Reorganization of posterior language area in temporal lobe epilepsy: A cortico-cortical evoked potential study

Rei Enatsu a, Yuichi Kubota a,d, Yosuke Kakisaka a,e, Juan Bulacio a, Zhe Piao a, Timothy O’Connor a, Karl Horning a, John Mosher a, Richard C. Burgess a,b, William Bingaman a,c, Dileep R. Nair a,b,*

a Epilepsy Center, Cleveland Clinic Foundation, Cleveland, OH, USA
b Department of Neurology, Cleveland Clinic, Cleveland, OH, USA
c Department of Neurosurgery, Cleveland Clinic, Cleveland, OH, USA
d Department of Neurosurgery, Tokyo Women’s Medical University, Tokyo, Japan
e Department of Pediatrics, Tohoku University School of Medicine, Sendai, Japan

Received 21 May 2012; received in revised form 15 June 2012; accepted 3 July 2012
Available online 20 July 2012

KEYWORDS
Language; Reorganization; Temporal lobe epilepsy; Cortical stimulation; Evoked potential

Summary
Objective: To investigate the connectivity associated with the reorganized language network in patients with temporal lobe epilepsy (TLE) using cortico-cortical evoked potential (CCEP), which reveals the brain networks.
Methods: Six patients with intractable TLE who underwent chronic intracranial electrode placement and revealed an atypical distribution of posterior language areas (Wernicke’s areas) were studied. Alternating 1 Hz electrical stimuli were delivered to the anterior language areas (Broca’s areas). CCEPs were recorded by averaging electrocorticograms time-locked to stimuli from the subdural electrodes. Thereafter, the posterior language areas identified by the electrical cortical mapping and CCEP distributions were compared by calculating the root mean square of CCEP responses.
Results: CCEP responses were observed in various areas within the temporal, temporo-parietal or temporo-occipital area. The correlation between CCEP distributions and posterior language areas revealed two patterns. In two patients, the posterior language areas were located within CCEP distribution, but out of the maximum responses in the temporal lobe. On the other hand, parts of the language areas were outside CCEP-positive areas in four patients.

* Corresponding author at: Epilepsy Center, Desk S51, Cleveland Clinic, 9500 Euclid Avenue, Cleveland, OH 44195, USA.
Tel.: +1 216 444 2560; fax: +1 216 445 4378.
E-mail address: naird@ccf.org (D.R. Nair).

0920-1211/$ — see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.eplepsyres.2012.07.008
Introduction

Two specific cortical areas are essential for language function. Broca’s area (anterior language area: ALA) is located just in front of the cortical region that contains the motor representation and is responsible for a speech output (Geschwind, 1970). Wernicke’s area (posterior language area: PLA) lies next to the auditory cortex and is involved in recognition of the spoken language. Wernicke and then later Geschwind postulated that these perirolandic language areas were connected via the arcuate fasciculus and destruction of this connection would produce conduction aphasia (Geschwind, 1970).

It is well known that epilepsy is likely to cause atypical language organization (Hamberger and Cole, 2011). Unlike the sudden disruption of established language circuits following stroke or traumatic brain injury, slowly progressive disease such as chronic epileptic activity might shift language from the left to the right hemisphere (Lieugeois et al., 2004; Brazdil et al., 2005; Janszky et al., 2006; Gaillard et al., 2007; Powell et al., 2007), or relocate language areas from traditional to non-traditional sites within the dominant hemisphere (Duchowny et al., 1996; Brazdil et al., 2005; Federico, 2011; Hamberger and Cole, 2011). Mbwana et al. (2009) reported several subgroups of language reorganization in left-sided seizure disorders which includes intra-hemispheric reorganization (i.e., compensation by ipsilateral adjacent regions) and inter-hemispheric reorganization (i.e., shift to contralateral homologous regions). This phenomenon is clinically relevant, particularly in the context of epilepsy surgery for the treatment of pharmacologically refractory seizures, because it is necessary to localize and to spare the language function before resecting the epileptogenic cortex.

