Automatic processing of tones and speech stimuli in children with specific language impairment

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It is well known from behavioural experiments that children with specific language impairment (SLI) have difficulties discriminating consonant–vowel (CV) syllables such as /ba/, /da/, and /ga/. Mismatch negativity (MMN) is an auditory event-related potential component that represents the outcome of an automatic comparison process. It could, therefore, be a promising tool for assessing central auditory processing deficits for speech and non-speech stimuli in children with SLI. MMN is typically evoked by occasionally occurring 'deviant' stimuli in a sequence of identical 'standard' sounds. In this study MMN was elicited using simple tone stimuli, which differed in frequency (1000 versus 1200 Hz) and duration (175 versus 100 ms) and to digitized CV syllables which differed in place of articulation (/ba/, /da/, and /ga/) in children with expressive and receptive SLI and healthy control children (*n*=21 in each group, 46 males and 17 females; age range 5 to 10 years). Mean MMN amplitudes between groups were compared. Additionally, the behavioural discrimination performance was assessed. Children with SLI had attenuated MMN amplitudes to speech stimuli, but there was no significant difference between the two diagnostic subgroups. MMN to tone stimuli did not differ between the groups. Children with SLI made more errors in the discrimination task, but discrimination scores did not correlate with MMN amplitudes. The present data suggest that children with SLI show a specific deficit in automatic discrimination of CV syllables differing in place of articulation, whereas the processing of simple tone differences seems to be unimpaired.

Children with specific language impairment (SLI) show perceptual deficits for speech and non-speech auditory stimuli, especially if these stimuli occur in rapid sequences. These deficits are well documented at the behavioural level (e.g. Tallal and Piercy 1974, 1975; Elliott and Hammer 1988; Elliott et al. 1989). Whether this is a speech specific or a general auditory processing deficit has been a controversial question over recent years (Farmer and Klein 1995). Bishop (1997) queries whether this deficit at the behavioural level is due to impaired sensory information storage or to problems at higher levels of processing. As this question cannot be easily answered by behavioural experiments, the use of event-related potentials (ERP) might be a useful method for assessing auditory and speech perception in children with SLI at different levels of processing.

Mismatch negativity (MMN) is a component of the auditory ERP that reflects the outcome of an automatic comparison process between acoustic stimuli. It can be considered as a representation of sensory memory (Näätänen 1992, Winkler et al. 1993, Tervaniemi et al. 1994). MMN is typically elicited by occasionally occurring 'deviant' stimuli in a sequence of identical 'standard' sounds. The deviant may differ from the standard stimulus in frequency, duration, intensity, or even more complex features (for reviews see Näätänen 1992, Kraus et al. 1995). MMN can be elicited by unattended stimuli (Näätänen 1990). Therefore, the study of auditory processing in children with SLI by MMN seems promising as many of these children also have attention disorders (Beitchman et al. 1990) or might have problems understanding verbal instructions. Whereas a number of studies have investigated MMN in children with dyslexia (Csépe and Gyurkósza 1998, Hugdahl et al. 1998, Schulte-Körne et al. 1998, Baldeweg et al. 1999) and children with learning disabilities* (Kraus et al. 1996), so far there have been only a few studies of MMN in children with SLI (Korpilahti and Lang 1994, Korpilahti 1996, Holopainen et al. 1997).

Results of these MMN experiments are contradictory. Korpilahti and Lang (1994) and Holopainen and coworkers (1997) described an attenuated MMN amplitude to frequency deviants (500 versus 553 Hz) in two groups of children with SLI aged 7 to 13 and 3 to 6 years respectively. A significant group difference was additionally found for a large duration deviance (50/500ms) but not for a smaller duration difference (50/110ms). So far, only Baldeweg and coworkers (1999) have reported an MMN deficit in individuals with dyslexia to a frequency deviant, while Schulte-Körne and colleagues (1998) and Csészpe and Gyurkósza (1998) found group differences only in an experimental condition using speech stimuli. Hugdahl and coworkers (1998) found even higher MMN amplitudes to frequency deviants (100Hz versus 1050Hz) in the group with dyslexia than in the control group.

