Gradual recovery from dyslexia and related serial magnetoencephalographic changes in the lexicosemantic centers after resection of a mesial temporal astrocytoma

Case report

KYOUSUKE KAMADA, M.D., YUTAKA SAWAMURA, M.D., FUMIYA TAKEUCHI, PH.D., KIYOHIRO HOUKIN, M.D., HIDEAKI KAWAGUCHI, M.D., YOSHINOBU IWASAKI, M.D., AND SHINYA KURIKI, PH.D.

Department of Neurosurgery, Research Institute for Electronic Science, Department of Laboratory Medicine, Hokkaido University; and Department of Neurosurgery, Sapporo Medical College, Sapporo, Japan

Letter-perception centers are not held in as high regard as motor- and language-related cortices during planning of neurosurgical procedures, and there have been no reports suggesting cortical reorganization of reading ability. The authors describe a patient with a left mesial temporal glioma in whom two letter-perception centers (the anterior portion of the left superior temporal gyrus and the left fusiform gyrus) were successfully localized before surgery by performing magnetoencephalography (MEG) during reading tasks. Control MEG examinations of 15 healthy volunteers were also performed to assist in a careful interpretation of patient results. Although a radical resection of the mesial temporal glioma, which involved the left fusiform gyrus, caused severe dyslexia, the patient’s impaired reading skills improved gradually during a 1-year postoperative period. In the meantime, the spared left superior temporal gyrus displayed an overshot recovery of MEG responses. During the postoperative period there was no obvious recovery in MEG signals and no compensatory activity in the contralateral fusiform gyrus. This case demonstrates that lexicosemantic centers involved in the reading process can be noninvasively localized using MEG and that the results obtained are highly reliable for surgical planning. The results of the repeated MEG reflected sequentially the patient’s recovery from dyslexia. This is the first report in which MEG studies have been shown to predict preoperatively the risk of dyslexia and demonstrate its serial physiological recovery.

KEY WORDS • dyslexia • glioma • mesial temporal lobe • functional recovery • magnetoencephalography

Abbreviations used in this paper: fMR = functional magnetic resonance; IQ = intelligence quotient; LORETA = low-resolution electromagnetic tomography; MEG = magnetoencephalography; PET = positron emission tomography; RMS = root mean square; SLTA = Standard Language Test for Aphasia; WAIS-R = Wechsler Adult Intelligence Test–Revised.

J Neurosurg 100:1101–1106, 2004

Gradual recovery from dyslexia and related serial magnetoencephalographic changes in the lexicosemantic centers after resection of a mesial temporal astrocytoma

Case report

KYOUSUKE KAMADA, M.D., YUTAKA SAWAMURA, M.D., FUMIYA TAKEUCHI, PH.D., KIYOHIRO HOUKIN, M.D., HIDEAKI KAWAGUCHI, M.D., YOSHINOBU IWASAKI, M.D., AND SHINYA KURIKI, PH.D.

Department of Neurosurgery, Research Institute for Electronic Science, Department of Laboratory Medicine, Hokkaido University; and Department of Neurosurgery, Sapporo Medical College, Sapporo, Japan

Letter-perception centers are not held in as high regard as motor- and language-related cortices during planning of neurosurgical procedures, and there have been no reports suggesting cortical reorganization of reading ability. The authors describe a patient with a left mesial temporal glioma in whom two letter-perception centers (the anterior portion of the left superior temporal gyrus and the left fusiform gyrus) were successfully localized before surgery by performing magnetoencephalography (MEG) during reading tasks. Control MEG examinations of 15 healthy volunteers were also performed to assist in a careful interpretation of patient results. Although a radical resection of the mesial temporal glioma, which involved the left fusiform gyrus, caused severe dyslexia, the patient’s impaired reading skills improved gradually during a 1-year postoperative period. In the meantime, the spared left superior temporal gyrus displayed an overshot recovery of MEG responses. During the postoperative period there was no obvious recovery in MEG signals and no compensatory activity in the contralateral fusiform gyrus. This case demonstrates that lexicosemantic centers involved in the reading process can be noninvasively localized using MEG and that the results obtained are highly reliable for surgical planning. The results of the repeated MEG reflected sequentially the patient’s recovery from dyslexia. This is the first report in which MEG studies have been shown to predict preoperatively the risk of dyslexia and demonstrate its serial physiological recovery.