In vivo human language network studies have begun using non-invasive methods, such as diffusion tensor imaging (DTI) (Powell et al., 2007; Frey et al., 2008; Glasser and Rilling, 2008; Upadhyay et al., 2008; Ellmore et al., 2010) and invasive cortical/subcortical electrical stimulation mapping (Schaffler et al., 1996; Duffau et al., 2008b). Although the combination of these techniques provides approximate information about the relationship between the cortical language area and subcortical network (Duffau et al., 2008c; Duffau, 2008a; Ellmore et al., 2009), these techniques cannot provide a direct locational correlation between language areas and termination of the subcortical fibers among cortical regions. It would be optimal if both functional cortical regions and the termination of white matter connections could be mapped, so as to be able to track exact neuronal connections. Electrical stimulation in vivo was recently introduced in humans to track the various brain networks (Wilson et al., 1990, 1991; Greenlee et al., 2007; Lacruz et al., 2007, 2010; Oya et al., 2007; Rosenberg et al., 2009; Keller et al., 2011) and evaluate the cortical excitability (Valentin et al., 2002, 2005a, b; Flanagan et al., 2009). Cortico-cortical evoked potentials (CCEPs) are an electrical stimulation method, which was developed by averaging responses time-locked to electrical stimuli. This method provides an opportunity to track connectivity among various functional areas that can be defined by cortical electrical stimulation (Matsumoto et al., 2004b, 2007, 2011; Terada et al., 2008, 2012; Umeoka et al., 2009; Kikuchi et al., 2012; Koubiessi et al., 2011).

Previous CCEP studies elucidated the physiological language network and revealed the well-correlated CCEP responses with cortical language areas (Matsumoto et al., 2004a; Conner et al., 2011). We revealed a bidirectional connection between ALAs and PLAs in the patients with typical language distribution, and the PLAs were identified within CCEP responses elicited by the electrical ALA stimulation (Matsumoto et al., 2004a). However, the reorganized language area was not analyzed in these previous reports and the connectivity associated with the reorganized language network is still unclear.

By means of CCEP, we report here the connectivity pattern of “reorganized” PLAs from the ALAs in patients with intractable temporal lobe epilepsy, and discuss the mechanism of language reorganization and the utility of CCEP in these patients.

Methods

Patients

Six patients with epileptogenicity including the temporal lobe (temporal, temporo-parietal or temporo-occipital lobe epilepsy) who showed atypical distribution of the PLA (described in the next section) were studied. All patients had undergone chronic intracranial electrode placement over the lateral convexity of the frontal and temporal lobe for presurgical evaluation of medically intractable partial epilepsy between 2006 and 2011 (Table 1). The subdural electrodes were made of platinum and measured 3.97 mm in diameter with a center—center inter-electrode distance of 1 cm (custom-made at Cleveland Clinic Foundation, OH). Depth electrodes were made of platinum 2.5 mm contacts with a 2.5 mm gap and a diameter of 1.25 mm (Integra, Plainsboro, NJ).

The study was performed extraoperatively after the standard presurgical evaluation and restarting antiepileptic medications. The relationship of the electrode position to major cerebral sulci was identified on a pre-surgical three-dimensionally reconstructed MRI image coordinated with post-operative high resolution volumetric CT (1 mm slice thickness).

After the intracranial electrode evaluation, all patients underwent resective surgery. The resected cortical area

Conclusion: Our results suggest that language reorganization might be associated with a functional shift from the termination of anterior—posterior language connection to the surrounding cortices. It should be noted that language areas can be identified outside the anterior—posterior language connection.

© 2012 Elsevier B.V. All rights reserved.
Language reorganization in temporal lobe epilepsy

was also clarified by a pre-surgical three-dimensionally reconstructed MRI image coordinated with post-operative MRI. This coordination was performed using the in-house program (Vamis; program developed by Cleveland Clinic Foundation, OH). The present study was approved by the Institutional Review Board Committee of Cleveland Clinic Foundation, and informed consent was obtained from all patients (IRB #4513).