Several studies have reported a close correspondence between MMN parameters and behavioural measures of discrimination (Lang et al. 1990; Näätänen et al. 1993; Kraus et al. 1995, 1996). Korpilahti (1996), however, found no significant correlations between MMN amplitudes and test scores in a number of language, memory, and discrimination tasks. To determine how useful MMN might be in early assessment of language disorders, we also studied the relation between automatic discrimination (MMN) and discriminative abilities at the behavioural level.

*North American usage: mental retardation.

The aim of this study was to compare MMN with tone and speech stimuli in two subgroups of children with SLI and normally developing control children. Based on the literature, we hypothesized an MMN deficit to speech stimuli, but expected intact automatic processing for the tone condition as the greater number of studies reported evidence in this direction.

Method

PARTICIPANTS

Sixty-three children divided into three equal groups (expressive SLI, receptive SLI, control participants) participated in this study (see Table I). Children with SLI had either been referred to the special outpatient clinic for developmental problems at the University of Munich, Germany by a paediatrician or audiologist or were selected from special schools for children with language problems within the scope of a larger study. The control children were recruited at mainstream kindergartens and schools. The diagnostic criteria of the ICD-10 (World Health Organization 1991) for expressive and receptive language disorders were applied. These criteria require the exclusion of other impairments that might account for a language deficit. Therefore, all children were tested and included if they had normal hearing thresholds (audiometric screening procedure), no neurological impairment (clinical examination and parent questionnaire), and a non-verbal IQ >85 on the non-verbal scale of the German version of the Kaufman Assessment Battery for Children (K-ABC; Melchers and Preuß 1991). Additionally, we screened the control children for psychiatric symptoms and developmental and neurological disorders using the Child Behavior Checklist (CBCL: Arbeitsgruppe Deutsche Child Behavior Checklist 1993) and a parent questionnaire. Control children who had increased scores on one of the CBCL scales (>60 for total score and externalizing or internalizing disorders, >70 for the subscales) or whose parents reported a history of developmental disorders (e.g. dyslexia) or learning problems were excluded from the study. Children with SLI were included only if they scored at least 2SDs below the mean in subtests of the Heidelberger Sprachentwicklungstest (HSET; Grimm and Schöler 1991). We used the scores of the subtest Imitating Grammatical Structures (IS: 'Imitieren grammatischer Strukturformen') as a measure of expressive language skills and the scores of the subtest Comprehending Grammatical Structures (VS: 'Verstehen grammatischer Strukturformen') as a measure of language comprehension. Children with expressive SLI had T-scores of 30 or below in the IS subtest, children of the receptive SLI group had T-scores of 30 or below in the VS subtest. The children were matched pairwise: mean age 8 years and 2 months (SD 6 months). Mean values and standard deviations for each group with respect to age, sex, hand preference, and non-verbal IQ are shown in Table I. The groups did not significantly differ in age, ratio of sex, or handedness, but a one-way ANOVA with post-hoc Scheffé tests revealed that the children with receptive SLI had a significantly lower non-verbal IQ than the control group.

PROCEDURE

The ERP experiment and additional tests were carried out in two sessions. During the first session all data necessary to determine the diagnostic criteria (audiometric screening, K-ABC, CBCL, parent questionnaire) were collected and informed written consent of parents was obtained. ERP recordings were made during the second session. Afterwards auditory discrimination for the stimuli used in the ERP experiment was tested by a forced choice task. Previous experiments had shown that this type of task (instead of the paradigm used in the ERP experiment) was more suitable to assess the discrimination performance of children with SLI who often have attentional problems as well. For the behavioural task the stimuli were recorded on a digital tape and presented in pairs (either standard–standard or standard–deviant) with 1-second stimulus onset asynchrony (SOA). The next pair followed after 3 seconds. The children had to decide whether the presented stimuli were 'same' or 'different'. Before the actual task we made sure that the children understood the task by using pictures and examples. The children could take the time they needed for their answer. Thus, we could not record reaction times but our aim was to assess the best discrimination performance possible. The stimuli were presented in blocks similar to the ERP experiment (one block with tone stimuli, one block with speech stimuli); in cases where a child needed a short break, the digital tape was stopped. The task consisted of 15 identical and 15 different pairs for each deviant type, that is 60 stimulus pairs for the tone and the speech condition each to keep the probability for 'same' and 'different' equal.

