N400. The observed group differences in the spatial distribution of this effect, then, support findings according to

Table 6. *Correlations between SETK-2 Language Scores and the Difference Wave between Legal Pseudo- and Illegal Nonwords for the At-Risk Group*

	Word production		Sentence production	
Time window (ms)	*r*	*p*	*r*	*p*
250–400	T7: – .54	.021	F3: – .49	.038
	T8: – .64	.004	FZ: – .48	.046
400–500	T8: – .52	.025	T7: – .48	.042
500–600			P3: – .50	.035
600–700			P3: – .51	.031
900–1000	PZ: – .51	.029		
1000–1100	PZ: – .51	.029		
	P8: – .48	.046		

which increasing language skills in 1-year-olds are associated with increasing cerebral specializations of language processing brain systems (Mills et al., 1993).

The Phonotactic Familiarity Effect

Normally developing children displayed early ERP differences between legal pseudowords and phonotactically illegal nonwords, which indicates that the processing of phonotactically illegal nonwords requires more effort than the processing of legal pseudowords. This difference in processing may reflect the fact that phonotactically illegal phoneme clusters have not been previously processed and thus have not left any memory representations, whereas the phonotactically legal phoneme clusters have already been perceived in previous word contexts and thus should have existing memory representations. Children with later risk for SLI, however, did not show clear differences in their processing of legal and illegal nonsense words. This still seems to be the case, although the missing significant interaction between group and condition from 250 to 400 ms and small visually observable differences in the risk group ERP average point to relatively high individual variation within this group, which may have masked the observable relation between later language skills and early ERP effects. Significant correlations between language scores and the difference between pseudo- and nonwords, indeed, suggest the development of processing differences between legal and illegal nonsense words in those children who have relatively better later language skills. Whether the absence of the phonotactic familiarity effect in the group as a whole is caused by weaker memory representations for legal phoneme clusters in these children or by their inability to provide additional resources for the adequate processing of illegal phoneme clusters cannot be determined from the present data, and might be a topic for further research.

The N400 Semantic Effect

Children with later age-adequate language skills displayed a long-lasting, N400-like negativity to both incongruous words and legal pseudowords at the age of 19 months. Over centro-parietal brain regions, differences between incongruous and congruous words were already present from 250 to 400 ms. This resembles the adult N400 time course in the present paradigm (Friedrich & Friederici, 2005a) as well as in many other auditory semantic priming studies (e.g., Holcomb & Neville, 1990; Holcomb et al., 1992; for a review, see Kutas & Federmeier, 2000). The difference between legal pseudowords and illegal nonwords started at about the same time after stimulus onset, but it appears to have a more anterior distribution than the difference between incongruous and congruous words. This is mainly caused by the overlapping phonotactic familiarity effect. When comparing pseudowords to congruous words, however, the distribution of the difference wave is very similar to that of the word stimuli (Figure 3).

In contrast to the ERP pattern of normally developing children, the at-risk group did not show an N400 at the age of 19 months, either to incongruous words or to pseudowords. This finding suggests that the N400 develops earlier in children with later age-adequate language skills than in children with risk for SLI according to their expressive language development. The presence of the phonological-lexical priming effect in the at-risk group suggests that at the time of the ERP measures children at risk for SLI already possessed lexical knowledge of the stimuli presented. As this priming effect is triggered by a picture and can only be mediated by the activation of the adequate concept and the corresponding lexical element in the mental lexicon, the absence of the N400 cannot be caused by a lack of comprehension due to nonexisting vocabulary or missing semantic knowledge. Thus, it appears that N400 mechanisms are not yet matured in these children. Interestingly, the 19-month-olds in the at-risk group display a similar pattern to 12-month-olds without family history of SLI who also showed early phonological-lexical priming without semantic priming in the N400 range (Friedrich & Friederici, 2005a). This finding and the fact that 14-month-olds already show an N400 on incongruous words (Friedrich & Friederici, 2005b) strongly suggest the early presence of a developmental delay in children at risk for SLI as measured by their expressive language development at the age of 30 months. About 1 year earlier, they are already delayed in the maturation of semantic integration mechanisms indexed by the N400.

