Altered hemispheric asymmetry of auditory P100m in dyslexia

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Abstract

In various studies, deviances of hemispheric laterality in the organization of the perisylvian region in dyslexia have been suggested. Although associated with impaired language functioning, the clinical significance of atypical cerebral lateralization remains unclear. The present study examined interhemispheric source differences of magnetic responses to the German synthetic syllable [ba:] in the auditory cortex of 14 dyslexic children and 12 normally literate controls aged 8–15 years. In all subjects, two main deflections, P100m and N260m, were evident in the responses over each hemisphere. While in the control group the right P100m dipole was located more anterior than the corresponding dipole of the left hemisphere, the dyslexic group displayed a rather symmetrical source configuration between the hemispheres. This symmetry reflected a deviance in the right perisylvian region for the dyslexic subjects' P100m, which was generated ≈1 cm more posterior than the response in controls. The deviation was also obvious relative to the source location of the later component, N260m, which did not systematically differ between the participant groups. Our results suggest that the altered hemispheric asymmetry reflects an atypical organization of the right hemisphere in children and adolescents with dyslexia.

Introduction

Research on the neural basis of developmental dyslexia has suggested interhemispheric deviances in the organization of the perisylvian region (e.g. Larsen *et al*., 1990; Galaburda, 1993; Kushch *et al*., 1993; Dalby *et al*., 1998; Shaywitz *et al*., 1998; Pugh *et al*., 2000; Robichon *et al*., 2000; Simos *et al*., 2000a,b, 2002; Helenius *et al*., 2002). Functional neuroimaging studies involving the visual presentation of language tasks have shown typical or enhanced activity in left-hemisphere frontal-lobe language sites, but reduced or absent activity in left temporo-parietal language areas in people with dyslexia (Paulesu *et al*., 1996; Rumsey *et al*., 1997; Shaywitz *et al*., 1998; Brunswick *et al*., 1999; Temple *et al*., 2001). By contrast, McCrory *et al*. (2000) reported right-hemisphere differences during auditory word repetition: the dyslexic individuals demonstrated less haemodynamic activation than normal readers in the right superior temporal and right postcentral gyri. Regarding findings of an atypical brain-activation profile observed either in the left hemisphere or the right, McCrory and colleagues proposed that the neural manifestation of dyslexia is task-specific, i.e. functional rather than structural in nature.

Using magnetoencephalography (MEG), we recently reported pronounced deviations in the organization of the left-hemisphere auditory cortex in children with dyslexia (Heim *et al*., 2000). The source location of the magnetic wave elicited by passive listening to speech and nonspeech stimuli ≈210·ms after onset (M210) was found to be shifted away from the *planum temporale* towards anterior regions and probably into the superior temporal sulcus. The dyslexic group did not

differ from the control group in the earlier magnetic field (M80) whose centre of activity might be tied to Heschl's gyrus.

Because in our previous MEG study responses were solely recorded over the left supratemporal cortex, there is no information whether dyslexic individuals and normal readers may also differ in magnetic source configuration of the right hemisphere. The current study was designed to investigate possible interhemispheric source differences of event-related magnetic fields between children and adolescents with dyslexia and normally literate controls. Event-related fields were recorded in response to stop consonant–vowel syllables using a multi-channel MEG system covering the entire cranium.

Materials and methods

Subjects

We studied 14 children and adolescents with developmental dyslexia (five females) and 12 control subjects (five females) who had no history of reading and writing impairment. Mean age was 12.92 years (range: 8.6–15.9) and 12.27 years (range: 8.5–15.0) for dyslexic and control groups, respectively ($P > 0.05$, n.s.) Informed written consent was obtained from the parents of the children before testing began. Subjects received shopping vouchers and/or cinema tickets for participating. All participants had German as a first language, all showed normal peripheral hearing and none was reported as having had a history of neurological disease, psychiatric disorder or psychotropic medication. As assessed with the Edinburgh Handedness Inventory (Oldfield, 1971), one dyslexic subject was left-handed and one control subject was ambidextrous (laterality quotients −90 and −10, respectively).