STIMULI AND ERP EXPERIMENT

The ERP experiment consisted of four blocks of tones and four

Table I: Participant characteristics mean (SD)

Variable	*Expressive SLI*	*Receptive SLI*	*Control children*	*Total*
n	21	21	21	63
Age (y:m)	8:0 (1:1)	8:1 (1:2)	8:2 (1:2)	8:1(1:1)
range	68–118	71–121	72–124	–
Non-verbal IQ	103.19 (11.23)	98.19 (10.12)[c]	108.75 (11.19)	103.29 (11.52)
range	86–120	85–118	94–130	–
HSET VS[a]	41 (8.39)	27.62 (4.44)	–	–
HSET IS[a]	21.57 (6.4)	21.86 (6.81)	–	–
Sex (M/F)	19/2	14/7	13/8	46/17
Hand preference (Right/non-right[b])	15/5	15/6	19/1	49/12

[a] T-scores; [b] Tested by the Edinburgh Inventory of Handedness (Oldfield 1971); the number of non-right handed participants comprised all children who did not show a clear right-hand preference. Data for two children are missing; [c] Significantly lower than for control group (Scheffé test). SLI, specific language impairment; HSET, Heidelberger Sprachentwicklungstest; VS, Comprehending Grammatical Structures; IS, Imitating Grammatical Structures.

blocks of speech-stimuli in balanced order, each containing 333 stimuli with a constant SOA of 1 second. In the tone blocks, the standard stimulus (1000 Hz, 17ms, rise and fall time 10ms) was replaced by a frequency deviant (1200 Hz, 175ms) in 15% of the trials and by a duration deviant in another 15% (1000 Hz, 100ms). Speech stimuli consisted of digitized (rate 30 000 Hz) consonant–vowel syllables with 175ms duration spoken by a female German voice. The standard phoneme was /da/ (70%). The deviants /ga/ (15%) and /ba/ (15%) differed in the place of articulation, i.e. the second and third formants of the stimuli show different start frequencies. All stimuli were presented in pseudo-random order (i.e. at least two standard stimuli followed every deviant) to the right ear via earphones at 86 dB SPL intensity. During the recording the children watched a silent video tape. They were instructed to ignore the auditory stimuli.

EEG RECORDING AND DATA ANALYSIS

Silver–silver chloride electrodes were attached at three frontal (Fz, F3, F4) and three central (Cz, C3, C4) electrode sites according to the International 10-20 system. Electrodes were referenced to averaged mastoids. Two additional pairs of electrodes were used to detect horizontal and vertical eye movements. Data were acquired using the Neuroscan system (Neurosoft Inc, Herdon, VA, USA) at a sampling rate of 25Hz. On-line bandpass filter limits were set to 0.1 and 3Hz, and signals were stored for off-line analysis.

The time epoch for analysis consisted of 80ms after stimulus onset and a 200ms prestimulus baseline against which amplitude measurements were made. Off-line processing included ocular artifact correction using the method by Gratton and colleagues (1983), and artifact rejection of epochs containing EEG activity exceeding SD 80 μV and averaging of epochs.

MMN was obtained by subtracting standard from deviant evoked responses for each deviant type. MMN was measured as mean amplitudes across certain time intervals. These intervals were defined by significant differences ($p<0.001$) between standard and deviant responses (one-sample t-tests) in the all participants (compare Kraus et al. 1995, Schröger 1998).