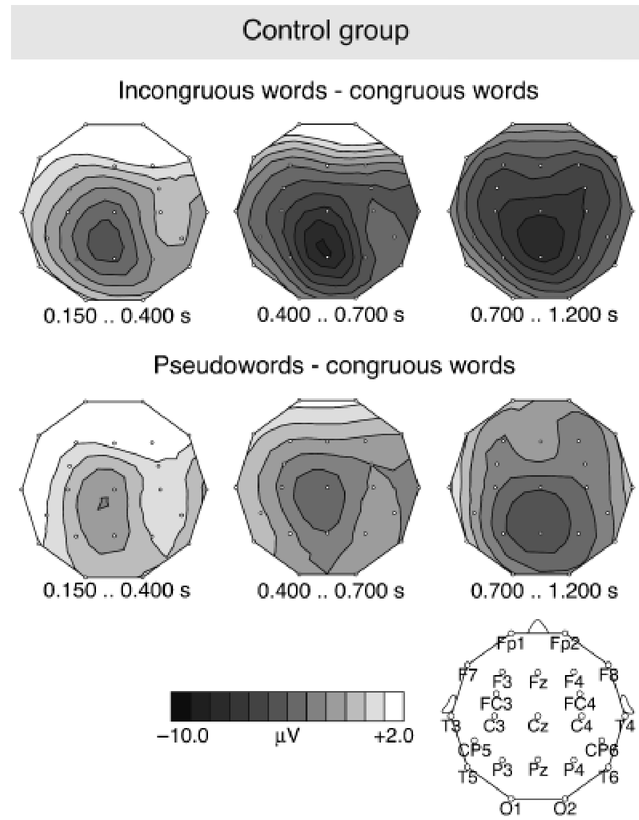

Figure 3. Spatial distribution of the difference between incongruous and congruous words and between pseudowords and congruous words for the control group.

There is, however, a somewhat different interpretation for the missing N400 in younger children and in children who are impaired in their later language development. It might be the case that, in principle, the N400 mechanisms are already available in less matured children, but that the mechanisms cannot operate on the present knowledge base in these children. Simulations with artificial neural networks motivate this assumption. Using the unsupervised neural system ART 1 (Carpenter & Grossberg, 1987) and the self-supervising architecture ARTMAP that consists of two connected ART 1 modules (Carpenter, Grossberg, & Reynolds, 1991), it can be shown that the initiation of a memory search for more adequate semantic representations and the establishing of new concepts within semantic memory depend on the present state of specific representations available within a conceptual domain (Friedrich, 1997a, 1997b). For example, new words can only guide the formation of new concepts if existing concepts accessed first are sufficiently stable such that a clear semantic "mismatch" occurs. If the memory for these concepts is only weak, that is, the representations are sparsely differentiated or have weak memory traces due to slower learning or shorter experience, then activated concepts might slightly be modified, but mechanisms for overcoming the first access and searching for more adapted concepts within memory are not initiated.

Although it is not the purpose of the present article to associate specific mechanisms of artificial neural architectures with specific mechanism within the brain, there might be a parallel to the mechanisms underlying N400 elicitation. Similar to the artificial mechanisms described, it could be the case that the N400 mechanisms require sufficiently stable memory representations to be initiated. Thus, the specific knowledge base within a conceptual domain might be responsible for the occurrence of the N400 mechanisms. That is, the N400 mechanisms may be present earlier, but in less matured children they cannot be applied due to the children's weaker semantic memory representations. In this case, the absence or presence of an N400 would index the quality and stability of existing conceptual knowledge in children. This would imply that 19-month-old children at risk for SLI are impaired in their development of semantic memory representations of concepts acquired early. These weaker memory representations might result from a lower learning rate or an aberrant kind of neural simultaneousness (Fitch and Tallal, 2003; Gathercole & Baddely, 1990), which in turn may be caused by temporal processing deficits present in children with SLI (Benasich et al., 2002; Kail, 1994; Tallal & Piercy, 1973, 1974, 1975; Tallal & Stark, 1981).

The observed relation between N400 development and children's later production abilities moreover suggests a relation between the N400 mechanisms in comprehension and the vocabulary spurt in production. Even before the vocabulary spurt, any semantic stimulus is comprehended according to some conceptual knowledge present in the child. However, this comprehension may often be inadequate because memory representations are underspecified and appropriate representations are not yet established. Only a mechanism that overrides the use of inadequate memory representations enables the establishment of new concepts and, thus, the fast learning of new words with new meanings instead of slowly modifying existing concepts. In this way, the N400 integration mechanism might even be causally associated with the rapid increase in vocabulary observed during the vocabulary spurt.

