Lexical–semantic processes in children with specific language impairment

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The current study used event-related brain potentials to investigate lexical–semantic processing of words in sentences spoken by children with specific language impairment and children with normal language development. Children heard correct sentences and sentences with a violation of the selectional restriction of the verb. Control children showed an N400 effect followed by a late positivity for the incorrect sentences. In contrast, children with specific language impairment showed no N400 effect but did show a late, broadly distributed positivity. This absence of the N400 effect is due to a relatively large negativity for correct sentences, suggesting weaker lexical–semantic representations of the verbs and their selectional restrictions in children with specific language impairment. *NeuroReport* 17:1511–1514 © 2006 Lippincott Williams & Wilkins.

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Introduction

Specific language impairment is a developmental disorder which selectively affects the domain of language processing. Children with specific language impairment are worse than usual for their age on language tasks involving processing of phonological, syntactic and/or semantic information [1]. At the same time, these children have normal nonverbal intelligence and no further neurological, physical or emotional abnormalities [2]. The etiology of specific language impairment is poorly understood. There is, however, recent evidence that capacity for language development may be genetically encoded [3,4].

The use of event-related potentials (ERPs) has been very informative in determining the temporal characteristics of language processing. One ERP component in particular, the N400 (centro-parietal negativity between 0.3 and 0.5 s post stimulus onset), is observed regularly in adults, children and even infants [5–7] in response to words which are semantically incongruous with their preceding context; context being established at either the single word, sentence or discourse level. It is assumed that the N400 reflects lexical access and semantic integration processes. Several factors, such as word frequency, degree of contextual semantic fit and word position, can influence the amplitude of the N400 (for an overview see [8]).

Working memory and long-term semantic memory have been shown to have an impact on the processes reflected in the N400, especially with regard to sentence comprehension. The establishment of sentential context, necessary for eliciting an N400 effect, depends on functional working memory. Several studies have shown that language-impaired children perform worse than unimpaired children on verbal short-term working memory tasks (e.g. digit span test), in particular those that focus on phonological information, such as the nonword repetition test ([9,10], for an overview see [11,12]). Such a deficit in working memory could potentially cause modulation of the N400 as compared with children with normal working memory capacities.

The aim of the present study is two-fold: first, to investigate lexical–semantic processes as indicated by the N400 component in language-impaired children and control children, and second to evaluate whether the peak amplitude of the N400 predicts verbal short-term memory capacity (subtest Digit Span) and use of word knowledge (subtest Vocabulary).

Materials and methods

Participants

Sixteen children with specific language impairment and 16 control children [12 boys, mean age M=9;7, SD=1;9, $t(15)=-0.47$, NS] matched pairwise on age, sex and nonverbal intelligence quotient (IQ) were investigated. Children with specific language impairment were selected based on the criteria of the International Classification of Diseases 10 (ICD-10) [2]. Their language comprehension and/or production abilities were at least 1.5 standard deviations below the mean and an additional discrepancy between their language abilities and the nonverbal IQ of at least 1 standard deviation was required. All children were German-speaking monolinguals, without any hearing deficit or reported neurological disorders. Nonverbal IQ,

as tested by the Kaufman-Assessment Battery for children (K-ABC, [13]) or the German Version of the Wechsler Intelligence Scale for Children (HAWIK-III, [14]), was quite similar for both groups [impaired group: M=101.7 (SD=12.1), control group: M=102.5 (SD=9.3), $t(15)=0.26$, NS]. The groups, however, differed significantly from one another in their language comprehension [impaired group: M=37.1 (SD=7.1), control group: M=51.6 (SD=5.1), $t(15)=7.69$, $P<0.001$)] and language production [impaired group: M=23.3 (SD=6.9), control group: M=53.1 (SD=6.5), $t(15)=15.15$, $P<0.001$], as assessed by the Heidelberger Sprachentwicklungstest (HSET, [15]). Groups also differed in their working memory capacity as tested by the subtest Digit Span of the K-ABC [13] [impaired group: M=6.7 (SD=1.8), control group: M=10.4 (SD=1.9), $t(15)=4.55$, $P<0.001$] and their vocabulary as assessed by the subtest Vocabulary of the HAWIK-III [14] [impaired group: M=8.4 (SD=2.9), control group: M=10.4 (SD=2.3), $t(13)=2.33$, $P<0.05$]. (Note that two language-impaired children and their control counterparts had to be excluded from the analysis of the subtest Vocabulary due to a technical error.) Following the recommendations of the Ethic Commission of the Ludwig-Maximilians-University Munich parents of all children gave informed consent.