Statistical analysis of the ERP data was performed separately for the tone and the speech condition using analyses of variance. Details of the specific analyses are given in the Results section. Greenhouse–Geisser ε-correction of degrees of freedom were used when appropriate. Reported p values have been corrected if necessary.

Results

MMN

The different wave forms in the tone condition (Fig. 1a) show

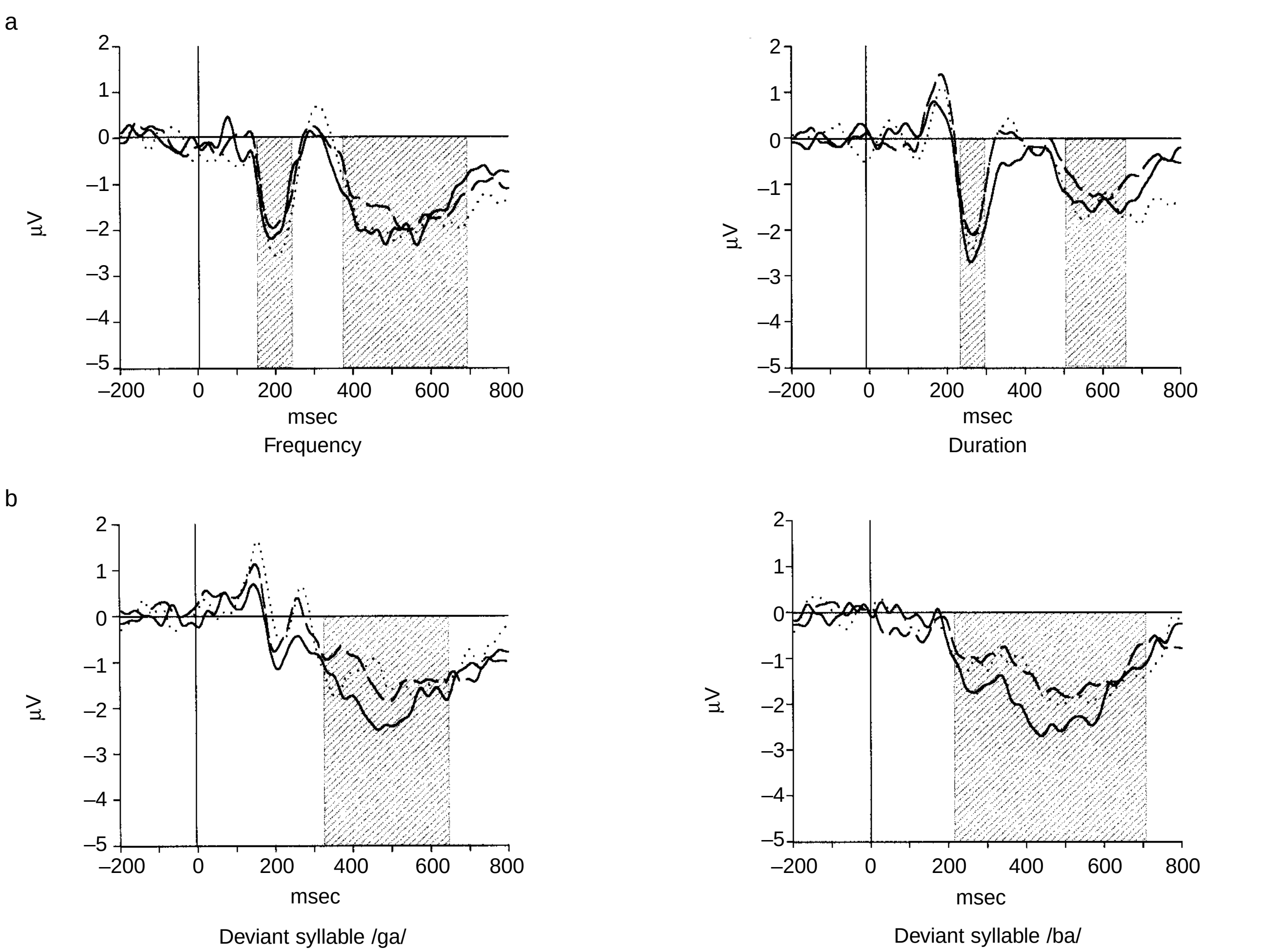

Figure 1: *Different wave forms in (a) tone condition (frequency and duration) and (b) speech condition elicited by four deviant stimuli superimposed for three diagnostic groups. Hatched areas mark time intervals for which mean amplitudes were calculated.—, controls; ...., expressive SLI; - - - -, receptive SLI.*

