Group Intervention Changes Brain Activity in Bilingual Language-Impaired Children

This investigation assessed the effectiveness of a phonological intervention program on the brain functioning of bilingual Finnish 6- to 7-year-old preschool children diagnosed with specific language impairment (SLI). The intervention program was implemented by preschool teachers to small groups of children including children with SLI. A matched group of other bilingual children with SLI received a physical exercise program and served as a control group. Auditory evoked magnetic fields were measured before and after the intervention with an oddball paradigm. The brain activity recordings were followed by a behavioral discrimination test. Our results show that, in children with SLI, the positive intervention effect is reflected in plastic changes in the brain activity of the left and right auditory cortices.

Keywords: auditory, MEG, mismatch response MMNm, P1m, specific language impairment SLI

Introduction

A large number of children (3–8%) suffer from language impairment (Tomblin and others 1997; APA 2000). Specific language impairment (SLI) is diagnosed when a child fails to make normal progress in language development, with no evident cause for the delay (APA 2000; Bishop 2004). This impairment can adversely affect various aspects of both the comprehension and expression of language. Not only may this impairment jeopardize the school progress of these children, but it could also lead to secondary problems that include social and motivational difficulties.

The underlying problems in SLI may be heterogeneous, multiple factors possibly acting synergistically, the exact nature of the deficits remaining unknown (see e.g., Bishop and others 1999; Lane and others 2001; Rosen 2003; Leppänen and others 2004). However, many SLI children seem to suffer from auditory perceptual deficits. More specifically, it has been proposed that some SLI children may suffer from temporal processing deficits (Tallal and Piercy 1973; Tallal and others 1996; Wright and others 1997) which affect phoneme discrimination. Intervention programs for SLI children have included, for example, specific training of acoustic processing rates (Merzenich and others 1996; Tallal and others 1996). Training of phonological awareness, that is, the conscious awareness of the sound structure of words, has also been applied to SLI children in order to reduce the risk of reading problems (Korkman and Peltomaa 1993; Van Kleek and others 1998; Laing and Espeland 2005).

Our language intervention program focussed upon phonological discrimination, phonological production, and phonological and linguistic awareness. The intervention applied in this study differed from, for example, FastForWord (FFW, Scientific Learning Corporation 2004) in including only natural speech instead of acoustically modified speech. Further, whereas FFW intervention is focusing on receptive functions, the present program included also oral, verbal, and articulatory activities. Thus, the program is more comparable with phonological awareness programs (Bradley and Bryant 1985; Lundberg and others 1988; Korkman and Peltomaa 1993; Laing and Espeland 2005).

The present study included bilingual Swedish-Finnish preschool children with SLI. Finland is a bilingual country with a minority Swedish-speaking population. In areas with a high density of Swedish speakers, all the community services are provided in Swedish. These include childcare, schooling, and healthcare. Bilingual children in our study were all from families with at least one Swedish-speaking parent, they went to Swedish-speaking kindergartens, and were recruited for the study from a Swedish-speaking clinic for children with developmental, learning, and neurological problems located in Helsinki.

It has been suggested that bilingualism could further exacerbate SLI and adversely affect language-learning abilities and academic achievement (Crutchley and others 1997; Salameh and others 2002) either directly or through family-related factors (Crutchley 2000). Not all studies though indicate additional problems in bilingual SLI children, at least not in the domain of grammatical morphology (Paradis and others 2003). Several studies on children without SLI actually show that early acquisition of a second language and regular use of 2 languages may have beneficial effects on various cognitive abilities in young children (Kessler and Quinn 1987; Rubin and Turner 1989; Bruck and Genesee 1995; Louzou and Stuart 2003; Paradis and others 2003), especially on tasks requiring control of attention (Bialystok 1988; Bialystok and Codd 1997; Bialystok and Majumder 1998; Cromdal 1999; Bialystok and Shapiro 2005).