Stimuli and experiment

The experiment consisted of four conditions, each containing 48 sentences in passive voice, presented via loudspeaker. All sentences comprised a noun, an auxiliary and a past participle. In the context of this paper, only two conditions will be discussed, namely the correct condition (e.g. *Das Brot wurde gegessen.* 'The bread was eaten.') and the semantic violation condition (e.g. *Der Vulkan wurde gegessen.* 'The volcano was eaten.'). In all conditions, the target word was a regular German past participle starting with the morpheme *ge-* in final position of the sentence. All sentences were spoken by a female native German speaker and recordings were digitized into audio files (16-bit, 20 kHz).

Procedure

The diagnostic procedure and the ERP recording were carried out in two separate 2 h sessions. For the ERP experiment, 192 sentences were presented in four blocks in pseudorandomized order. After each sentence offset, there was a break of 3 s to avoid movement artifacts followed by a period for response (maximum of 2 s) during which children had to judge the sentence's correctness by pressing one of the two buttons. This was practiced before the experiment on 15 trials.

Electroencephalogram recording

The electroencephalogram (EEG) data were recorded from 22 Ag/AgCl electrodes, referenced to the right mastoid (electrode impedances $<5\,k\Omega$, sampling rate of 256 Hz, bandpass filter 0.16–30 Hz). Vertical (below and above the right eye) and horizontal (at outer left and right canti) electro-oculograms were monitored by a bipolar montage. Offline, the recordings were rereferenced to the average of the right and left mastoid.

Data analyses

The EEG analysis included only trials which were answered correctly. For the ERPs, EEG epochs of 1.5 s beginning at the onset of the past participle were averaged relative to a 0.1 s prestimulus baseline. Mean ERP amplitudes were calculated for two time windows (0.4–0.8 and 1.0–1.5 s). For the analyses of the 16 lateral electrodes, repeated-measures analyses of variance with the between-subject factor Group (language-impaired children vs. controls) and the within-subject factor Condition (correct vs. semantically incorrect) were conducted for each time window separately. The global analysis for the lateral electrodes included also the topographical variables Hemisphere (right vs. left) and Region (anterior vs. posterior). As there were no significant interactions between the variables Condition and Group and either topographical variable, we refrain from reporting this part of the analysis. The midline electrodes were analyzed using the factor Group and the factors Condition and Electrode (Fz, Cz, Pz and Oz). For each group, separate follow-up analyses (with the factors Condition and Electrode) for lateral and midline electrodes were conducted whenever a marginally significant interaction ($P<0.1$) was observed between the factors Group and Condition.

Furthermore, we tested the correlation between the mean peak amplitude of the N400 (automatically detected between 0.4 and 0.8 s in the difference wave at the electrodes F3/4, Fz, C3/4, Cz, P3/4 and Pz) and verbal short-term working memory capacity (subtest Digit Span) and use of word knowledge (subtest Vocabulary, Pearson's correlation coefficient, one-tailed significance). A linear regression analysis (the variable Group entered the model first) was calculated only for a significant correlation (referred to a Bonferroni adjusted $\alpha'=0.025$) in order to assess whether the N400 would predict verbal short-term working memory capacity and use of word knowledge by controlling for a group effect.

Results

In the judgment task, children of both groups performed clearly above chance level in both conditions [mean percentage of correct judgments per condition: language-impaired children, correct: M=83.2 (SD=7.1), semantically incorrect: M=91.9 (SD=4.4); controls, correct: M=91.3 (SD=5.2), semantically incorrect: M=96.0 (SD=5.9)]. The mean percentages of correct judgments were submitted to an analysis of variance with the factors Group and Condition. There was a reliable main effect of Group [$F(1,30)=12.46$, MSE=47.01, $P<0.01$], a main effect of Condition [$F(1,30)=38.04$, MSE=18.91, $P<0.001$] and a marginal interaction between Condition and Group [$F(1,30)=3.45$, MSE=18.91, $P=0.07$]. This shows that language-impaired children performed worse than the control children, and semantically incorrect sentences were classified correctly more often than sentences of the correct condition – more so, however, for the language-impaired group.