two negative deflections; broad and longer lasting negativities can be seen in the speech condition (Fig. 1b). One-sample *t*-tests for each time point revealed two time intervals with significant differences ($p<0.001$) between standard and deviant responses for the tone condition; this corresponded to the two negative deflections of the difference wave. There was only one significant time interval for each of the speech deviants. The time intervals used for calculating mean amplitudes are shown below the difference in waveforms in Figure 1 and in Table II.

Table III shows the mean (SD) MMN amplitudes for the three diagnostic groups at the electrode Fz. To analyze MMN data an ANOVA for repeated measures was performed using the electrode site (six levels F3, F4, Fz, C3, C4, Cz), deviant type (frequency versus duration in the tone condition, /ga/ versus /ba/ in the speech condition) and – in the tone condition – the time window as within-subject factors. Helmert a priori contrasts were used to compare the levels of the group factor diagnosis (control group, expressive SLI, receptive SLI).

In the tone condition there was no significant difference between the diagnostic groups and there was no interaction of the group factor with other factors. In the second time window, MMN amplitudes were higher for the frequency deviant (interaction time window × deviant type: $F(1,60)=1.48$, $p=0.008$) than for the duration deviant. They varied with respect to the electrode site (main effect electrode site: $F(5,300)=3.13$, $\varepsilon=0.45$, $p=0.04$). In the speech condition a significant main effect of the factor diagnosis ($F(2,60)=3.78$, $p=0.03$) was found. Children with SLI showed attenuated MMN amplitudes compared with those of the control children ($F(1,60)=6.86$, $p=0.01$). The two diagnostic subgroups of children with receptive and expressive SLI did not differ significantly, although mean amplitudes of the children with receptive SLI were somewhat lower than those of the children with expressive SLI. MMN amplitudes did not differ between the two deviant syllables and the electrode sites. No significant interactions of these factors with the factor diagnosis were observed.

Table II: Time windows with significant difference ($p<0.001$) between standard and deviant waveform

Stimulus	*Time window I*	*Time window II*
Frequency deviant	163–241	378–695
Duration deviant	234–296	507–659
Syllable /ga/	339–656	–
Syllable /ba/	218–706	–

DISCRIMINATION TASK

Table IV shows the means and SDs of errors in the discrimination tasks for the three groups. One-way ANOVAs revealed significantly higher error scores for children with SLI in all discrimination tasks. Children with expressive SLI made significantly more errors than control children in all tasks (post-hoc Scheffé tests); children with receptive SLI had higher error scores when comparing the duration deviant with the standard. To investigate the correlation between MMN amplitudes as a measure of automatic processing of stimulus differences and the behavioural discrimination performance, Pearson's correlation coefficients between MMN amplitudes (mean values of the six electrodes) and error scores were calculated. The coefficients varied between $r=-0.09$ and 0.17; none of them reached significance.

RELATION BETWEEN MMN AND IQ, HANDEDNESS, AND DATA QUALITY

To test the hypothesis that differences in MMN amplitudes

Table III: MMN amplitudes, mean (SD), of three diagnostic groups to tone and speech stimuli in µV at electrode Fz

	Expressive SLI (F80.1)	*Receptive SLI (F80.2)*	*Control group*
Frequency time window I	–2.05 (1.76)	–1.37 (1.66)	–1.46 (1.92)
Frequency time window II	–1.66 (2.08)	–1.43 (1.57)	–1.90 (2.17)
Duration time window I	–1.93 (1.97)	–1.79 (2.30)	–2.51 (2.34)
Duration time window II	–1.54 (1.69)	–1.18 (2.01)	–1.45 (2.16)
Syllable /ga/	–1.49 (1.54)	–1.21 (1.66)	–2.38 (1.57)
Syllable /ba/	–1.49 (1.45)	–1.23 (1.26)	–1.92 (1.60)

SLI, specific language impairment.