Conclusion

The results from the present study allow two main conclusions, one concerning the particular aspects of impaired language development and one concerning the relation of word production and word comprehension in general. With respect to the first issue, we show that children who are delayed in their language development by the age of 30 months have deficits in their semantic development already about 1 year earlier. Whether these deficits involve the maturation of a qualitatively new semantic integration mechanism or the presence of insufficient semantic memory representations that disallow the integration process still needs to be determined by future investigations. In either case, the present findings indicate that deficits in expressive language development observed in 2-and-a-half-year-olds have precursors in the children's specific ERP pattern obtained about 1 year earlier. Once the general problem of single subject ERP analyses has been solved, these precursors can be used as diagnostic measures to identify children with a potential risk for SLI early during development.

The presence of the N400 in children with normal expressive language development and its absence in children with poor expressive language development suggest a direct relation between specific word comprehension mechanisms and children's production abilities. This relation may also serve as a basis for understanding the vocabulary spurt. However, whether the developmental stage indicated by the emergence of an N400 represents a necessary precondition for the onset of the vocabulary spurt is still an open topic for future research.

REFERENCES

Bates, E., Bretherton, I., & Snyder, I. (1988). *From first words to grammar: Individual and dissociable mechanisms*. Cambridge: Cambridge University Press.

Bates, E., Thal, D., & Janowsky, J. S. (1992). Early language development and its neural correlates. In I. Rapin & S. Segalowitz (Eds.), *Handbook of neuropsychology, child neurology* (Vol. 6, pp. 69–110). Amsterdam: Elsevier.

Bayley, N. (1993). *Bayley scales for infant development. Manual*. New York: The Psychological Corporation.

Benasich, A. A., Thomas, J. J., Choudhury, N., & Leppänen, P. H. T. (2002). The importance of rapid auditory processing abilities to early language development: Evidence from converging methodologies. *Developmental Psychobiology*, *40*, 278–292.

Benedict, H. (1979). Early lexical development: Comprehension and production. *Journal of Child Language*, *6*, 183–200.

Bentin, S. (1987). Event-related potentials, semantic processes, and expectancy factors in word recognition. *Brain and Language*, *31*, 308–327.

Bentin, S., McCarthy, G., & Wood, C. C. (1985). Event-related potentials, lexical decision and semantic priming. *Electroencephalography and Clinical Neurophysiology*, *60*, 343–355.

Bentin, S., Mouchetant-Rostaing, Y., Giard, M. H., Echallier, J. F., & Pernier, J. (1999). ERP manifestion of processing printed words at different psycholinguistic levels: Time course and scalp distribution. *Journal of Cognitive Neuroscience*, *11*, 235–260.

Bishop, D. V. M. (1992). The underlying nature of specific language impairment. *Journal of child Psychology and Psychiatry*, *33*, 3–66.

Carpenter, G. A., & Grossberg, S. (1987). A massively parallel architecture for a self-organizing neural pattern recognition machine. *Computer Vision, Graphics, and Image Processing*, *37*, 54–115.

Carpenter, G. A., Grossberg, S., & Reynolds, J. H. (1991). ARTMAP: Supervised real-time learning and classification of nonstationary data by a self-organizing neural network. *Neural Networks*, *4*, 565–588.

Coch, D., Maron, L., Wolf, M., & Holcomb, P. J. (2002). Word and picture processing in children: An event-related potential study. *Developmental Neuropsychology*, *22*, 373–406.

Conti-Ramsen, G., & Jones, M. (1997). Verb use in specific language impairment. *Journal of Speech, Language, and Hearing Research*, *40*, 1298–1313.

Fitch, R. H., & Tallal, P. (2003). Neural mechanisms of language-based learning impairments: Insights from human populations and animal models. *Behavioral and Cognitive Neuroscience Reviews*, *2*, 155–178.

Friederici, A. D., & Hahne, A. (2001). Developmental patterns of brain activity for semantic and syntactic processes. In B. Höhle & J. Weissenborn (Eds.), *Approaches to bootstrapping in early language development* (pp. 231–246). Amsterdam/Philadelphia: John Benjamins.

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, *1*, 183–192.

Friedrich, M. (1997a). Der Erwerb hierarchisch ordenbarer Kategorien in einem neuronalen Netz der Adaptiven Resonanztheorie. *ZASPIL*, *8*, 57–80.