Dyslexic participants were recruited by advertisement from among members of the German Dyslexia Association and by recommenda-

TABLE 1. Psychometric data across subject groups (median)

	Control subjects (n = 12)	Dyslexic subjects (n = 14)	U-test†	P-value
Non-verbal IQ	118.38	97.38	24.5	0.002
Standard word reading‡				
Errors (maximum, 72)	0.00	7.00	1.5	0.001
Time (s)	62.50	98.00	13.5	0.001
Standard passage reading‡				
Errors (maximum, 261)	5.00	33.00	0	0.001
Time (s)	120.50	218.50	6	0.001
Word reading				
Points (maximum, 300)	290.50	232.50	2	0.001
Time (s)	131.00	235.50	11	0.001
Pseudoword reading				
Points (maximum, 300)	267.00	168.50	0	0.001
Time (s)	200.00	282.50	29	0.005
Standard spelling‡				
errors (%)	10.00	70.00	3	0.001
Digit span forwards§	5.95	5.30	33.5	0.05
Digit span backwards§	4.70	3.70	19.5	0.004

†Mann–Whitney U-test; ‡lacking German normative data for older children, we decided not to transform reading and spelling raw scores into percentage-ranks; instead absolute error scores and percentage of errors, respectively, are shown; §Value missing in three dyslexic subjects.

tions of the local educational counseling service. Literacy skills of both groups were measured with standardized assessments of reading (Linder & Grissemann, 1998) and spelling (Rathenow *et al.*, 1981; Müller, 1983, 1997; Grund *et al.*, 1994, 1995), nonstandardized word- and pseudoword reading, and digit span tests. Non-verbal intelligence was estimated using Raven's Standard Progressive Matrices (Heller *et al.*, 1998). The overall psychometric test performance is shown in Table 1. While all participants demonstrated at least normal nonverbal intelligence (IQ > 85), IQ scores were significantly lower in the dyslexic than in the control group. Consistent with their difficulties, dyslexic subjects were significantly outperformed by the normally literate controls on all language-related tests.

Materials and procedure

German stop consonant–vowel syllables were created with a sampling rate of 10 kHz in the cascade mode of a Klatt formant synthesiser (Klatt, 1980). The total stimulus duration was 250 ms including a formant transition period of 40 ms. The syllables were selected based on the results of a categorical perception experiment conducted in normally literate subjects. In those experiment, participants were asked to identify stimuli in a 10-item [ba:]–[da:] continuum. The mean identification scores for stimuli 5 and 8 in the continuum were 88% and 91% for children (n = 16) and 96% and 91% for adults (n = 17). These two stimuli occurring near the category boundary of the continuum were referred to as [ba:] and [da:]. The syllables were composed of three formants (F1–F3) and differed in the onset frequencies of the second and third formant transition. The starting points of the second and third formants were 1365 and 2337 Hz for the [ba:] stimulus and 1567 and 2515 Hz for the [da:] stimulus. The steady-state formant frequencies of the vowel [a:] were 770, 1340 and 2400 Hz for F1, F2 and F3, respectively. The fundamental frequency of each syllable started at 128 Hz and decreased linearly to 109 Hz at stimulus end. The amplitude of voicing was constant at 54 dB and fell linearly to 11 dB during the last 25 ms of each stimulus.

A series of 650 syllables was delivered binaurally through magnetically silent and echo-free plastic tubing terminating in ear inserts. The duration of the intertrial interval (defined as stimulus onset to stimulus onset) was constant at 1 s. The stimulus intensity was 60 dB above the individually determined hearing level. A passive oddball paradigm was used in which the syllable [ba:] served as the standard (probability of occurrence 80%) and [da:] as the deviant stimulus (probability of occurrence 20%). Subjects were exposed to three further blocks each of 650 stimuli: (i) [ba:]–[da:] contrasts including 90-ms formant transitions; (ii) ideal [ba:] vs. variant [ba:] contrasts with 40-ms formant transitions; or (iii) 90-ms formant transition periods. These data are not reported here. Experimental blocks were interleaved with 2–5 min breaks. Presentation order of blocks was varied between subjects.

To control for level of arousal, participants watched silent movies or cartoons displayed on a special magnetic-field-free screen. The subjects were instructed to attend to the video program and to ignore the auditory stimuli. In addition, subjects were asked to prevent unnecessary eye or body movements during recordings. Compliance was verified by video monitoring.

MEG recording and data analysis

Magnetic responses were measured simultaneously from the left and right hemispheres using a whole-head neuromagnetometer (BTi, MAGNES 2500™; 4D Neuroimaging, San Diego, CA, USA) housed in a magnetically shielded chamber. Subjects were seated with their legs extending horizontally on a height-adjustable bed, their backs leaning against a backrest, and their heads inside the helmet-like sensor. Within the sensor, 148 superconducting quantum interference detectors (magnetometer-type) were arranged in a circular concave array so that they covered the entire cranium. The distance between two adjacent magnetometers measured 28 mm. The intrinsic system noise was $10 \, \text{fT}/\sqrt{\text{Hz}}$ down to 0.5 Hz.