Linguistic experience alters perception of speech sounds so that it is difficult for adult second language learners to discriminate some nonnative speech contrasts (e.g., Werker 1994). Pronunciation of the second language is also better in early learners (Flege and others 1995). It has been shown that monolingual children lose at least some of their sensitivity to foreign phonemes between the age of 6 and 12 months (Werker and T Bates 1984; Cheuvre and others 1998; Rivera-Gaxiola and others 2005). The exact mechanism of the sensitivity loss remains
unclear. A “neural commitment” to acoustic features of the individual’s first language (e.g., Kuhl 2004; Zhang and others 2005) has been suggested to affect learning of the phonetic system of a second language. Pallier and others (1997) have shown that even early exposure to a second language before the age of 6 years is not enough to attain first-language-type phonological competence.

It is possible that the problems in perceiving correctly second language phonemes add to the difficulty in language-impaired children to communicate in their second language. A further difference between our training program and those of others was that our intervention included exercises that were specifically tailored for the bilingual background of our subjects. These exercises were focused on strengthening discrimination and production of Swedish phonemic contrasts that are sensitive to the influence of Finnish in bilingual, Swedish–Finnish children.

The ability to discriminate sounds can be tested using behavioral methods but also with methods reflecting more directly the underlying neural activity. Of the latter, auditory evoked brain responses can be measured even in the youngest children with minimal task requirements: children are instructed to simply remain still while watching a silent film or cartoon. In addition to the so-called obligatory brain responses that are evoked by any repetitive stimulus, responses sensitive to acoustic changes can also be obtained. When an auditory stimulus is repeated, and then infrequently replaced by another sound, the brain will automatically, without the experimental volunteer even paying attention to the stimuli, detect the sudden deviation in the stimulus stream evoking a mismatch response (MMN) (Naätänen 1992; Tiitinen and others 1994). This response can be measured with auditory evoked responses a few hundred milliseconds after the change in stimulus. Several studies have shown that the MMN correlates with behavioral measures of sound-discrimination accuracy (Naätänen and others 1993; Kraus and others 1996; Winkler and others 1999; Amenedo and Escera 2000; Kujala, Kallio, and others 1994). This MMN has served as a tool to investigate the brain functions that mediate auditory discrimination processes, including those related to language (Naätänen and others 1997), and impairments of language like dyslexia (Kujala and Naätänen 2001; Renvall and Hari 2003).

Several electrophysiological studies support the notion of deficits in sound discrimination in children with language impairment. The amplitude of the MMN was reduced for frequency changes of pure tones (Korpilahti and Lang 1994; Korpilahti 1995; Holopainen and others 1997, 1998) and for speech sounds (Uwer and others 2002) in groups of language-impaired compared with control children. There are 2 studies indicating that small infants with a family history of SLI differ in their evoked responses from infants without a family history of language-learning impairments, the former showing delayed (Friedrich and others 2004) or smaller (Benasich and others 2006) mismatch responses. Our hypothesis was that the intervention would increase the mismatch responses of SLI children.

The temporal cortex sources of the MMN can be recorded with magnetoencephalography (MEG). It measures magnetic fields evoked by electric currents in the neurones, particularly by those currents oriented tangentially to the surface of the head leaving the radial currents mostly invisible. Thus, it is considered to selectively record activity from sensory areas located in fissures, like auditory areas on the upper bank of the temporal lobes in both hemispheres. MEG has the same millisecond range time resolution as electroencephalography. In addition, MEG allows accurate localization and comparison of the underlying sources, for example, in different hemispheres (Hämäläinen and others 1993). MEG has also been used to study auditory functions in infants and small children. Pilko and others (2005) recently compared auditory evoked fields and potentials measured with a paradigm evoking mismatch response in healthy 6-year-old children. The waveforms of the main responses, P1 and MMN, were comparable with both methods.

In the present study, bilingual children with SLI were divided into 2 groups. One group received the phonological intervention program (PHONO group), whereas the other group took part in a physical exercise program (MOTOR group). The effectiveness of the phonological program was tested in 2 different ways. Auditory evoked magnetic fields were measured before and after the 8-week intervention period. The brain measurements were immediately followed by a behavioral discrimination test for the same stimuli.