**Functional and anatomical brain mapping**

Cortical electrical stimulation was performed for functional mapping as part of the routine pre-surgical evaluation. Repetitive square wave electrical currents of alternating polarity with a pulse width of 0.3 ms were delivered at a frequency of 50 Hz for 2–5 s (Grass S-88 and S117; Astro-Med Inc., West Warwick, RI). The current was increased from a low stimulus intensity of 1.0–2.0 mA, followed by stepwise increments up to the maximum 15 mA. The regions of cerebral cortex were defined as language areas when stimulation interrupted the ability of object naming or to read aloud a sentence in the absence of the following: (i) positive tongue motor response (e.g. tongue contraction); (ii) negative tongue motor response (e.g. impairment of rapid alternating movements); and (iii) afterdischarges (ADs) (Schaffler et al., 1996). Stimulation was performed in the perirolandic and perisylvian language areas. After screening the language area, we attempted to determine the type of language deficit: speech production deficit or language comprehension deficit. We defined speech production deficit as the inability to perform spontaneous speech tasks (e.g. counting, reciting the alphabet, repeating single words or short sentences) during the stimulation. Language comprehension deficit was defined as the inability to perform auditory comprehension tasks (e.g. one/two step auditory commands, the token test (patients were asked to pick up a token of a certain color or shape), asking questions) or visual comprehension tasks (e.g. visual questions or commands) during the stimulation.

As the language impairment can be elicited within the perisylvian language area outside the classical location of Broca’s and Wernicke’s areas, we use the term anterior (ALA) and posterior language areas (PLA). The ALA was defined as the language area in front of the Rolandic fissure and above the Sylvian fissure in the region that corresponds approximately to the inferior frontal gyrus following the previous proposal (Schaffler et al., 1996). On the other hand, we used the term ”PLA” to refer to the language area in the lateral convexity of the temporal or parietal lobe in this study. The “typical” PLA was defined as the language area located in the middle and posterior part of superior temporal gyrus (STG), in the posterior part of middle temporal gyrus (MTG) and in the lower part of supramarginal gyrus (SMG). The anterior border is 1 cm behind the junction of the Rolandic and Sylvian fissures, and the posterior border was 5.5–6 cm behind this point. The lowest and highest borders are located 3 cm below and 2–2.5 cm above the junction of the Sylvian and Rolandic fissures (Schaffler et al., 1996). This anatomical location was defined as the standard PLA location. The PLA identified outside of this area was classified to the “atypical” PLA.
Cortico-cortical evoked potentials

The method of CCEPs has been described in more detail elsewhere (Matsumoto et al., 2004b, 2007). Bipolar electrical stimulation was applied to the ALA. A constant current, monophasic square wave pulse with 0.3 ms duration was delivered at a frequency of 1 Hz. Alternating stimulus polarity was used to counterbalance stimulus artifacts and to avoid electrical charges building up at the cortex and the polarization of platinum electrodes. The current was given at the intensity that produced clinical signs during the standard cortical stimulation. The intensity was kept below the after-discharge threshold. The stimulus intensities were 15 mA in Patient 1—4, 12 mA in Patient 5 and 7 mA in Patient 6.

During the stimulation, raw data were recorded from the cortical surface using all the implanted electrodes. An extracranial scalp electrode (contralateral mastoid) was used as the reference. The signals were recorded with a bandpass filter between 0.08 and 300 Hz at a sampling rate of 1000 Hz. During the recording of CCEPs, the patients were not requested to perform any specific task.

The raw data were recorded by a Nihon Kohden EEG system (Neuro Workbench; Nihon Kohden America, Inc., CA) and CCEPs were obtained by off-line averaging time locked to stimuli using AVR (original program of Cleveland Clinic Foundation introduced by Z.P.). The averaging time window was 400 ms with a 100 ms prestimulus baseline and filtering was set from 1 to 300 Hz. After averaging, the epoch distorted by the definite artifact was discarded from the analysis. In each session, 50—100 responses were averaged. These averaged CCEP data were reviewed by Matlab R2006b (Matlab R2006b version 7.3.0.267; MathWorks, Inc., Natick, MA).

Analysis of CCEPs

It has been previously reported that the CCEP response consists of early (N1) and late (N2) negative deflection and the posterior language electrode is located within the area of N1 or N2, but not necessarily in both (Matsumoto et al., 2004b). Therefore, to evaluate both components simultaneously, we calculated the root mean square (RMS) for each response, which is defined as the square root of squares of amplitude value (µV) divided by the length of time from 10 ms to 300 ms (1 ms slide). The initial 10 ms period from the stimuli was obscured by the stimulus artifacts; hence, we excluded the initial 10 ms from the stimulus onset.

In order to illustrate the distribution of each activity over the cortex, a circle map was employed based on RMS percentage distribution, in which the diameter of the circle at each electrode represented the percentage of the maximal RMS of that particular activity. Electrodes showing higher than 10% of the maximum value were accepted for further analysis in this study.