Syllable-evoked brain responses were recorded continuously at a sampling rate of 508.63 Hz with a bandpass of 0.1–100 Hz. Eye movements and blinks were monitored by recording horizontal and vertical electro-oculograms. In an off-line mode, magnetic signals were first corrected for magnetocardiographic activity by means of a linear regression algorithm included with the 4-D Neuroimaging software package. Then, averaged waveforms for the standard and deviant syllables were calculated across epochs of 800 ms, including a 100-ms prestimulus baseline. Epochs with a MEG or electro-oculogram change >3.5 pT or >120 µV, respectively, were omitted from further analysis. The baseline was corrected for each channel accord-

TABLE 2. The latencies and field amplitudes of P100m and N260m peaks for the two subject groups (mean ± SEM)

	Left hemisphere		Right hemisphere	
	Peak latency (ms)	Peak amplitude RMS (fT)	Peak latency (ms)	Peak amplitude RMS (fT)
Control subjects ($n = 12$)				
P100m	98.57 ± 2.90	89.94 ± 8.97	94.48 ± 3.62	66.73 ± 7.96
N260m	260.13 ± 5.50	126.65 ± 11.83	267.18 ± 4.16	124.27 ± 7.62
Dyslexic subjects ($n = 14$)				
P100m	95.72 ± 2.43	76.54 ± 6.67	100.37 ± 4.40	64.53 ± 6.60
N260m	261.26 ± 4.03	140.33 ± 17.25	268.58 ± 3.78	139.75 ± 12.33

For statistical results see text.

TABLE 3. The dipole moments and locations of P100m and N260m for the two subject groups (mean ± SEM)

	Left hemisphere				Right hemisphere			
	q	x	y	z	q	x	y	z
Control subjects ($n = 12$)								
P100m	19.76 ± 2.08	1.44 ± 0.21	5.05 ± 0.15	5.74 ± 0.22	15.04 ± 4.27	2.23 ± 0.31	−5.23 ± 0.42	5.65 ± 0.27
N260m	25.17 ± 2.79	0.87 ± 0.35	4.98 ± 0.16	5.21 ± 0.17	28.00 ± 4.85	1.41 ± 0.24	−4.88 ± 0.34	5.15 ± 0.26
Dyslexic subjects ($n = 14$)								
P100m	16.95 ± 1.99	1.42 ± 0.21	4.83 ± 0.23	5.93 ± 0.18	11.12 ± 1.30	1.26 ± 0.23	−5.31 ± 0.19	5.76 ± 0.24
N260m	32.94 ± 5.01	1.15 ± 0.19	4.77 ± 0.24	5.38 ± 0.25	24.41 ± 3.08	1.80 ± 0.20	−5.23 ± 0.30	5.32 ± 0.24

q, dipole moment (nA.m); x, y, z, source locations (cm); for statistical results see text.

ing to the mean value of the signal during the 100 ms prior to the stimulus. After that, evoked fields were digitally low-pass filtered to 20 Hz using a second-order zero-phase-shift Butterworth filter (filter roll-off 12 dB/oct).

Source parameters of the event-related magnetic fields were estimated with a single equivalent current dipole (ECD) in a spherical volume conductor using subsets of 34 channels over the left and right perisylvian regions. An ECD defined by the dipole moment, orientation and space coordinates was computed for each sample point by means of a least-squares fit. The location estimates of each ECD were specified with reference to a head-based Cartesian co-ordinate system. The origin of this co-ordinate system was set at the mid-point of the medial–lateral (y-) axis interconnecting the centre points of the entrance to the auditory meatus of the two ears (positive towards the left ear). The posterior–anterior (x-) axis projecting from the origin to the nasion (positive towards the nasion) and the inferior–superior (z-) axis being perpendicular to the x-y plane (positive towards the vertex).

Data quality sufficient for utilizing this source analysis technique was achieved for magneto-cortical responses to the standard syllable [ba:]. In the latency window between 50 and 300 ms from stimulus onset a sequence of two prominent waves was detectable in each participant: one wave with a latency which peaked between 78 and 139 ms and another which peaked between 221 and 288 ms. Rounding mean latencies to tens and considering dipole orientation (see below), these components were labelled as P100m and N260m, respectively.

ECDs of the left and right hemispheres were selected around the root mean square (RMS) maximum of the P100m and N260m to the syllable [ba:]. They were accepted when they fulfilled the following criteria based on statistical and anatomical considerations: (i) goodness of fit >84%; (ii) confidence volume <2 cm³; (iii) RMS > 24 fT; (iv) dipole moment >3 nA.m; (v) correct dipole orientation: P100m ECD pointed upwards, N260m ECD pointed downwards; and (vi) inferior–superior value $3 < z < 8$ cm.