Materials and Methods

Subjects

Eighteen Finnish bilingual preschool children, all diagnosed with SLI, participated in this investigation. First, a diagnosis of developmental disorder of speech and language according to the International Classification of Diseases (ICD) 10 criteria was required (diagnoses F80- F80.3, F80.9, or R17). One child had a diagnosis based on language, visuo-motor, and attention disorder but a cognitive capacity within the normal range (F83). The diagnoses were based on clinical assessments by a speech pathologist using age-appropriate language tests. In these assessments, a test result of 1.5 standard deviation (SD) below the age norm was considered significantly abnormal. The bilingual background of the child was taken into account. Second, children with general cognitive impairment were ruled out using an age-appropriate test of intelligence (Wechsler 1999). Third, children with major sensory or motor disability were not included, nor had any of the children a pervasive developmental disorder (F84). The mean age of the children when the diagnosis was done was 5.2 years (SD = 0.6, range 4.4–6.5). All neuropsychological and behavioral testing was carried out in Swedish.

In all families at least one of the parents spoke Swedish and in 11 families the other parent spoke Finnish, in one Russian, and in one English. In 5 families, both parents were Swedish speaking. Eleven of the children had Swedish as the dominant language. 3 were balanced bilinguals, and in 2 cases Finnish was dominant according to parental report. One of the children did not want to participate in the MEG recordings and another one did not show up for the follow-up MEG measurements. The mean age of the remaining 16 children (5 girls) was 6.6 years (range 6.1–7.1 years). The study was approved by the local Ethical Committee. One of the parents of each child signed an informed consent form.

The children were divided into 2 different intervention groups, the groups being matched by age, gender, and language background as carefully as possible. One group underwent a phonological intervention program (PHONO group). The other group served as a control group and took part in a physical exercise program (MOTOR group). Participation in our study did not interfere with the ongoing therapies of the children provided by the community.

In order to match the groups, preassessments were undertaken using an abbreviated form of the Swedish version of the Wechsler Primary and Preschool Scales of Intelligence Revised (WPPSI-R; Wechsler 1999) and language subtests from the Swedish version of the NEPSY—A Developmental Neuropsychological Assessment (Korkman and others 2000). Two children did not take part in the NEPSY assessment, and one of these children did not take part in the WPPSI-R assessment. The groups did not differ with respect to the mean (M) of the 2 verbal subtests (information and arithmetic) of the WPPSI-R: PHONO group and the MOTOR groups.
intervention was an adaptation of previously published intervention programs (Korkman and Peltomaa 1993; Häggström and Lundberg 1994; Mickos and Carlson 2003). It consisted of 1) speech and articulation exercises, 2) phoneme discrimination exercises, 3) exercises training phonological and linguistic awareness and rapid processing. In all parts of the intervention, a special emphasis was put on sounds that are common in Swedish but not in Finnish. Such sounds are often particularly difficult for children who are influenced by Finnish phonology.

The speech and articulation exercises aimed at making the children aware of their oral apparatus and articulatory processes. Examples included participating in a story by making sounds (e.g., ‘prr’ as a purring cat or ‘zzzz’ as a bee); licking the inside of the mouth with the tongue like in painting the interior of a house; blowing on cotton balls; making bubbles in a glass through a straw; etc. Different kinds of sounds were produced (long and short sounds, fricatives, nasals, etc.).

The phoneme discrimination exercises aimed at training discrimination, identification, and production of phonemes. Many exercises utilized picture material with words with minimal pairs. In particular, many phonemes that occur in Swedish but not in Finnish were included (e.g., ‘pl’ = arrow and ‘bil’ = car). In some of these exercises, the children were to tell if the teacher said the correct word while pointing to a picture. In other exercises, the children had to pick cards that represented one of the words in a pair or had to say the words.