Table IV: Error scores of discrimination tasks, mean (SD), for three diagnostic groups and F values of one-way ANOVA comparison

Variable	*Expressive SLI F80.1*	*Receptive SLI F80.2*	*Control children*	*F values (df)*
n^a	18	19	19	
Comparison of frequency	7.22 (7.06)	3.25 (5.11)	1.48 (2.4)	6.05 (2;53), $p=0.004$
Comparison of duration	12.27 (7.04)	10.06 (7.64)	3.07 (3.12)	10.03 (2;51), $p<0.001$
Comparison of syllables /da/–/ga/	6.68 (5.67)	5.38 (5.67)	2.41 (3.38)	3.52 (2;51), $p=0.04$
Comparison of syllables /da/–/ba/	8.63 (12.61)	3.51 (3.48)	1.10 (1.72)	4.74 (2;51), $p=0.01$

[a] Scores could not be obtained for all children as five children with SLI were not able to complete task and two control children did not take part in testing session; SLI, specific language impairment.

between the diagnostic groups are due to factors other than language impairment, we calculated correlations between MMN amplitudes and non-verbal IQ, hand preference, and the number of epochs included in the averages as a measure of data quality. For non-verbal IQ there were only two correlation coefficients (of 18) with a probability below the 10% level (IQ – 'late' MMN to frequency deviant for the control children: $r=0.45$, $p=0.05$; IQ–syllable /ba/ in the expressive SLI group $r=-0.51$, $p=0.02$). One of them was positive, the other negative, i.e. a higher IQ was associated with a lower MMN amplitude for the control children, whereas the association was the opposite for children with expressive SLI. The correlation coefficients between MMN amplitude and handedness varied between –0.42 and 0.44. None of them reached the 5% significance level.

The number of EEG epochs included in the averages was not significantly associated with MMN amplitudes for children with SLI nor for the control children. Only the correlation between MMN amplitudes to the speech stimuli and the number of averaged EEG epochs for the children with expressive SLI had a significance below $p=0.05$. In general, the number of artifact-free EEG epochs was higher for children with SLI (mean number of EEG epochs between 163.2 and 168 [SD 18–22.2] for the deviants and 759.4–788.7 [SD 81.4–94.9] for the standard stimuli) than for control children (deviant stimuli: 150.8–153.5 [SD 23.8–28.3]; standards: 684/694 [SD 153/130]. For standard stimuli (one-way ANOVA for standard tone: $F[2,60]=4.17$, $p=0.02$; standard speech stimulus: $F[2,60]=4.77$, $p=0.01$) and the deviant syllable /ga/ ($F[2,60]=3.42$, $p=0.04$) this difference was significant. In brief, we did not find evidence that the factors non-verbal IQ, handedness, and data quality might account for MMN differences between the diagnostic groups.

Discussion

A significant difference between children with SLI and normally developing control children was seen only in the speech condition. The two subgroups of children with SLI (expressive and receptive), however, did not differ significantly. No significant group differences emerged in the tone condition. The present data, therefore, suggest that children with SLI experience a deficit in automatic processing of different speech stimuli, whereas their ability to process simple tone differences automatically (such as frequency or duration differences) is intact. The fact that children with receptive SLI did not significantly differ here from the children with expressive SLI supports the hypothesis that these children have the same perceptual deficit that might be somewhat more marked in children with receptive problems.