Friedrich, M. (1997b). Die Entstehung und Überwindung von Übergeneralisierungen im neuronalen Netz ARTMAP. *ZASPIL*, *8*, 81–100.

Friedrich, M., & Friederici, A. D. (2004). N400-like semantic incongruity effect in 19-month-olds: Processing known words in picture contexts. *Journal of Cognitive Neuroscience*, *16*, 1465–1477.

Friedrich, M., & Friederici, A. D. (2005a). Phonotactic knowledge and lexical-semantic processing in one-year-olds: Brain responses to words and nonsense words in picture contexts. *Journal of Cognitive Neuroscience*, *17*, 1785–1802.

Friedrich, M., & Friederici, A. D. (2005b). Lexical priming and semantic integration reflected in the ERP of 14-month-olds. *NeuroReport*, *16*, 653–656.

Friedrich, M., Weber, C., & Friederici, A. D. (2004). Electrophysiological evidence for delayed mismatch response in infants at risk for specific language impairment. *Psychophysiology*, *41*, 772–782.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language*, *29*, 336–360.

Goldfield, B. A., & Reznick, J. S. (1990). Early lexical acquisition: Rate, content and vocabulary spurt. *Journal of Child Language*, *17*, 171–184.

Gray, S. (2003). Word learning by preschoolers with specific language impairment: What predicts success? *Journal of Speech, Language, and Hearing Research*, *46*, 56–67.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, *24*, 95–112.

Grimm, H. (2000). *SETK-2: Sprachentwicklungstest für zweijährige Kinder (2.0–2.11). Diagnose rezeptiver und produktiver Sprachverarbeitungsfähi gkeiten*. Göttingen: Hogrefe.

Grimm, H., & Doil, H. (2000). *ELFRA: Elternfragebögen für die Früherkennung von Risikokindern (ELFRA-1, ELFRA-2)*. Göttingen: Hogrefe.

Guttorm, T., Leppänen, P. H. T., Poikkeus, A.-M., Eklund, K. M., Lyytinen, P., & Lyytinen, H. (2005). Brain event-related potentials (ERPs) measured at birth predict later language development in children with and without familial risk for dyslexia. *Cortex*, *41*, 291–303.

Hahne, A., Eckstein, K., & Friederici, A. D. (2004). Brain signatures of syntactic and semantic processes during development. *Journal of Cognitive Neuroscience*, *16*, 1302–1318.

Holcomb, P. J. (1993). Semantic priming and stimulus degradation: Implications for the role of the N400 in language processing. *Psychophysiology*, *30*, 47–61.

Holcomb, P. J., Coffey, S. A., & Neville, H. J. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology*, *8*, 203–241.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes*, *5*, 281–312.

Kail, R. (1994). A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech and Hearing Research*, *37*, 418–421.

Kooijman, V., Hagoort, P., & Cutler, A. (2005). Electrophysiological evidence for prelinguistic infants' word recognition in continuous speech. *Cognitive Brain Research*, *24*, 109–116.

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, *4*, 463–470.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*, 203–205.

Leonard, L. B. (1998). *Children with specific language impairment*. Cambridge, MA: MIT Press.

Leppänen, P. H. T., Pihko, E., Eklund, M., & Lyytinen, H. (1999). Cortical responses of infants with and without a genetic risk for dyslexia: II. Group effects. *NeuroReport*, *10*, 969–973.

Leppänen, P. H. T., Richardson, U., Pikho, E., Eklund, K. M., Guttorm, T. K., Aro, M., et al. (2002). Brain responses to changes in speech sound durations differ between infants with and without familial risk for dyslexia. *Developmental Neuropsychology*, *22*, 407–422.

Lyytinen, H., Ahonen, T., Eklund, K., Guttorm, T. K., Laasko, M.-L., Leinonen, S., et al. (2001). Developmental pathways of children with and without familial risk for dyslexia during the first years of life. *Developmental Neuropsychology*, *20*, 539–558.

Marchman, V., & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. *Journal of Child Language*, *21*, 331–366.

Mervis, C. B., & Bertrand, J. (1995). Early lexical acquisition and the vocabulary spurt: A response to Goldfield and Reznick. *Journal of Child Language*, *22*, 461–468.