The phonological and linguistic awareness exercises included sound blending games (e.g., pointing to the correct picture when hearing ‘ba—na—na’); phoneme deletion games (e.g., telling which sound the teacher deleted from a word); and phoneme addition games (forming new words by adding a phoneme to a word). Other exercises included rhyming games or remembering multiple instruction (e.g., ‘Go to the door.’ ‘Tap your tummy.’ ‘Open the door’).

The physical exercise program included motor activities. The children were to play flying airplanes (lying on a pillow, stretching their arms and legs); dance (e.g., holding each others’ hands, then putting their hands on their neighbor’s waist, then knees, and so on); clap hands in specific sequences; balance by walking toe to heel along a rope on the floor; etc.

Both interventions lasted for 8 weeks and were implemented in the child’s preschool setting by a preschool teacher according to a detailed, written schedule. Small groups of children were formed that included 1 or 2 SLI children and 4–6 normally developing children. Both the phonological and the physical exercise program extended over an 8-week period. The intervention sessions lasted 20–30 min and took place 3 times a week. Altogether 15 kindergartens with preschool activities participated in the study.

**Stimuli and Experimental Protocol**

In the MEG recordings, 2 sets of stimuli were used, both with one frequently repeated ‘standard’ stimulus and 2 kinds of ‘deviants’ occurring at random rare instances among the standards. Stimuli, originally recorded from a female bilingual speaker with Swedish pronunciation as isolated syllables (Fig. 1), were produced using the semisynthetic speech generation technique (Alku and others 1999). In MEG recordings, stimuli were presented binaurally with an oddball paradigm in 2 separate runs. For one standard stimulus (76%), there were always 2 deviants (12% each). The first stimulus set consisted of a voiced plosive followed by a vowel: /da/ as a standard, /ba/ and /ga/ as deviants. The duration of the stimulus was 213 ms, with 115 ms in the beginning for the plosive and transition, and 98 ms for the vowel. The second set consisted of syllables that comprised an unvoiced fricative followed by a vowel: /su/ as the standard, /so/ and /sy/ as deviants. The phoneme duration was 219 ms for the fricative and 152 ms for the vowel with a total duration of 371 ms. In the first stimulus set, the vowel and in the second set, the fricative were identical for all 3 stimuli. The intensities of the 3 syllables of both sets were normalized. The interstimulus interval from the beginning of the stimulus to the beginning of the next stimulus was 700 ms.

**Recordings**

Auditory evoked magnetic fields were recorded with a 306-channel helmet-shaped whole-head device consisting of 102 sensor elements each comprising 2 orthogonal planar gradiometers and 1 magnetometer (Elekta Neuromag Oy, Helsinki, Finland) in a magnetically shielded room (ETS-Lindgren Euroschild Oy, Eura, Finland). The sampling rate was 500 Hz and the measuring band pass 0.1–200 Hz. Eye movements were monitored with 2 electrodes, one in the upper corner of the left and the other in the lower corner of the right canthus. Epochs containing deflections exceeding 150 μV were automatically discarded. During the experiments, children lay supine watching silent cartoons of their choice reflected onto the ceiling of the magnetically shielded room. They were instructed not to pay attention to the auditory stimuli. One measurement session typically lasted for 15–20 min depending on the number of eye movements. Between the 2 sessions, there was a small break. Head positioning was carried out in the beginning of each file/stimulus set.

MEG recordings of children are challenged with possible movements during the experiments, which affects the equivalent current dipole (ECD) calculations. The best solution would be continuous head position monitoring with subsequent movement compensation (Taulu and others 2005). Unfortunately, at the time of the recordings, this was not available. We tried to minimize possible head movements by filling the empty space between the measurement helmet and the child’s head with light padding on both sides. If the child moved during the measurement, the file was discontinued and started again with a new head positioning. Out of 64 MEG recordings (4 files for each child), only 3 had to be restarted, once due to technical problems. One of the experimenters always accompanied the child inside the shielded room.