To the best of our knowledge, no other study has yet been published comparing MMN with speech stimuli in children with SLI and control individuals. When using tones with a frequency deviant as stimulus material, Korpilahti and Lang (1994) and Holopainen and coworkers (1997) found an MMN deficit in children with SLI. Results from MMN experiments in children with dyslexia (Csépe and Gyurcósza 1998, Schulte-Körne et al. 1998) using consonant–vowel (CV) syllables as stimuli attribute MMN deficits to speech stimuli rather than to simple tone differences. The two latter studies reported intact automatic processing of frequency deviations in children with dyslexia. Csépe and Gyurcósza (1998) found consistent deficits in the processing of CV syllables that differed in place of articulation in children with dyslexia. A significantly attenuated amplitude of the difference wave to synthesized speech stimuli was reported by Schulte-Körne and colleagues (1998) for children with dyslexia but only for the late part of their analysis interval (303 to 620 ms).

When comparing these divergent results it must be borne in mind that the participants in these studies varied considerably in age and in the type and severity of their disorder. For example, children studied by the Korpilhati group seemed to be severely impaired in their language development and maybe also in their intellectual development (authors did not report mean IQs). The children with dyslexia who participated in the study by Schulte-Körne and coworkers (1998) were older (mean age 12 years; 9 years and 4.9 years in the Finnish studies) and went to a type of school (Gymnasium) which usually takes children of above average intelligence. Thus, the inconsistency of the results might be at least partly accounted for by differences in age, intelligence, and severity of impairment.

Bishop (1997) raised the question as to whether the discrimination deficits that have been observed on a behavioural level in children with SLI can be accounted for by a defective sensory trace or rather, by task-related factors. She cited some evidence for intact sensory information processing (e.g. Neville et al. 1993) but hoped that MMN studies would help to answer this question while avoiding some of the methodological problems of behavioural tasks. As MMN is considered an electrophysiologic correlate of sensory memory, our results support the hypothesis that children with SLI experience a deficit at this early level of processing. Therefore, attentional or short-term memory deficits alone cannot account for lower performance in behavioural discrimination tasks. This deficit of the sensory memory trace in children with SLI, however, seems to be restricted to certain stimulus material, such as CV syllables. This requires the existence of different generators for MMN to tone and speech stimuli in humans which can be presumed on the basis of results for patients with aphasia reported by Aaltonen and colleagues (1993). The automatic processing of tone stimuli was not impaired in these patients, whereas MMN to certain speech stimuli was absent. Evidence from animal experiments (Kraus et al. 1994, Rauschecker et al. 1995) also shows that MMN generators are organized in a hierarchical manner. While pure tone contrasts elicit MMNs even at the thalamic level (Kraus et al. 1994), the detection of speech sound as well contrasts with rapid frequency changes like /da/–/ga/ demands contributions from the auditory cortex (Rauschecker et al. 1995). Abnormal development of these regions of the auditory cortex might lead to the differential deficit seen in children with SLI. Further research should focus on these processing deficits in more detail, for example, to clarify whether they are restricted to speech stimuli or also refer to non-speech stimuli with rapid frequency changes. Thus MMN experiments might help to solve the controversy of whether children with SLI experience a general auditory processing deficit or a speech specific deficit (see Farmer and Klein 1995)

In general, children with SLI showed poorer performance in the behavioural discrimination tasks. The correlation between behavioural performance and automatic processing as revealed by MMN was low; none of the correlation coefficients reached significance. This contrasts with the results reported by Lang (1995), Aaltonen (1987), and Kraus (1996) and their respective colleagues. Most of these studies used young, healthy adults as participants, so that motivational factors probably did not influence discrimination performance. The low correspondence found in our study suggests that behavioural performance was probably also affected by factors other than discriminative ability, such as working memory or executive processes.

Conclusion

Our data suggest that children with SLI show a specific deficit in the automatic discrimination of CV syllables that differ in place of articulation, but MMN to simple tone differences does not seem to be impaired, at least if there is enough time. In an active discrimination task with the same stimulus material, children with SLI performed significantly poorer than control individuals but there was no correspondence between the two measures. Thus, perceptual problems and difficulties in the later stages of processing (e.g. memory or attention deficits) also have to be taken into account to explain the difficulties of children with SLI.

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