The mean goodness of fit varied between (mean ± SEM) 92 ± 1 and 97 ± 1%, the mean confidence volume between 27 ± 17 and 66 ± 26 mm³. Subject groups did not differ statistically on either source parameter (goodness of fit, $F_{1,24} = 2.3$, $P > 0.05$, n.s.; confidence volume, $F_{1,24} = 0.9$, $P > 0.05$, n.s.) The goodness of fit for the P100m ECD was better in the left than in the right hemisphere (97 vs. 94%). Furthermore, in the right hemisphere the ECD of the N260m accounted for on average 3% more of the measured field variance than the P100m ECD ($F_{1,24} = 4.8$, $P < 0.04$). The confidence volume was significantly smaller for the N260m ECD than for the dipole fit of the P100m (41 vs. 219 mm³; $F_{1,24} = 11.6$, $P < 0.002$).

Statistics

The peak latencies and RMS values of the P100m and N260m were submitted to two-way analyses of variance (ANOVAs) with Group (dyslexic vs. control) as between-subjects factor and Hemisphere (left vs. right) as repeated-measures factor. Three-way ANOVAs were conducted on the strengths (i.e. dipole moments) and locations (x, y and z) of the ECDs with Component (P100m vs. N260m) and Hemisphere as within-subjects factors and Group as between-subjects factor. Significant results ($P < 0.05$) were followed by planned comparisons. Rank correlations between the chronological age and magneto-cortical responses were computed using Spearman's coefficient. Because there was no significant correlation of nonverbal IQ with any of the neuromagnetic parameters, analyses were not adjusted for nonverbal intelligence (for $n = 26$, min Spearman's $r = 0.03$, max. Spearman's $r = -0.35$, $P > 0.05$, n.s.)

Results

The magnetic field components P100m and N260m

In both subject groups, two main deflections, peaking at ≈100 and ≈260 ms after onset of the syllable, were obvious in the responses over each hemisphere. Figure 1 illustrates typical averaged neuromagnetic responses in an individual control and dyslexic subject. As