**Behavioral Testing**

After each MEG session, the ability of the children to discriminate between the stimuli was tested behaviorally. The stimuli and stimulus pairs were from the MEG protocol so that the standard with one deviant
constituted a pair: /da/-/ba/, /da/-/ga/, /su/-/so/, and /su/-/sy/. One block consisted of one sound pair in different combinations (A-B, A-A, B-B, or B-A). Twelve of the "same" and 12 of the "different" pairs were randomly presented. There were 4 blocks each with 24 sound pairs. The children were instructed to say if the sounds were the same or different. Hit rate = hits (correct "same" and "different" responses)/hits + misses (incorrect "same" and/or "different" responses) was used for statistical analysis. One training session with sounds that did not belong to the test proper, /se/-/se/, was given in the beginning.

**Data Analysis**

The evoked responses were averaged online separately for standards and deviants from 100 ms before to 700 ms after the stimulus onset and digitally low-pass filtered at 40 Hz. For evoked fields, the strength, location, and direction of underlying neuronal activity can be modeled with ECD. The ECDs in both hemispheres were calculated for the deflections studied. Twenty-three sensor triplets (69 channels) on both left and right temporal regions were used for the dipole fitting. The criteria for acceptable ECD were goodness of fit $g > 70\%$ (percent of the field pattern explained by the ECD) and the confidence volume $V < 1000 \text{mm}^3$ (describing the volume where the ECD can be located). If there were no dipoles at a given latency range meeting the criteria, the dipole strength was set to 0 nAm. The dipoles were fitted every 2 ms between 100–200, 300–400, and 400–600 ms for /su/, /so/, and /sy/ in order to cover the peaks P1m (in referring to "magnetic"), P2m, and MMNm. For /da/, /ba/, and /ga/, the latency ranges were 100–300 and 300–500 ms. The strongest ECD best meeting the criteria was chosen for each deflection for further analysis. The origin of the coordinate system for ECD locations (Table 3) is the midpoint of the coordinate system connecting the preauricular points. The $x$ axis is from the left-hand side (−) to the right (+), the $y$ axis from the origin to the nasion (+), and the $z$ axis is perpendicular to both of $x$ and $y$ axes, pointing upwards (+).

Traditionally, MMN has been analyzed by subtracting the activity evoked by standard stimuli from that evoked by the deviants. In this experiment, the original waveforms were used for dipole fitting. MMNm was considered to be present when response strengths differed significantly between standards and deviants during the N2m peak (response of opposite direction after P1m and P2m; see Fig. 2). In this way, the dipole fitting results were more reliable due to more prominent responses. Pihko and others (2005) have shown that the source strengths of the evoked magnetic responses can reflect speech sound discrimination in preschool children in a consistent manner with the traditionally used difference curve–based MMN calculated from evoked potentials.

**Results**

On the preintervention behavioral assessments, there was a main effect for syllable with no group differences (between-factor: group 2, within-factor: syllable 4, $F_{3,39} = 6.5, P < 0.002$). Syllable /ga/ was easy and /ba/ more difficult to discriminate from the standard /da/, and /sy/ was easy but /so/ difficult to discriminate form the standard /su/ (Newman–Keuls, $P < 0.05$ for both) (Table 1).

The sounds evoked magnetic fields in both left hemisphere (LH) and right hemisphere (RH), as shown in Figure 2 for one subject. The onset of each stimulus evoked an obligatory deflection P1m. Switching to the vowel evoked a second obligatory response P2m. For the stimuli /da/ba/ga/, P1m and P2m were in many cases fused to one prominent deflection (e.g., in Fig. 2) and could not be analyzed separately for all subjects. Therefore, the amplitude and latency values used for further analyses are those of the peak with maximum amplitude and referred to as those of P1m. P1m was elicited on average at 211 ms from the onset of the stimuli /da/ba/ga/ and at 147 ms from the onset of the /s/-sound. Switching to vowel /u/o/y/ after /s/- evoked a separate prominent P2m response at 342 ms (Table 2). Still later, the magnetic field distribution became different for the deviant and standard sounds. The deviants evoked a response, resembling the mismatch response in adults (Hari and others 1984; Näätänen 1992), with a maximum at about 330 ms after the change in the stimulus occurred. The only deviant stimulus that did not evoke this deviation-detection response was the syllable /so/.

