



Right hemisphere language mapping in patients with bilateral language -

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Abstract

Purpose. The configuration of language cortex in the dominant left hemisphere has been well described in the literature. However, language representation in the right hemisphere, particularly in patients with some degree of bilateral language remains unclear. Herein, we report six patients who underwent electrocortical stimulation (ECS) for language mapping following implantation of a right subdural electrode array (SEA).

Methods. The medical records of six bilateral language patients with right SEA implantation at the Minnesota Epilepsy Group between January 1996 and July 2004 were retrospectively reviewed. Language lateralization was based on the results of the intracarotid amobarbital procedure performed preoperatively. Anatomical localization of the SEA for each patient was verified using colored photographs of the cortical surface before and after SEA placement and by review of MRI scans taken with the SEA in place. Frontal and temporal language areas were identified by errors in any language modality including automatic speech, reading, naming, repetition, and comprehension during ECS.

Results. Language maps revealed the presence of frontal and/or temporal language areas analogous to the classic essential language areas of the dominant left hemisphere in four of six patients. One patient had a widespread distribution of single-language error sites over the right temporal lobe. One patient had a silent language map.

Conclusion. Our results identified the presence of language cortex in the right hemisphere in five of six patients classified with bilateral language based on intracarotid amobarbital procedure. These areas are assumed to be accessory language zones in relation to the left hemisphere. Further exploratory studies are needed to evaluate their clinical significance.

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1. Introduction

In the early 19th century, Broca and Wernicke first described left hemispheric language dominance based on their anatomopathological findings in patients who presented clinically with aphasic disturbances [1-3].

After the emergence of this theory, John Hughlings Jackson raised the possibility that language functions may be represented in both hemispheres [4]. According to Jackson, the right hemisphere was thought to be responsible for the automatic, involuntary use of words in speech, whereas the left hemisphere was believed to control the voluntary use of language.

Since that time, right hemisphere language has been an enigma, and many investigators have tried to identify

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and to clarify its contribution to language processing [58]. Penfield and his associates [5] found only one case in which right hemispheric language representation was identified in their series studied by electrocortical stimulation (ECS). They concluded that without any doubt, language representation might occasionally be found in the right hemisphere in both left- and right-handed patients. Patients undergoing corpus callosotomy have also afforded an opportunity to study right hemisphere language [9-12]. In split-brain patients, the findings for language processes after stimulation of the left visual field and auditory stimulation of the right hemisphere were consistent with the previous results. It was concluded that although the right hemisphere appeared completely mute with articulatory function, it did contain written and auditory word comprehension. In addition, the right hemisphere of these patients evidenced competence on semantic tasks and abstract as well as conceptual language.

One investigator analyzed 2133 cases with unilateral left or right cerebral lesions reported in the literature [6]. In his review, a small percentage of dextral patients who had right-sided lesions were found to have aphasic problems. The right hemisphere contribution to speech has also been evaluated with the Wada test. One study reported three right-handed patients who presented with aphasia following acute left cerebral ischemia [7]. In these patients, the injection of anesthesia in the left hemisphere did not affect the aphasic speech, whereas injection in the right hemisphere produced complete aphasia, suggesting that the right hemisphere was producing the aphasic speech demonstrated by these patients. Other authors found language cortex in the right hemisphere using ECS in three intractable epilepsy cases. However this language area did have an active contribution in language production since the Wada test evidenced left language dominance in these patients [8]. Subsequently, many right-handed patients who underwent left hemispherectomy for newly acquired left hemisphere pathology were also assessed for language [13,14]. After the surgery, using only the remaining right, nondominant hemisphere, these patients seemed to preserve the ability to comprehend speech and, later developed minor recovery of expressive speech. Most of the previously reported studies concerning language

in the right, nondominant hemisphere evaluated right-handed-patients with primary left language dominance. In this report, we describe the evidence for right hemisphere language representation in patients known to have bilateral language, a group that has been, to our knowledge, rarely discussed in the literature. One case report described a right-handed patient with bilateral language representation by Wada test who developed transient aphasia following a right temporal lobectomy for intractable seizures. Loring et al. concluded that apparent crossed aphasia in some cases might have bilateral language representation [15].