KEY WORDS • dyslexia • glioma • mesial temporal lobe • functional recovery • magnetoencephalography

Abbreviations used in this paper: fMR = functional magnetic resonance; IQ = intelligence quotient; LORETA = low-resolution electromagnetic tomography; MEG = magnetoencephalography; PET = positron emission tomography; RMS = root mean square; SLTA = Standard Language Test for Aphasia; WAIS-R = Wechsler Adult Intelligence Test–Revised.
Case Report

History. This 34-year-old, right-handed man experienced transient amnesia for a few minutes in April 2001. Before the incident he had done well in his employment as an office worker. Neurological examination revealed no abnormality on the day after the episode, but T₁-weighted MR images revealed a large hypointense mass in the left mesial temporal region. The lesion appeared homogeneously hyperintense on T₂-weighted MR images and was not enhanced following a Gd–diethylenetriamine pentaacetic acid injection. The mass involved the hippocampus, uncus, amygdala, and parahippocampal and fusiform gyri, but not the superior or middle temporal gyri. These findings suggested that the mass was a low-grade astrocytoma originating from the mesial temporal lobe. No neurological deficit had appeared before treatment and thus our major concern was whether the brain area to be involved in surgery would still function postoperatively.

Examination. Preoperative neuropsychological examinations, including the SLTA (Japanese edition), WAIS-R, Miyake auditory–verbal memory test, and Benton Visual Retention Test detected no language deficits or memory disturbance. The SLTA is the standardized test battery most commonly used to evaluate Japanese patients with aphasia. The aphasia severity ratings (range 0, most severe–10, normal) are based on the 19 subscores of the SLTA, and these were used as a primary language measurement for this patient. The following six subscores of the SLTA were sequentially analyzed: reading aloud words; reading comprehension (in which the patient points out images of objects indicated by written words); dictation of letters; naming; auditory comprehension (ability to obey verbal commands); and sentence repetition. The patient could complete the tasks of the SLTA without difficulty and obtained full points for all the subscores. The verbal and performance IQs, determined using the WAIS-R, were 112 and 118, respectively. The patient’s hand preference was predominantly right sided (+105 on the Edinburgh Handedness Inventory), and an intracarotid sodium amobarbital test (Wada test) revealed a left-hemisphere dominance for language functions and a right-hemisphere dominance for memory. Lexicosemantic MEG, performed using a letter-reading task, localized two letter-perception centers (the anterior portion of the left superior temporal gyrus and the left fusiform gyrus), as described in detail later in this paper. Because this large low-grade glioma was thought to be life threatening, but curable by a complete resection, we proposed radical removal of the tumor involving the inferior temporal region, informing the patient of the risks of possible postsurgical neurological deficits. The patient accepted the treatment plan and gave his informed consent to participate in preand postoperative lexicosemantic examinations including MEG and neuropsychological tests.

Operation. The middle and inferior temporal gyri were exposed by a frontotemporal craniotomy. The brain tumor was found after a corticotony, which encompassed a 4-cm anterior portion of the inferior temporal gyrus. Intraoperative observation disclosed tumor invasion into the inferior temporal gyrus, fusiform gyrus, amygdala, uncus, and hippocampus. The involved brain tissue was completely resected. The histopathological diagnosis was World Health Organization Grade II diffuse astrocytoma.

Postoperative Course. The patient awoke with severe dyslexia and a slight receptive aphasia. Auditory comprehension and repetition and naming capabilities were almost intact. Neurological and neuropsychological examinations were serially performed throughout an 8-month postoperative period. On the 7th postoperative day, the man still displayed severe reading and writing impairments (scores of 3 in reading aloud, 4 in reading comprehension, and 7 in letter dictation; Table 1) with a right upper homonymous quadrantanopia. Speech function and auditory comprehension were, however, relatively preserved. The man’s verbal IQ (WAIS-R) was 88, which was lower than preoperatively despite the fact that he retained a normal performance IQ (116).

Three months after surgery, the impairments had improved, but he still had difficulty in reading and exhibited phonemic paralexia (scores of 6 in reading aloud and 8 in reading comprehension). It is noteworthy that he could point out objects correctly with a finger, even though he could not read aloud the names of written objects (understanding without phonology) (Table 1). Eight months after surgery, the patient’s reading impairment had remarkably improved (scores of 8.5 in reading aloud and 9 in reading comprehension) and he became able to read newspapers with some effort. His verbal IQ (103) was much improved, but did not reach his preoperative level.

The Miyake auditory–verbal memory test and the Benton Visual Retention Test did not show any deterioration in the patient’s short-term memory and, clinically, he displayed little memory disturbance following the operation. He returned to his office work, but still acknowledged lingering reading difficulties.