P100m

N260m

left

inion

100 fT/div →

control subject
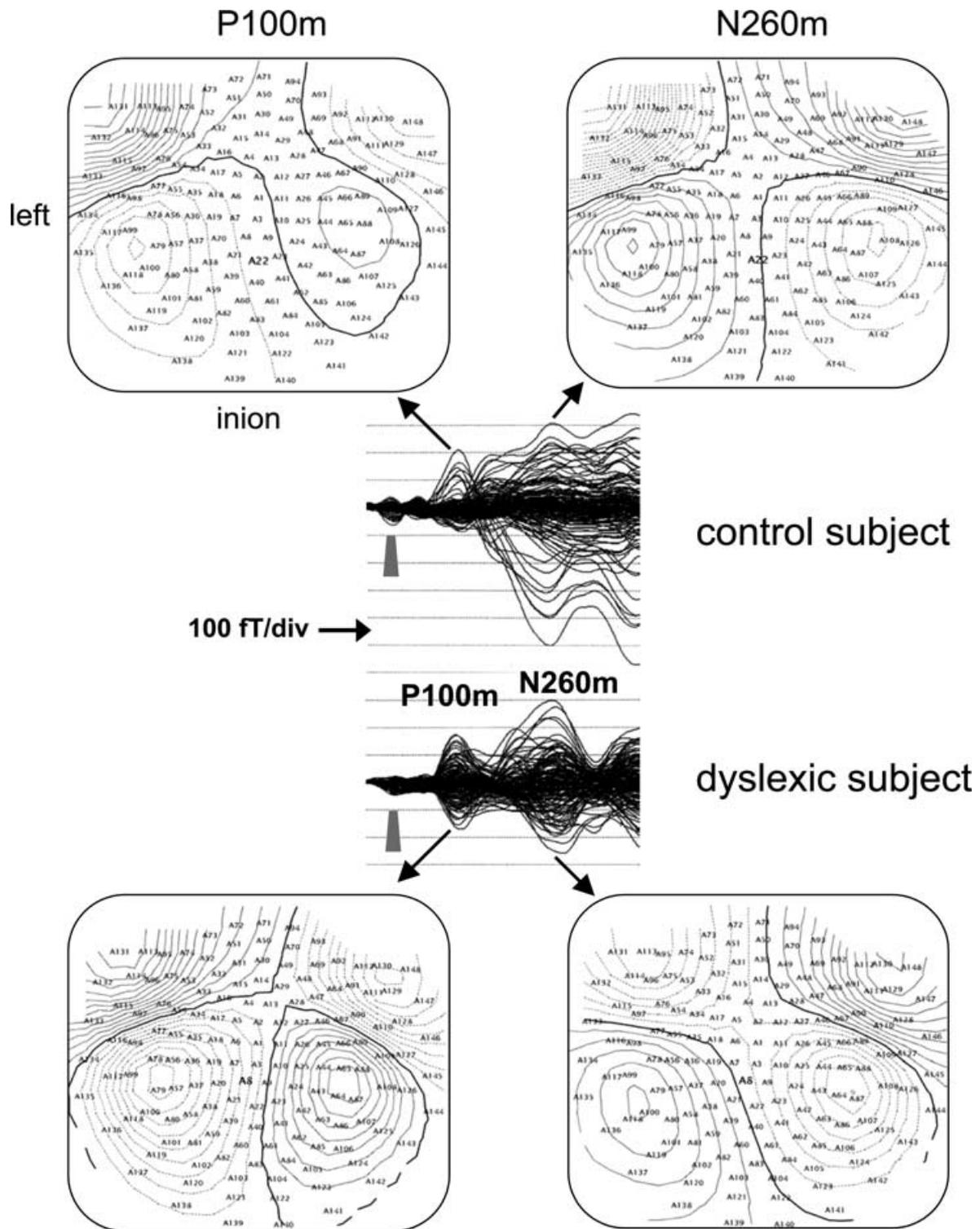
P100m   N260m

dyslexic subject

FIG. 1. (Middle) Averaged neuromagnetic responses (overlay of all 148 channels) to the syllable [ba:] in an individual dyslexic and an individual control subject. Peaks following stimulus onset (grey trapezium) are indicated as P100m and N260m. (Top and bottom) Corresponding isofield contour maps at the peak latencies of the two components. Solid contour lines indicate the outgoing, the dashed lines the ingoing magnetic field, and the thick solid line zero flux. The spacing of the contours is 10 and 20 fT for the P100m and N260m, respectively. A1–A148 represent the channel numbers. Following the 'right-hand rule', the components' sources in the left and right hemispheres are orientated as follows: the P100m dipoles pointed up (indexing positivity), the N260m dipoles pointed down (indexing negativity).

indicated by the contour maps, the dipoles of the first peak were orientated superiorly, indexing positive polarity (P100m) and the dipoles of the second peak were orientated inferiorly, indexing negativity (N260m).

Latencies and field amplitudes

Table 2 presents the latencies and RMS field amplitudes of P100m and N260m peaks for the dyslexic and control subjects. Two-way ANOVAs
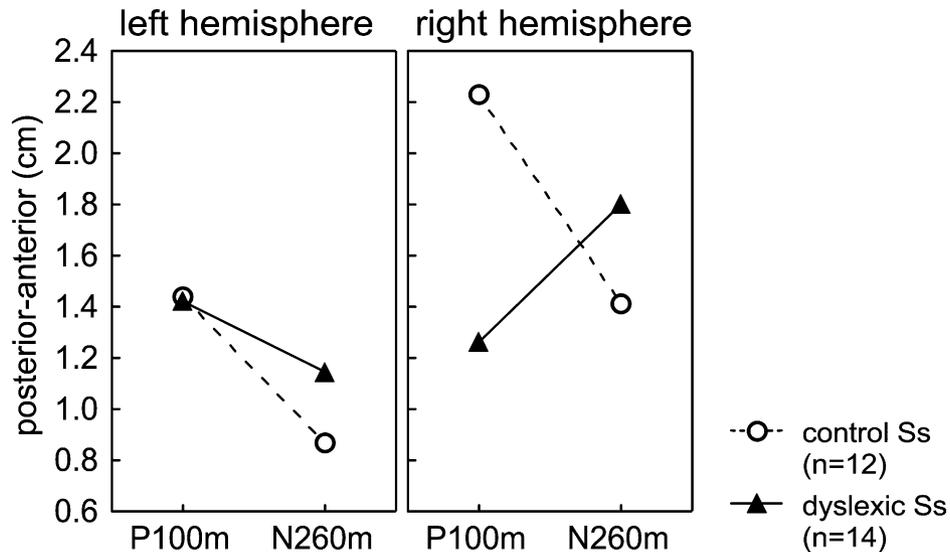
FIG. 3. Source locations of P100m and N260m along the posterior–anterior (*x*-) axis for the control subjects (○) and dyslexic subjects (▲). The *x*-coordinates of the two components were averaged for each group within hemispheres.

provided no significant group differences on the peak latencies of the two components. For the later peak, N260m, a significant Hemisphere main effect was observed with shorter mean latencies in the left (260.70 ms) than in the right (267.88 ms) hemisphere ($F_{1,24} = 5.9$, $P < 0.02$). Mean field amplitudes of P100m and N260m did not differ statistically between the dyslexic and control subjects. For both groups, significantly larger P100m amplitudes were recorded in the left (83.24 fT) than the right (65.63 fT) hemisphere ($F_{1,24} = 12.7$; $P < 0.002$). No effect of Hemisphere was observed for the later N260m peak.