Thereafter, we correlated the posterior language area with CCEP distribution and resected cortical areas.

Results

Location of posterior language areas

In all patients, the patient’s PLAs were identified in the ’atypical’ area, which is defined in the methods section. In Patient 1, the PLA showed separate distribution, including the left middle STG, posterior MTG, SMG and angular gyrus. One of these areas (posterior MTG) was located close to the temporo-occipital tumor (Fig. 1a). In Patient 2, the PLA was distributed broadly, including the area anterior to the junction of the rolandic and sylvian fissures (Fig. 1c). In Patient 3 and 4, the PLA was located at the temporo-occipital junction in MTG (Patient 3) and in both MTG and inferior temporal gyrus (ITG) (Fig. 2a and c). In Patient 4, encephalomalacia was located at the temporo-parietal junction close to the language area. In Patient 5, the intracrarotid methohexital (Wada) test showed bilateral hemispheric language dominance (Table 1) and the ALA and PLA were identified in the right hemisphere (Fig. 3a). The PLA was distributed broadly in STG and MTG, including STG anterior to the junction of the rolandic and sylvian fissures. In Patient 6, the PLA was located less than 1 cm behind the junction of the rolandic and sylvian fissures (Fig. 3c).

Cortico-cortical connectivity from the anterior to posterior language area

RMS values of CCEP responses ranged between 1.1 and 262.0 (µV). RMS percentage distributions are shown in Figs. 1–3. In terms of RMS values, CCEPs were distributed in a graded fashion with prominent large CCEPs recorded in the adjacent frontal or temporal lobes, followed by smaller responses in the surrounding areas. Besides the clustered graded CCEP responses, isolated responses which were spatially discrete from the clusters were recorded in the temporal, temporo-parietal or temporo-occipital lobe in Patient 1, 3, 4, 5. CCEP distributions were broader than the standard PLA locations.

In Patient 1, prominent isolated responses with higher than 40% (40.7–54.7%) of the maximum response were recorded in SMG, posterior STG/MTG, which correspond to the standard PLA location (asterisks in Fig. 1b). Furthermore, less prominent responses (less than 40%) were recorded in the surrounding cortices. In relation to the patient’s PLA, the language areas were identified in the surrounding cortices with less prominent responses (23.2–38.9%) rather than the cortex with prominent responses. In Patient 2, CCEP responses were recorded in STG in a graded fashion (Fig. 1d). The patient’s PLAs were located within CCEP distribution (19.2–77.4% of maximum responses) and one of these, closest to the stimulus site, showed CCEP responses with 77.4% response (asterisk in Fig. 1d). In Patient 3 and 4, discrete CCEP responses were recorded close to the patient’s PLAs; however, the PLAs and CCEP distributions were partly inconsistent in both patients (Fig. 2b and d). The PLAs showed CCEP responses of 27.9% and 16.3–27.2% of the maximum responses in Patient 3 and 4 respectively. In Patient 5, broad CCEP responses were recorded over the temporal lobe. Approximately half of the PLA (6 of 11 electrodes) was identified...
Figure 1  Functional mapping (a, c) and circle maps of CCEPs in the stimulation of anterior language area (b, d) in Patient 1 and 2. Waveforms are shown in the right column. Circle maps show the RMS percentage distribution, in which the diameter of the circle at each grid electrode represents the percentage to the maximal value. Temporo-parietal CCEP responses with above 40% maximum RMS are marked by asterisks (*). Dotted circle indicates language areas. CS = central sulcus; ITS = inferior temporal sulcus; NMA = negative motor area; PostCS = postcentral sulcus; PreCS = precentral sulcus; SF = Sylvian fissure; STS = superior temporal sulcus.

within the CCEP-positive area (12.2—16.7% responses), but the rest was outside of CCEP distribution (Fig. 3b). Furthermore, the maximum CCEP response in the temporal lobe (asterisks in Fig. 3b) was identified close to, but outside the PLA. In Patient 6, CCEP responses were recorded only around the stimulus site in a graded fashion (Fig. 3d). The PLA was located outside but close to CCEP distribution (Fig. 3d). In summary, the patient’s PLA was located within CCEP distribution, but out of the maximum responses in the temporal lobe in Patient 1 and 2 (Fig. 4a) and partially dissociated from CCEP distribution in Patient 3, 4, 5 and 6 (Fig. 4b).
Post-surgical language dysfunction and histopathology