TABLE 1
Results of the SLTA and lexicosemantic MEG investigations*

<table>
<thead>
<tr>
<th>Timing</th>
<th>SLTA Score (%)</th>
<th>MEG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reading</td>
<td>Writing</td>
</tr>
<tr>
<td>preop</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>7 or 10 days</td>
<td>42</td>
<td>75</td>
</tr>
<tr>
<td>3 mos</td>
<td>80</td>
<td>88</td>
</tr>
<tr>
<td>8 mos</td>
<td>90</td>
<td>92</td>
</tr>
</tbody>
</table>

* NT = not tested.
† Mean ± standard deviation.
‡ Neuropsychological tests and the MEG study were performed 7 and 10 days postoperatively, respectively.
§ p < 0.5, Student t-test.
Reading reorganization on MEG

**Summary of Tests and Findings**

**Lexicosemantic MEG Studies**

The MEG signals were recorded using a 204-channel biomagnetometer (VectorView; Neuromag, Helsinki, Finland) in a magnetically shielded room. Serial MEG studies were performed before the operation and 10 days, 3 months, and 8 months after surgery. Despite the fact that the patient’s reading comprehension skills generally improved throughout the postoperative period, the postoperative MEG findings were compared with the preoperative MEG findings. We acquired two data sets for each task to confirm stable and consistent MEG responses. In particular, we performed the preoperative MEG investigations on two different days (7 and 3 days before surgery) and also performed control examinations in 15 strongly right-handed volunteers who had experienced no adverse cerebral events or neurological deficits.

One hundred fifty words were visually presented with a 300-msec exposure time and interstimulus intervals ranging between 2800 and 3200 msec during the MEG recordings. Each word was a noun that consisted of three kana letters (Japanese phonetic symbols that were presented, centered at a 4° visual angle). The patient and volunteers were asked to categorize the presented word as abstract or concrete by pushing buttons with the index or middle finger, respectively (kana reading). To identify the lexicosemantic response specific to the kana-reading task, we presented 150 pairs of Arabic letters and asked the patient and volunteers to decide whether each pair had the same letters or different ones (figure discrimination). All volunteers and the patient received instructions and were allowed brief practice sessions before the measurement.

Each epoch consisted of a 500-msec prestimulus baseline and a 1500-msec analysis period following stimulus delivery. One hundred fifty epochs of magnetic signals were averaged and digitally filtered between 0.5 and 40 Hz. Significant deflections of neuromagnetic fields were visually identified on the basis of RMS fields containing more than 10 sensors in the frontotemporal or temporoparietal regions. Locations and dipole moments of equivalent current dipoles were calculated every 2 msec for each selected time period by using the single equivalent dipole model. Only dipoles with a correlation value greater than 0.9 between measured and calculated field distributions were accepted. To confirm the calculated results, the same MEG time periods were analyzed using one of the following: current-density maps or LORETA (Curry; Neuroscan Labs, Sterling, VA).

The estimated dipoles were converted into three-dimensional MR images by identifying external anatomical fiduciary markers (nasion and left and right preauricular points).

**Serial Changes in the Lexicosemantic MEG Studies**

**Preoperative MEG Findings.** The patient and healthy volunteers could easily complete both tasks after a brief practice period. The mean reaction time and the percentage of successful task performance of the patient were approximately 800 msec and 92.3%, respectively, which were within normal range (Table 1). Figure 1 depicts the RMS fields of the preoperative MEG study (thick black line) with the kana-reading task in the bilateral frontotemporal and temporoparietal regions. Late deflections peaking at approximately 350 msec were observed in both of the left frontotemporal and temporoparietal regions. In the contralateral hemisphere (right frontotemporal and temporoparietal regions), however, early and short-duration RMS peaks were recorded approximately 250 msec after the stimulation. In all 15 healthy volunteers, the late deflections were predominantly observed in the left frontotemporal region rather than in the right hemisphere. On the other hand, in the temporoparietal region there was no late response in five volunteers (33.3%), left-side dominance in seven (46.7%), and right-side dominance in three (20%).

The figure discrimination task evoked only early deflections (within 300 msec) in both hemispheres with no later activation in the patient or any volunteer; therefore, we considered that the later responses in the left hemisphere might be strongly related to the lexicosemantic processes in letter perception on the basis of our preliminary results and previous reports.7,8

Figure 2 demonstrates the representative MEG sources in two healthy volunteers. The left hemispheric responses were mainly localized in the superior, middle temporal, and supramarginal gyri (mean number of dipoles 122.4). In contrast, in the right hemisphere there were far fewer numbers of estimated dipoles (mean number of dipoles 32.4). Concerning the location of the temporoparietal dipoles, it was not common for the left inferior temporal region to have predominantly more dipoles than the right side. There was no consistent dominance of temporoparietal dipoles between the hemispheres (Fig. 2).