Locations of the ECDs of the responses P1m, P2m, and MMNm, determined from the preintervention recordings (Table 3), indicate activation at or near the left and right auditory cortices (Fig. 3). The locations were significantly more anterior in the RH compared with the LH for P1m (determined for the standards /da/ and /su/) and P2m (/su/). In addition, in the RH, P2m was more anterior than P1m (for /su/; main effect for hemisphere $F_{1,15} = 11.5, P < 0.01$ and for peak $F_{1,15} = 22.9, P < 0.001$; Newman–Keuls $P < 0.001$ for both P1m and P2m; $P < 0.05$ for P1m vs. P2m; for /da/ anterioposterior hemisphere difference $P < 0.01$). For the MMNm responses, the ECD locations also tended to be more anterior in the RH, the difference reaching significance only for /ba/ ($P < 0.01$) (Table 3).

The intervention effect was manifested as follows (see Table 4 for the strength of the ECDs). When the P1m responses to the /da/, /ba/, and /ga/ stimuli were compared (between-factor
group, with factors repetition 2, hemisphere 2, and syllable 3), there was a main effect for repetition ($F_{1,12} = 18.9, P < 0.001$), hemisphere ($F_{1,12} = 5.9, P < 0.05$), and an interaction for group and repetition ($F_{1,12} = 5.1, P < 0.05$). The results indicate that, in general, the responses were stronger in the LH, they were stronger when tested the second time, and the growth was more pronounced for the PHONO than the MOTOR group. Post hoc analysis showed that the P1m response of the PHONO group to /ba/ was significantly stronger in both hemispheres and to /ga/ in the RH when measured after the intervention (Fig. 4). Wilcoxon, /ba/ LH: $T = 0, P < 0.03$; /ba/ RH: $T = 0, P < 0.03$; /ga/ RH: $T = 1, P < 0.05$). No significant differences were seen for the MOTOR group. As for the latency of the P1m for responses to /da/ba/ga/, there was a main effect for repetition ($F_{1,10} = 14.4, P < 0.004$) with shorter latencies in the post-intervention measurements without any group or hemisphere effects.

Strength of the P1m for the /su/s/ stimuli did not show any group, hemisphere, or intervention effect. When the P2m responses to the deviants /so/ and /sy/ were compared, there was a main effect for hemisphere ($F_{1,14} = 5.4, P < 0.05$) with no intervention or group effect. The post hoc test indicated that, again, the responses were stronger in the LH ($P < 0.05$). The latency of the P2m for the /su/s/ stimuli was slightly shorter in the RH than the LH ($F_{1,10} = 7.2, P < 0.05$).

Further, the intervention influenced the amplitude of the mismatch responses of the PHONO group. Specifically, the strengths of the equivalent dipoles of the responses to the /sy/ deviant in the LH of the PHONO group were stronger when measured after the intervention ($T = 3, P < 0.05$), whereas there were no changes for the MOTOR group (Fig. 4).

In the behavioral discrimination test, the PHONO group demonstrated a significant improvement in discriminating between the sounds in the 2 syllable pairs /su/-/sy/ and /da/-/ba/ that were difficult in the pretest (repetition 2 x syllable 2, $F_{1,7} = 12.2, P < 0.02$), whereas the MOTOR group did not. When the changes in the behavioral test scores were compared with changes in corresponding MEG responses, the only significant correlation was between /su/-/sy/ and MMNm to /sy/ in the RH (Spearman $r = 0.64, P < 0.009$; both groups included in the analysis).