Source strengths and locations

Table 3 summarizes the ECD strengths and coordinates of the P100m and N260m for the dyslexic and control subjects. A three-way ANOVA performed on dipole moment data revealed a significant main effect for the factor Component ($F_{1,24} = 30.9$; $P < 0.001$). As was to be expected by the proportions of the RMS peaks (Table 2), dipole moments of the N260m (27.63 nA.m) were on average stronger than those of the earlier component P100m (15.72 nA·m). Neither differences between subject groups nor any other effect reached statistical significance. When analysing the dipole moments of each component separately in two-way ANOVAs, a significant main effect of Hemisphere was yielded for the P100m ECD ($F_{1,24} = 5.1$; $P < 0.03$). That is, the P100m source was on average stronger in the left (18.36 nA.m) than in the right (13.08 nA·m) hemisphere. As with the corresponding RMS field amplitudes, no interhemispheric differences were found for the N260m source strength.

A three-way ANOVA performed on the *x*-coordinates yielded significant main effects for the factors Component ($F_{1,24} = 6.9$, $P < 0.01$) and Hemisphere ($F_{1,24} = 9.1$, $P < 0.006$). In addition, there were two significant interaction effects: Group × Hemisphere ($F_{1,24} = 14.9$, $P < 0.001$) and Group × Component × Hemisphere ($F_{1,24} = 7.7$, $P < 0.01$). Figure 2 depicts the three-way interaction which was then evaluated in detail using planned comparisons.

Looking at the control group, a similar source configuration was observed in both hemispheres with the N260m source locations being significantly posterior to the P100m sources ($F_{1,24} = 7.5$, $P < 0.01$ and $F_{1,24} = 14.8$, $P < 0.001$ for left and right hemispheres, respectively). However, the P100m and N260m sources of the right hemisphere were

located on average more anterior than the corresponding sources of the left hemisphere (P100m $F_{1,24} = 6.7$, $P < 0.02$, and N260m $F_{1,24} = 6.4$, $P < 0.02$). Thus, control subjects displayed a hemispheric source asymmetry for both components. Whereas in the dyslexic group the generators of the N260m followed the more anterior right than left localization pattern ($F_{1,24} = 10.9$, $P < 0.003$), source locations of the P100m were found to be rather symmetrical between hemispheres. The absence of P100m source asymmetry in dyslexic subjects resulted in two significant effects in the right hemisphere: (i) a within-group difference for the N260m ECD located anterior to the P100m ECD (mean *x* difference = 0.54 cm; $F_{1,24} = 7.5$, $P < 0.01$) and (ii) a between-group difference for the P100m ECD located ≈1 cm more anterior in controls than in dyslexic subjects ($F_{1,24} = 6.6$, $P < 0.02$). These right-hemisphere effects are further illustrated in Fig. 3, which shows individual subject data projected onto the sagittal plane (*x*–*z* coordinates).

To account for a possible influence of neuroanatomical variability on the components' ECD locations, P100m source localizations were normalized with respect to the N260m sources according to Δ_{sc} (P100m$_{sc}$ − N260m$_{sc}$), where SC = source coordinate on *x*- or *z*-axes. As Fig. 3 (right) shows, in the right hemisphere of 11 out of 14 dyslexic subjects (79%) the P100m source was located posterior to the N260m source (indexed by negative Δ_x-values). On the other hand, in 10 out of 12 control subjects (83%) right-hemispheric P100m generator locations were anterior to those of the right-hemispheric N260m (indexed by positive Δ_x-values). No such group-specific source configuration was evident in the left hemisphere (Fig. 3, left).

Analysis of the source coordinates along the medial–lateral (*y*)-axis revealed no statistically meaningful effects (Table 3). Generator loci along the *z*-axis (Table 3) were found to be significantly influenced by the factor component for the sources of the N260m to be located more inferior than the sources of the P100m (mean *z*-coordinates 5.27 and 5.77 cm, respectively; $F_{1,24} = 18.8$, $P < 0.001$). Other effects failed to reach statistical significance.