The ERPs of the control children showed two distinct effects for semantically incorrect compared with correct sentences, namely a broadly distributed N400 effect (0.4–0.8 s) followed by a late positivity (1.0–1.5 s, Fig. 1). Interestingly, the language-impaired children did not exhibit an N400 effect, but showed a late and broadly distributed positivity.

These findings are supported by statistical analyses: for time window 1, a significant Group by Condition interaction

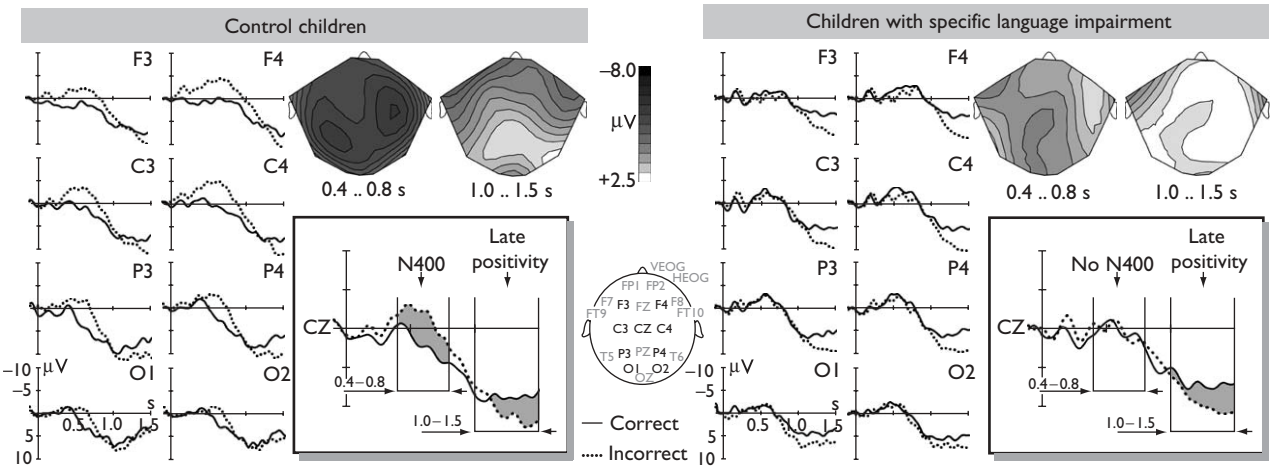

Fig. 1 Grand average of event-related potentials of the control children (left column) and the language-impaired children (right column). The semantically incorrect condition (dotted line) is plotted against the correct condition (solid line). The axis of the ordinates indicates the onset of the critical word (past participle). Negative voltage is plotted upwards. The pictures of the enlarged electrode Cz contain gray hatched sections referring to effects that revealed statistical significance.

Table 1 Regression analysis

	R^2	Adj R^2	ΔR^2	df	F change	β
Verbal short-term working memory						
Step 1: group	0.51	0.50	0.51	1, 30	31.63***	−0.72***
Step 2: peak amplitude of the N400	0.51	0.48	0.0001	1, 29	0.005	0.01
Model	F(2,29)=15.29***					
Word knowledge						
Step 1: group	0.13	0.10	0.13	1, 26	4.03	−0.37°
Step 2: peak amplitude of the N400	0.19	0.13	0.06	1, 25	1.80	−0.28
Model	F(2,25)=3.0°					

°$P = 0.07$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

was observed for the lateral [F(1,30) = 9.99, MSE=16.72, $P < 0.01$] and the midline electrodes [F(1,30) = 5.47, MSE=34.80, $P < 0.05$] as well as a marginally significant main effect of Condition [midline: F(1,30) = 3.38, MSE=34.80, $P = 0.08$]. For time window 2, again a significant Group by Condition interaction [F(1,30) = 3.76, MSE=14.0, $P = 0.06$] and a main effect of Condition [F(1,30) = 6.87, MSE=14.0, $P = 0.01$] was found for the lateral electrodes. For the midline electrodes, there was a main effect of Condition [F(1,30) = 5.32, MSE=39.47, $P < 0.05$].