### Discussion

Our results show that a well-targeted intervention will bring about plastic changes in the evoked magnetic fields of young language-impaired children. Following even the relatively short intervention period, the effect was manifested not only in a slight improvement in the behavioral discrimination test results but also in changes of brain activity some hundreds of milliseconds after the sound onset. The intervention effect was seen in both hemispheres indicating that the training modified

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**Table 2**

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**Table 3**

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SEM, standard error of mean. Latencies are given for P1m and P2m responses from LH and RH measured before (pre) and after (post) the intervention.
the functioning of auditory cortices in both the LH and RH of these children. Effects of intervention were observed both in sound encoding (obligatory P1m) and sound discrimination (mismatch response). Even though there were ample evidence and latency changes in the P1m responses to /da/ba/ga/ in both groups, the specific effect of intervention was seen in a more pronounced increase in the strength of the P1m responses of the PHONO group as well as in strengthening of the mismatch response to /sy/. The shortening of the latency of the P1m of both groups may be due to continued language rehabilitation, an age effect (the interval between the MEG measurements being about 3 months), or a combination of both.

Results of earlier evoked potential studies comparing the obligatory evoked potential deflections of language-impaired children with those of children with normal language development are somewhat inconsistent, reflecting probably the heterogeneity of the subject population as well as differences in the stimuli and paradigms used. Some studies have shown deviations—increase or decrease—in the latency and amplitude of the N1 response or its atypical topography in language-impaired children (Neville and others 1993; Lincoln and others 1995; Tonnquist-Uhlen and others 1996; Ors and others 2002), whereas others have not (Shafer and others 2000). McArthur and Bishop (2004) and Bishop and McArthur (2005) noted that at least in some of the SLI children, the N1-P2 waveforms were age inappropriate reflecting possibly maturational delay in cortical development. Consequently, these studies did not give us unambiguous expectations for the intervention effect in the sense of “normalizing” the evoked responses beyond the expected increase in the MMN. Further, the obligatory N1 response was not seen in the present study due to the young age of the children combined with the relatively fast interstimulus interval (Ponton and others 2002; Pihko and others 2005).

The waveforms of the evoked brain responses in our study were consistent with those of children of the same age group without language impairments, showing P1m and P2m followed by a mismatch response of opposite polarity evoked by the deviant speech sounds (Pihko and others 2005). The longer latency of the P1m to /da/ba/ga/ in comparison with that of /su/so/sy/ can be explained by 2 factors. First, our /ba/da/ga/ syllables had long voice onset times, which is known to delay the N1 peak in adults (Sharma and Dorman 2001). Further, because in many subjects only one peak, comprising both P1m and P2m, was present, the 2 peaks were analysed together taking into account the moment of maximum strength. This additionally increased the latency in cases where the P2m was more prominent. The more anterior locations of the ECDs in the RH in comparison with the LH are in agreement with the asymmetry of the locations of N1m and MMNm in the left and right auditory cortices of adults (Elberling and others 1982; Kaukoranta and others 1987; Tervaniemi and others 2005) and of P1m and P2m responses in children with normal language development (Pihko and others 2005).

It could be argued that the changes in the PHONO group were due to some unspecific factors like increase of attention to the linguistic stimuli after the intervention. However, it has been suggested that the MMN generated in the temporal lobes is not affected by attention (Näätänen 1990; Restuccia and others 2005). Because MEG selectively measures the activity of the temporal lobe sources of MMN (Hari and others 1984), it is unlikely that the present results can be explained by enhanced attention. On P1, in turn, attention has a diminishing effect in SLI children (Shafer and others 2005). Because the intervention increased P1m in our study, the result cannot be explained by increase in attention.

Consonant–vowel syllables like /da/ba/ga/ have often been used in studies on language or reading problems. They contain fast formant transitions in the beginning and may thus serve as a means to study children with problems in processing fast temporal changes in stimuli, one of the possible underlying problems in SLI (Tallal and others 1985). In our study, the intervention affected P1m responses evoked by syllables beginning with a consonant with fast formant changes but not the P1m evoked by the fricative or P2m responses evoked by the transition from a fricative to a vowel. Even if the P1m to syllables /da/ba/ga/ apparently includes the P2m evoked by the transition to the vowel, the contribution of P2m to the change is supposedly low based on the unaffected P2m evoked by /su/so/ sy/ as well as the nonchanging vowel in /da/ba/ga/.