Correlations between chronological age and magneto-cortical parameters

To test whether there are age-related changes in the magneto-cortical responses, correlations between age and both latencies and field amplitudes for the P100m and N260m peaks as well as their source

left hemisphere — **right hemisphere**

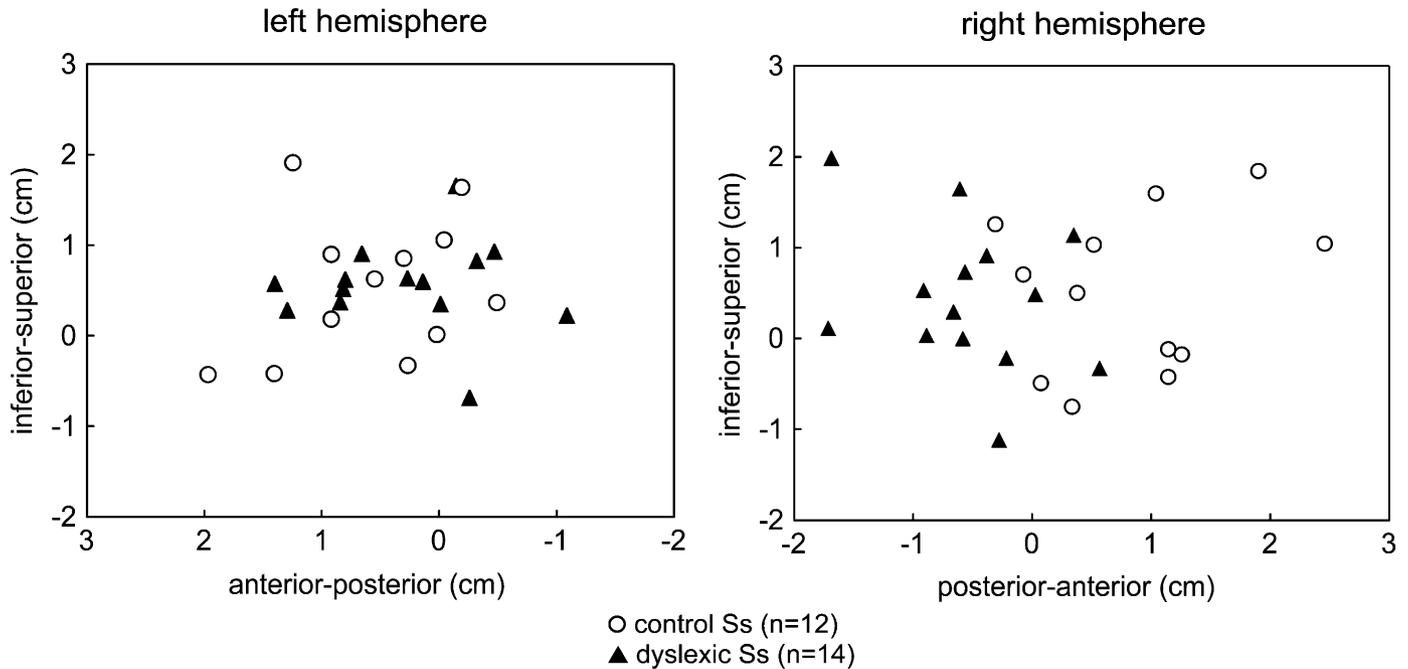○ control Ss (n=12)
▲ dyslexic Ss (n=14)

FIG. 3. Individual subject data from 12 control (○) and 14 dyslexic (▲) subjects for localizations of the P100m source relative to the source location of the N260m in each hemisphere. The abscissa represents the posterior–anterior (*x*)-axis, the ordinate the inferior–superior (*z*)-axis.

parameters were computed. Across the whole sample ($n = 26$), significantly negative age correlations were found for the P100m latency of the left ($r = -0.77$, $P < 0.001$) and right ($r = -0.43$, $P < 0.03$) hemispheres. Whereas the age-by-left-hemisphere P100m latency correlation remained statistically significant within each subject group ($r = -0.76$, $P < 0.002$ and $r = -0.79$, $P < 0.002$ for dyslexics and controls, respectively), the smaller correlation with the respective right-hemispheric value approached statistical significance in the dyslexic subjects ($r = -0.52$, $P < 0.06$, n.s.) but not in the controls ($r = -0.45$). None of the peak RMS amplitudes, dipole moments or source locations was significantly correlated with subject's age (across- and within-group analyses). Furthermore, age correlations with hemispheric laterality indices of the P100m and N260m *x*-coordinates (difference between right and left hemisphere divided by their sum) were not significant, either across- or within-subject groups (*P*-values between 0.14 and 0.97).