All patients underwent resective surgery after the presurgical evaluation. The resected area was next to the patient’s PLA and CCEP-positive area in Patient 1 and 4. In Patient 5, part of the PLA and CCEP-positive areas was resected. Post-surgical language deficit was not observed in Patient 1, 2, 3 and 6. Although objective language function and speech was normal, Patient 1 complained of some word-finding problems after the surgery. Patient 4 and 5 experienced post-surgical language dysfunction. Patient 4 had mild comprehensive and reading problems after the surgery, but she recovered 20 days later. Patient 5 had pronunciation and word-finding problems after the surgery and recovered 4 months later. Histopathological examination revealed low-grade glial/glioneural tumor (Patient 1), gliosis (Patient 2), hippocampal sclerosis/gliosis (Patient 3), encephalomalacia (Patient 4) and cortical dysplasia (Patient 5 and 6).
Figure 3  Functional mapping (a, c) and circle maps of CCEPs in the stimulation of anterior language area (b, d) in Patient 5 and 6. Temporo-parietal CCEP responses above 40% maximum RMS are marked by asterisks (*). Dotted circle indicates language areas.

Discussion

The present study evaluated the anterior-posterior language network in patients with temporal lobe epilepsy. We previously revealed that CCEP responses elicited by the ALA stimulation were well correlated with the distribution of PLAs in the patients with typical language distribution (Matsumoto et al., 2004a). Therefore, we expected that CCEP could also track the reorganized PLAs. However, the present results revealed a discrepancy between the anterior—posterior language connections and the reorganized PLAs. In two patients, the ALA has connections with the standard PLA location and with the patient's atypical PLAs, and connections were not strongest with the latest. In other four patients, parts of the patient’s PLAs were outside the area connected with ALAs.

In this study, patient’s PLAs were found in various regions, including the area anterior to the junction of the rolandic and sylvian fissures, ITG, angular gyrus and temporo-occipital junction. In Patient 5, the intracarotid methohexital (Wada) test showed bilateral hemispheric language dominance and language areas were identified over
Figure 4  Schematic depiction of the relationship between CCEP distribution and the posterior language area. (a) Posterior language area is located within CCEP distribution, but out of the maximum responses in the temporal lobe (Pattern 1). (b) Part of the language area is outside CCEP-positive area (Pattern 2). Gray area indicates the area densely connected with the anterior language area. AL: anterior language area, PL: posterior language area.

broad areas, including the anterior part of STG in the right hemisphere. Electrical cortical mapping in patients with bilateral language dominance (Jabbour et al., 2005) and left-handed patients (Duffau et al., 2008b) revealed the presence of right hemispheric language areas analogous to the classic language areas of the dominant left hemisphere; therefore, the broad distribution in Patient 5 is thought to be an "atypical" location. A previous functional MRI study reported that patients with temporal lobe epilepsy showed more widespread activation, particularly in the posterior language areas, compared to normal subjects (Rosenberger et al., 2009; Federico, 2011). Furthermore, cortical mapping with electrical stimulation in patients with epilepsy has shown language areas over a wide or atypical area of the left lateral cortex, extending beyond the traditional Broca’s and Wernicke’s areas (Schaffler et al., 1996). These reports are consistent with the variable location of PLAs among our patients. The atypical locations of PLAs are thought to be due to the anatomical distortion and functional reorganization of cortical architecture caused by epilepsy or by the underlying structural lesion. The present results describe the connections from the ALA to various areas within the temporal, tempo-parietal or tempo-occipital area including the temporal pole and ITG. This wide variation in location is consistent with previous CCEP reports which revealed wider CCEP distribution than the PLA identified by electrical stimulation (Matsumoto et al., 2004b; Conner et al., 2011). This suggests the existence of a broad neuronal network surrounding the previously recognized core region of the language area. It has been reported that anterior and posterior language areas are connected via the arcuate fasciculus (Geschwind, 1970). More recent studies indicate the involvement of the superior longitudinal fasciculus, extreme capsule fiber system and uncinate fasciculus in the language network (Schmahmann and Pandya, 2006a,b; Frey et al., 2008; Friederici, 2011). The wide CCEP distribution in the present and previous studies might reflect these broad subcortical connections.