Following up the Group by Condition interaction in time window 1, a significant main effect of Condition for the control children was observed for the lateral and the midline electrodes reflecting an N400 effect [lateral: F(1,15) = 7.79, MSE=5.93, $P = 0.01$, midline: F(1,15) = 7.24, MSE=10.50, $P < 0.05$]. For the language-impaired children, no effect reached significance [lateral: F(1,15) = 2.26, MSE=2.43, $P = 0.15$, midline: F<1]. Following up the Condition by Group interaction in time window 2, we found a reliable effect of condition for the language-impaired children, indicating a broadly distributed late positivity also present over the lateral electrodes [F(1,15) = 11.48, MSE=3.17, $P < 0.01$].

The correlation analysis showed that larger amplitudes of the N400 effect were significantly associated with better verbal short-term working memory abilities ($r = -0.36$, $P < 0.02$). The regression analysis further indicated that verbal short-term working memory capacity was predicted by the grouping but not by the peak amplitude of the N400 effect (see Table 1). Moreover, larger amplitudes of the N400 effect were significantly associated with better use of word knowledge ($r = -0.39$, $P < 0.02$). Again, only the predictive value of the grouping was confirmed by the regression analysis.

Discussion

The present study examined processing of words in sentences in children with specific language impairment and control children. To this end, modulation of the N400 component was investigated in each group, and correlations between the N400 effects and (1) verbal short-term memory and (2) word knowledge were tested. Behaviorally language-impaired children and controls both performed well; however, language-impaired children were significantly worse than controls. This is not surprising, because poorer language comprehension is one of the diagnostic criteria of specific language impairment. Children in both groups were better at identifying semantic violations than correct sentences. Sentences containing semantic violations may have been particularly salient for children, as they are highly unusual in normal everyday situations.

The ERP data revealed a reliable N400 effect (difference between response to correct vs. incorrect sentences) for controls, converging with the findings of Hahne *et al.* [6] for

8-year-olds. No N400 effect was found for the language-impaired children. The absence of the N400 effect in language-impaired children can be attributed to a relatively large N400 amplitude in this group in response to correct sentences.

In contrast to the current results, Neville *et al.* [16] investigated language-impaired/reading disabled children in a sentence reading task and found generally larger N400 effects for the impaired group than for the controls. In this study language stimuli were presented visually, which is potentially more demanding than auditory language comprehension, especially for children [17]. The fact that the N400 component observed for impaired children was generally larger than that observed in controls is in accordance with our findings regarding responses elicited by correct sentences.

In a previous behavioral study, it was shown that language-impaired children have weaker representations of selectional restrictions of verbs [18]. This may offer an explanation for the relatively large N400 component observed for impaired children with respect to the correct sentences. Specifically, weaker representation of verb meaning in general may cause greater difficulties for impaired children in integrating verbs into a sentence context. As pointed out previously such difficulties in lexical integration are associated with larger N400 amplitudes.

The correlation analyses, which were conducted with data from children in both groups, revealed that smaller N400 effects were associated with poorer verbal short-term memory capacity and poorer use of word knowledge in general. The regression analyses with the variables group and peak amplitude of the N400 demonstrated that the ERPs did not predict verbal short-term memory capacity or vocabulary. The grouping, however, had the strongest predictive power for the N400 amplitude, reflecting the fact that there was hardly any variance within the groups and clear differences between the groups.

In both groups, semantic violations additionally elicited a late positive ERP component. This positivity was broadly distributed for the language-impaired children, but restricted to central electrodes for controls. As the late positivity is assumed to reflect processes of sentential judgment as required by the judgment task [19], differences in the distribution of the late positivity may reflect more effort in the part of language-impaired children in performing the judgment task.

Conclusion

The present study investigated lexical–semantic processes (N400) in children with language impairment and control children in auditory sentence comprehension. For normal control children, an N400 effect followed by a late positivity was found. Children with language impairment showed no N400 effect but did have a late positivity. The absence of the N400 effect suggests either weaker lexical–semantic representation of the verbs and their selectional restrictions or difficulties in lexical–semantic integration processes per se. Additionally, smaller N400 effects were shown to be associated with poorer verbal short-term working memory capacity and poor vocabulary across groups of children.

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