Discussion

In all participants, two main deflections, P100m and N260m, in response to the syllable [ba:] were evident in the event-related field from each hemisphere. As an important finding, differences in source locations of the P100m were observed between dyslexic and control subjects. In the control group, the source configurations were similar for both hemispheres with N260m ECDs located significantly posterior to P100m ECDs. The P100m as well as N260m source locations of the right hemisphere were significantly more anterior than the left-hemisphere homologues. Consequently, the control subjects displayed a hemispheric source asymmetry for either component. This interhemispheric asymmetry is consistent with reports of a more anterior location for adult N100m in the right than in the left hemisphere (e.g. Elberling *et al.*, 1982; Eulitz *et al.*, 1995; Ohtomo *et al.*, 1998; Heim *et al.*, 2003). In the dyslexic group, the sources of the N260m coincide with the typical more-anterior-right-than-left localization pattern, whereas generator loci of the P100m were found to be rather symme-

trical between hemispheres. This absence of asymmetry reflected a striking deviance in the organization of the right hemisphere: the N260m source was located significantly anterior to the P100m source with the latter being positioned ≈1 cm posterior to the P100m ECD in the control group.

In a previous study involving dyslexic adults, we reported similarly reduced interhemispheric asymmetry in source locations of magnetic waves 100 ms after stimulus onset. While there was no significant between-group difference in the centre of activity over the left hemisphere, the dyslexic subjects' N100m source of the right hemisphere was positioned ≈0.70 cm posterior to the source in the control participants (Heim *et al.*, 2003).

These results support the notion that, in both children and adults with dyslexia, magnetic responses ≈100 ms after syllable onset were generated in different perisylvian structures than in normally literate controls. Because the adult N100m reflects inter alia the extraction of phonological features from speech (Obleser *et al.*, 2003), this might indicate changes in the functional neuroanatomy of the language system. It is debatable whether the deviations in cerebral organization form the neural substrate of dyslexia or rather constitute epiphenomena of different processes such as an altered cortical maturation. Inverse relationships between age and P100/P100m latencies (cf. Paetau *et al.*, 1995; Sharma *et al.*, 1997; Ponton *et al.*, 2000) show that maturation affects the timing of this component. The neural substrate generating the P100m indexed by the spatial parameters, however, did not correlate with age, pointing to changes in cortical organization in dyslexia.

Reduced or absent lateralization in the source configuration of auditory magnetic fields ≈100 ms after stimulus presentation appears to be a common feature observed in both children and adults with dyslexia. We do not know whether the juvenile P100m and adult N100m represent the same or different components. Auditory evoked potential peaks, frequently reported in school-age children, are the P85–120 and N200–250 (Courchesne, 1990; Ceponiene *et al.*, 1998, 2001). However, their equivalents among adult auditory event-related

potentials are unclear (Ceponiene *et al.*, 1998). Considering the dipole orientation of the present P100m to the syllable [ba:], this might be a correlate of the adult auditory P1/P1m. Recently, Ceponiene *et al.* (2002) suggested that in 9-year-olds the neural generators of the auditory N100 might have different morphologies than in the mature brain (e.g. orientations). Thus, the latency of the P100m is also reminiscent of the adult component N1m.

The deviance in the right cerebral hemisphere observed in the dyslexic subjects is in line with the PET findings by McCrory *et al.* (2000) showing reduced activation in several right-hemisphere regions in general and an area of the right secondary auditory cortex in particular in a group of adult dyslexics. Other functional neuroimaging studies of dyslexia reported atypical activation patterns in the left hemisphere (Paulesu *et al.*, 1996; Rumsey *et al.*, 1997; Shaywitz *et al.*, 1998; Brunswick *et al.*, 1999; Temple *et al.*, 2001). By the same token, our previous MEG study (Heim *et al.*, 2000) revealed deviations in the organization of the left-hemisphere auditory cortex in children with dyslexia. There, an unusual source location was detected for a later response ($\approx$210 ms post-stimulus) relative to the earlier M80 to pure tones and consonant syllables. In the current study, on the other hand, a relative change in generator position of the earlier magnetic P100m to the later N260m was observed in the right perisylvian region. It is likely that differences in subject characteristics such as chronological age (mean age in the Heim *et al.*, 2000 study, 10.6 years; mean age in the present study, 12.6 years) or stimulus materials (naturally spoken syllables in the Heim *et al.*, 2000 study vs. synthetic syllables in the present study) account for the discrepancy. Thus, the findings of left- and right-hemisphere deviances by no means contradict each other but characterize the temporal dynamic of the relevant brain processes in individuals with dyslexia. This is not surprising in the context of the notion of the brain as a highly dynamic system (e.g. Elbert *et al.*, 2001).

Our findings, while preliminary, support altered hemispheric asymmetry in people with dyslexia. Moreover, they emphasize the contribution of the right primary auditory cortex and adjacent regions to the neural correlates of developmental dyslexia.

Acknowledgments

Abbreviations

ECD, equivalent current dipole; MEG, magnetoencephalography, magnetoencephalographic; RMS, root mean square.

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