The correlation between CCEP results and patient’s PLAs revealed two patterns (Fig. 4a and b). In two patients (Patient 1 and 2), the PLAs were located within CCEP distribution, but outside of the maximum responses in the temporal lobe (herein termed Pattern 1; Fig. 4a). A previous CCEP study reported that the ALA stimulation elicited responses in the lateral tempo-parietal areas and the CCEP distribution contained PLAs despite the variable location of the language areas, whereas the maximum of CCEP response was not always observed at the PLAs (Matsumoto et al., 2004b). The present findings observed in Patient 1 and 2 are similar to previously reported CCEP results in the patients with typical language distribution. Conner et al. (2011) reported that the CCEP amplitude significantly correlates with the number of DTI pathways connecting the stimulation and recording sites. Taking their results into account, Pattern 1 of CCEP results indicate that the patient’s PLA is located outside of the cortical area densely connected from the ALA, but still within the boundary of the anterior—posterior language connection.

On the other hand, parts of the language areas were outside CCEP-positive areas in four patients (Patient 3, 4, 5 and 6) (herein termed Pattern 2; Fig. 4b). This finding is not consistent with the previous CCEP report (Matsumoto et al., 2004b) and the classical Wernicke’s theory (Geschwind, 1970). Ellmore et al. (2009) reported that 20% of the language processing area was not within the fiber pathway terminations from the Broca’s area. Therefore, the presence of Pattern 2 suggests that the core of language areas could shift to the surrounding language processing area, resulting from cortical plasticity or compensation in patients with chronic temporal lobe epilepsy. The acquired brain lesions can cause intra-hemispheric reorganization and inter-hemispheric reorganization (Staudt et al., 2008; Staudt, 2010). The degree of language reorganization is related to structural damage over the left hemisphere. Hence, Pattern 1 and 2 might reflect the process of the language reorganization. We hypothesize that PLAs may initially shifts from the densely connected area to the sparcely connected area within the termination of the anterior—posterior language connection (Pattern 1). Thereafter, it may shift to the surrounding cortex outside of the anterior—posterior language connection (Pattern 2). In other words, the connection to the standard PLA location remains in place even though this area no longer behave as speech areas. Both this remaining connections and reorganized language areas may be associated with language processing.
With respect to post-surgical language function, transient language deficit was observed in two patients in which the area near (Patient 4) or within (Patient 5) the language area was resected. It should be noted that the resection site was outside of the language area and CCEP-positive area in Patient 4. This resected adjacent cortex is recognized as nonfunctional by cortical mapping and it is also recognized as outside of anterior—posterior language connection by CCEP. However it may still have a certain role in language processing. Although electrical cortical mapping is thought to be the gold standard for pre-surgical evaluation, it could not identify the role of the surrounding cortex around the core of the language area. Further evidence is necessary to clarify the complex functioning of the language system of the human brain.

The present study includes several limitations. Previously, it has been reported that epileptic activity causes language reorganization within the dominant hemisphere (Duchowny et al., 1996; Mbwana et al., 2009; Federico, 2011; Hamberger and Cole, 2011); however, we should note that there is no definite criteria of the PLA. In the present study, the standard PLA location was defined, based on the frequency with which electrical stimulation interfered with language (Schaffer et al., 1996). The atypical location in the present study meant a less than 10% chance to identify the language function, and can include physiological variance. Therefore, it is difficult to identify the exact reorganized language area, and the physiological network can be included in the present study. Another issue is the effect of pathology. As seen in Table 1, the patient group included various pathologies (tumor, gliosis, hippocampal sclerosis, encephalomalacia and cortical dysplasia). The destructive effect might cause language relocation as well as epileptogenesis. Furthermore, patients were receiving anticonvulsants at the time of this study. The effect of anticonvulsants on CCEP recordings is not clear; therefore, we cannot exclude the possibility that medication effects biased our results.

In conclusion, our results suggest that the PLAs can shift to the surrounding cortices outside the anterior—posterior language connection. The surrounding cortices may play a significant role in language processing as well as in the termination of the anterior—posterior language connection. Based on the present results, we hypothesize that language reorganization is caused by a functional shift from the termination of the anterior—posterior language connection to the surrounding cortices.

Acknowledgement

We confirm that we have read the journal’s position on issues involved in ethical publication and affirm that this report is consistent with those guidelines. None of the authors has any conflicts of interest in relation to this work to disclose.

References