In the patient, the estimated dipoles of the left frontotemporal response were mainly concentrated in the anterior portion of the left superior and middle temporal gyrus (38 dipoles) (Fig. 3A and B). Additionally, 102 dipoles of the left temporoparietal responses were densely concentrated adjacent to the posterior border of the tumor in the fusiform gyrus (Fig. 3C and D), which was relatively strong compared with the control data. The right frontotemporal and temporoparietal responses of the patient were observed in the right supramarginal gyrus and in the fusiform gyrus, respectively. The 24 right-hemisphere dipoles did not reach even one third of that of the left hemisphere, indicating left-side dominance for the reading process in this patient. It was notable that all 102 dipoles in the left hemisphere were mainly located in the fusiform gyrus where the tumor invaded. The LORETA analysis demonstrated two clusters of stronger sources in the anterior portion of the left superior temporal gyrus and the left fusiform, as did the single equivalent dipole model. We reexamined the patient 4 days after the first examination to confirm that the lexicosemantic MEG should reveal the consistent results for preoperative functional mapping. The second MEG examination demonstrated that the left fusiform gyrus was extremely active with the letter-reading task, just as the first examination had.

**Postoperative MEG Findings.** On the 10th day after surgery, the patient could not complete the reading task due to severe dyslexia. He was, therefore, asked to look passively at the presented letters. The most significant change on the MEG study was that no significant responses were detected in the left hemisphere (Fig. 1).

**J. Neurosurg. / Volume 100 / June, 2004**
Three months after surgery, the patient’s reading skills had improved and he could slowly read kana character by character. His mean reaction time and rate of success were approximately 1320 msec and 63.8%, respectively, which remained worse than his performance preoperatively. Although small RMS deflections appeared in the left frontotemporal region, peaking at approximately 420 msec (later than the preoperative response), these responses were too small in amplitude to localize. There was no obvious deflection in the left temporooccipital region. In contrast to the left hemisphere, the RMS profiles detected in the right frontotemporal region were almost identical to the preoperative MEG studies.

Eight months after surgery, the patient had recovered notably from the dyslexia and could perform the reading task with some effort. His mean reaction time and rate of success were further improved. It is noteworthy that the amplitudes of the left frontotemporal responses were more than 1.5 times higher than those of the preoperative responses. Estimated dipoles of the left frontotemporal response were mainly concentrated in the anterior portion of the superior and middle temporal gyri (78 dipoles) (Fig. 4) and showed 56.4 nAm of the mean dipole moment, which was 1.5 times stronger than that of the preoperative response (36.2 nAm). The peak latency periods of the left frontotemporal responses, however, were still later than those measured preoperatively (at ~ 420 msec). The activities of the left temporooccipital region remained quiescent. The right frontotemporal region revealed a sharp RMS deflection with slightly high amplitudes, peaking at 250 msec after the stimuli. The right temporooccipital responses had been consistently peaking at approximately 250 msec with similar RMS amplitudes throughout the serial MEG investigations. The right hemisphere had 37 dipoles in the frontotemporal and temporooccipital regions.

Discussion

The radical resection of the mesial temporal glioma injured the left fusiform gyrus, where the lexicosemantic MEG dipoles were concentrated, and, as a result, caused severe dyslexia. The patient’s impaired reading skills, however, were generally improved a year later. In the meantime the spared left frontotemporal region, which used to be one of the semantic centers, produced an overshoot recovery of MEG responses. This finding indicates that MEG provides a noninvasive method of identifying and visualizing the lexicosemantic centers used in the reading process. It is a matter of course that the preoperative identification of eloquent cortices related to higher brain functions is beneficial for neurosurgical planning. Furthermore, it is scientifically important that the sequential recovery of MEG signals on repeated studies be observed along with the patient’s clinical recovery from dyslexia.

Although it is well known that right-handed patients with left inferior temporal lesions suffer from impaired reading skills, we empirically know that dyslexia may not appear in 100% of these patients and that if it does, it sometimes is improved later. Researchers who have performed PET studies in healthy volunteers have reported that visually presented letters activate the bilateral superior temporal and posterior inferior temporal regions as well as the Broca area.
Measurements of evoked potentials in patients with epilepsy have demonstrated responses at approximately 200 msec (N200) on the cortices of the bilateral temporal base, including the fusiform gyrus, after letter presentation. The sole function of the fusiform gyrus can barely be investigated using cortical stimulation, fMR imaging or PET scanning, because of its anatomical characteristics (small size and deep location) and the surrounding vascular structures (the vein of Labbé and the basal veins of Rosenthal). The functional role and dominance of the fusiform gyrus, therefore, remain obscure.