In adults, neural encoding of acoustic changes ongoing in a speech signal is reflected in N1 providing necessary but not sufficient information for behavioral discrimination of speech sounds (Sharma and Dorman 2000). In contrast, MMN has been shown to reflect phonemically relevant differences in the listener’s first language, whereas subjects with no knowledge of that language did not show MMN to the same differences (Näätänen and others 1997; Sharma and Dorman 2000). Accordingly, a group of Finnish monolingual children developed
prominent P1m and P2m in the present study were evoked by sound onsets and changes in the sound structure of the speech stimulus, respectively, as are N100m and N100m in adults (Kaukoranta and others 1987; Renvall and Hari 2002). Consequently, we can say that P1m and P2m reflect stimulus processing which occurs at a sensory level. It has been shown that N1m increases after 3 weeks’ discrimination training (Menning and others 2000) or does not habituate after a short but intensive training (Brattico and others 2003). Thus, we can speculate that the changes in P1m could be due to the exposure to the relevant phonetic training.

At a group level, there was a coarse correspondence between the behavioral data and brain responses: a MMNm was elicited for both deviants /ba/ and /ga/ and for deviant /sy/, which was behaviorally easy to discriminate from the standard but not for /so/, which was more difficult to discriminate. However, our study failed to show a positive correlation between the significant changes in the behavioral test results before and after the intervention and changes in the P1m or MMNm. Similarly, in the study of Shafer and others (2005), there was no correspondence between poor behavioral performance and absence of MMN in SLI children for discrimination of vowels. They suggested that MMN and performance in the behavioral tasks did not reflect identical processes. Also other factors than syllable discrimination, such as lack of attention and concentration on the task at the end of the visit to the laboratory, might have affected our behavioral test results. In addition, different individual therapies the children attended to, language exposure at home, as well as variable underlying problems and degree of impairment added variability to our data. All this, combined with the relatively small group sizes, may have affected the strength of the results.

Slight improvements in the language domain are sometimes difficult to estimate in young SLI children due to multiple external factors that may influence a child’s performance, among these test practice effects and variations in motivation and cooperation. Our approach of recording automatically elicited evoked magnetic fields in preschool SLI children seems to be a feasible way of obtaining accurate information on the neural processes underlying their speech perception. In fact, sound reception and discrimination in the brain has been investigated with this approach in very young individuals, even in newborns (Huotilainen and others 2003; Kujala and others 2004; Plisko and others 2005; Sambeth and others 2006), and fetuses (Huotilainen and others 2005). Consistently with previous studies evaluating the impact of training programs on behavior and auditory physiology of children with dyslexia (Kujala, Karma, and others 2001; Temple and others 2003) or with learning problems (Hayes and others 2003; Warrier and others 2004), our study indicates the effectiveness of the intervention on the central auditory processing of children with SLI. In addition, our study demonstrates that MEG can be successfully applied to evaluate plastic changes in children’s brains. This is encouraging in terms of determining training effects even in younger children with language impairments. In future, when some of the practical challenges in studying small children will be taken care of in MEG equipment and software development, the intersubject variability will decrease. This will make the results even more consistent allowing, for example, better accuracy in studying lateralization of speech-related functions. These improvements would include head movement compensation, as well as having the head closer to sensors simultaneously on both sides.
Our study shows that preschool children can benefit from a targeted intervention provided in the form of play by preschool teachers. It has recently been shown that infants' speech perception skills (Tsao and others 2004) or discrimination of rapid auditory cues measured behaviorally (Benasich and Tallal 2002) and with event-related potentials (Guttorp and others 2005; Kuhl and others 2005; Benasich and others 2006) significantly predict language outcome. An important implication of these studies and of our results is that some of the problems faced during the first school years could be prevented or at least alleviated beforehand. This, in turn, could have long-term beneficial effects on the schooling and well-being of these children.

Notes
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