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1993). Language acquisition and cerebral specialization in 20-month-old infants. *Journal of Cognitive Neuroscience*, *5*, 317–334.

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1994). Variability in cerebral organization during primary language acquisition. In G. Dawson & K. Fischer (Eds.), *Human behavior and the developing brain* (pp. 427–455). New York: The Guilford Press.

Mills, D. L., Prat, C., Zangl, R., Stager, C. L., Neville, H. J., & Werker, J. F. (2004). Language experience and the organization of brain activity to phonetically similar words: ERP evidence from 14-and 20-month-olds. *Journal of Cognitive Neuroscience*, *16*, 1452–1464.

Molfese, D. L., Narter, D. B., Van Matre, A. J., Ellefson, M. R., & Modglin, A. (2001). Language development during infancy and early childhood: Electrophysiological correlates. In J. Weissenborn & B. Höhle (Eds.), *Approaches to bootstrapping in early language development* (pp. 181–229). Amsterdam/Philadelphia: John Benjamins.

Nobre, A. C., & McCarthy, G. (1994). Language related ERPs: Scalp distributions and modulation by word-type and semantic priming. *Journal of Cognitive Neuroscience*, *6*, 233–255.

Plunkett, K., & Marchman, V. (1993). From rote learning to system building: Acquisition of morphology in children and connectionist nets. *Cognition*, *48*, 21–69.

Rescorla, L. (2002). Language and reading outcomes to age 9 in late-talking toddlers. *Journal of Speech, Language, and Hearing Research*, *45*, 360–371.

Rescorla, L., Dahlsgaard, K., & Roberts, J. (2000). Late-talking toddlers: MLU and IPSyn outcomes at 3;0 and 4;0. *Journal of Child Language*, *27*, 643–664.

Reznick, J. S., & Goldfield, V. A. (1992). Rapid change in lexical development in comprehension and production. *Developmental Psychology*, *28*, 406–413.

Rice, M., Buhr, J. C., & Nemeth, M. (1990). Fast mapping word-learning abilities of language-delayed preschoolers. *Journal of Speech, Language, and Hearing Research*, *55*, 33–42.

Rugg, M. D., & Nagy, M. E. (1987). Lexical contribution to nonword-repetition effects: Evidence from event-related potentials. *Memory and Cognition*, *15*, 473–481.

Schafer, G., & Plunkett, K. (1998). Rapid word learning by fifteen-month-olds under tightly controlled conditions. *Child Development*, *69*, 309–320.

SLI Consortium (2002). A genomewide scan identifies two novel loci involved in specific language impairment. *American Journal of Human Genetics*, *70*, 384–398.

SLI Consortium (2004). Highly significant linkage to the SLI1 locus in an expanded sample of individuals affected by specific language impairment. *American Journal of Human Genetics*, *74*, 1225–1238.

Tallal, P., & Piercy, M. (1973). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature*, *241*, 4468–4469.

Tallal, P., & Piercy, M. (1974). Developmental aphasia: Rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia*, *12*, 83–93.

Tallal, P., & Piercy, M. (1975). Developmental aphasia: The perception of brief vowels and extended stop consonants. *Neuropsychologia*, *13*, 69–74.

Tallal, P., & Stark, R. E. (1981). Speech acoustic cue discrimination abilities of normally developing and language impaired children. *Journal of the Acoustical Society of America*, *69*, 568–574.

Thierry, G., Vihman, M., & Roberts, M. (2003). Familiar words capture the attention of 11-month-olds in less than 250 ms. *NeuroReport*, *14*, 2307–2310.

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word-object associations by 14-month-old infants. *Developmental Psychology*, *34*, 1289–1309.

Werker, J. F., & Yeung, H. H. (2005). Infant speech perception bootstraps word learning. *Trends in Cognitive Sciences*, *9*, 519–527.

West, W. C., & Holcomb, P. J. (2002). Event-related potentials during discourse-level semantic integration of complex pictures. *Cognitive Brain Research*, *13*, 363–375.

Windfuhr, K. L., Faragher, B., & Conti-Ramsen, G. 2002. Lexical learning skills in young children with specific language impairment (SLI). *International Journal of Language & Communication Disorders*, *37*, 415–432.

Woodward, A. L., Markman, E., & Fitzsimmons, C. M. (1994). Rapid word learning in 13- and 18-month-olds. *Developmental Psychology*, *30*, 553–566.

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