Authors of recent MEG studies performed in healthy volunteers have found lexicosemantic activity in the fusiform gyrus and the left superior temporal gyrus at approximately 200 (early) and 400 (late) msec following letter presentation. Authors of these studies have emphasized that the fusiform gyrus as well as the left superior temporal gyrus may principally contribute to reading processes. Although the temporooccipital regions of normal controls exhibited various dipole distributions, such as left-side dominance (46.7%), right-side dominance (20%), and no response (33.3%) in our preliminary study, strong activation was especially demonstrated in the left fusiform gyrus in our patient. On the basis of these results, the fusiform gyrus of the dominant hemisphere plays an important role for reading processes, but the functional dominance of this structure should be carefully investigated for each patient.

It is noteworthy that the patient’s dyslexia remarkably improved until 8 months following resection of the fusiform gyrus in his dominant hemisphere. Previous PET and fMRI imaging studies have indicated a possibility of cortical reorganization in patients who display dramatic recoveries of motor functions. These studies have demonstrated activations not only in the contralateral cortex, but also in the ipsilateral sensorimotor cortex and in other cortical regions, indicating the involvement of a widespread network in the recovery process. In our case, the left temporooccipital region became silent on MEG following resec-

![Figure 2](image-url)  
**Fig. 2.** Lexicosemantic MEG dipole distributions in two healthy volunteers (Volunteers A and B). Estimated dipoles of late deflections in the frontotemporal regions are predominantly concentrated in the left hemisphere (107 dipoles in Volunteer A and 90 in Volunteer B) compared with the right side (42 and 22 dipoles, respectively). The temporooccipital regions exhibit no late response (Volunteer A) and a right-side–dominant dipole distribution (45 dipoles in the right and four dipoles in the left hemispheres of Volunteer B).

![Figure 3](image-url)  
**Fig. 3.** Lexicosemantic MEG dipole locations in the left frontotemporal (A and B) and left temporooccipital regions (C and D) before surgery. The dipoles are concentrated in the anterior portion of the superior and middle temporal gyri (white triangles) and in the fusiform gyrus (white squares), which contains the tumor.
tion, whereas the responses of the contralateral homologous (right) tempororooccipital region constantly maintained the same RMS profiles. The left frontotemporal region showed a marked recovery in MEG amplitude, but the peak latency period did not completely return to its preoperative state. Although we observed no compensatory activity or reorganization in the ipsilateral tempororooccipital region, the responses of the left frontotemporal region at 8 months after surgery became 1.5 times higher in amplitude than those before surgery. The patient experienced difficulty in reading letters after surgery and thus required more concentration to perform the reading task. One should consider, at least in part, that the spared left frontotemporal region might have contributed to the patient’s recovery from dyslexia.

Our single equivalent dipole model provided a similar result to those of previous reports and is helpful for understanding the process of language perception. Nevertheless, it is critical to consider the responsibility of multiple dipoles existing in the bilateral fusiform gyrus or in other regions, which may provide additional supplementary functions in the reading process. The LORETA is one of the currently available density maps that can potentially be used to analyze multiple sources in the electro- and magnetophysiological fields. It can separately localize two or three active sources with different time courses, which the single dipole model fails to localize. Because LORETA and the single dipole approach yield the same results, the source localization of this study became more reliable. Furthermore, the resection of the fusiform gyrus that produced the active sources was a useful tool in the elucidation of the pathophysiology of aphasia, dysphasia, and dyslexia.

**References**

14. Sakurai Y, Momose T, Iwata M, et al: Semantic process in kana reading task can readily identify the semantic magnetic responses and provide a noninvasive means for analyzing functional brain structures relating to letter perception. To our knowledge, this is the first report in which a method has been introduced that can be used to predict a risk for postoperative dyslexia and monitor functional recovery from the symptom. This technique can be applied to analyze other semantic processes and will be a useful tool in the elucidation of the pathophysiology of aphasia, dysphasia, and dyslexia.

Manuscript received December 12, 2002. Accepted in final form February 9, 2004.

Address reprint requests to: Kyousuke Kamada, M.D., Department of Neurosurgery, Graduate School of Medicine, University of Tokyo, 7–3–1 Hongo, Bunkyo-ku, Tokyo, 113–8655, Japan. email: kamady-k@umin.ac.jp.