2.- Methods

2.1. Subjects

Six patients with bilateral language who had undergone language mapping of the right hemisphere using ECS were identified. These patients were evaluated between January 1996 and July 2004 at the Minnesota Epilepsy Group. Data collected from their medical records included age at mapping, gender, handedness, age at seizure onset, seizure type, diagnostic procedures, neuro-psychological evaluation, surgical resection, and seizure outcomes. Demographic data are summarized in Table 1.

Two of the six patients were adults, and the other four were in the pediatric age group. Male-to-female sex ratio was 3/3. Five patients were right-handed and one was left-handed. In four of these six patients, the age at seizure onset was less than 10 years (Table 1). All patients had been diagnosed with complex partial seizures. Abnormal ictal and interictal EEG recordings originated from the right frontal lobe in three patients and from the right temporal lobe in the remaining three (Table 2). Three patients had normal magnetic resonance imaging (MRI) of the brain. Patient 4 had cortical dysplasia involving the right anteromedial temporal lobe, with right mesial temporal sclerosis. Patient 5 had cortical dysplasia of the right anterosuperior frontal lobe, and patient 6 had a right mesial temporal tumor (Table 2). All patients underwent comprehensive neuropsychological assessment preoperatively. Five of six

Table 1 Demographic data^a

Patient	Age at operation	Age at seizure onset	Gender	Handedness	FHH	FSIQ	
1	18 years	2; years	M	L	-	N/A	82
2	34 years	18 years	F	R	-	-	84
3	8 years, 9 months	4 years	F	R	L	-	114
4	9 years, 10 months	9 years	M	R	L	-	83
5	16 years	6 months	F	R	L	-	41
6	11 years	11 years	M	R	L	-	118

M, male; F, female; L, left; R, right; FHH, family history of handedness; FSIQ, Full-Scale Intelligence Quotient; N/A, not applicable.

Table 2
Presurgical diagnostic procedure evaluation¹

Patient	Surface EEG ^b	MRI	SPECT	PET	Surgery	Surgery outcome
1	RF	N	N	RT	RFT, MSR	Free
2	RT	N	RF	RFT	RFT, MSR	Reduction (60%)
3	RF	N	R MTS	RFT	RFT, MSR	Free
4	RT	Cortical dysplasia and right MTS	N/A	N/A	RT, MSR	Free
5	RF	Cortical dysplasia ^d	N/A	RF	RFT	Free
6	RT	Mesial structure tumor	N/A	N/A	Tumor resection	Free

^a R, right; F, frontal; T, temporal; FT, frontotemporal; N, normal; MTS, mesial temporal sclerosis; N/A, not applicable; MSR, mesial temporal resection.

^b Ictal and interictal abnormality.

^c Cortical dysplasia involving the right anteromedial temporal lobe.

^d Cortical dysplasia involving the right frontal lobe.

patients demonstrated baseline abilities within normal limits across most cognitive areas evaluated. IQ scores are listed in Table 1. Patient 3 demonstrated a mild deficit in visual memory, and patient 6 evidenced mild impairment on one measure of verbal memory. Patient 2 was mildly below average overall. Although the cognitive function of patient 5 fell in the moderate range of mental retardation on formal testing, her social presentation and verbal communication skills suggested functional abilities exceeding her IQ. She was included because she met the basic criterion of adequate verbal skills and ability to cooperate with the intracarotid amobarbital procedure and the language mapping. Only three of the six patients had comprehensive neuropsychological testing postoperatively. Two of them showed a decline in confrontation naming, while one showed a significant memory decline involving both verbal and visual recall. Performance in all other areas remained stable. Surgery - involved anterior frontal, temporal, or frontotemporal topectomy. All surgical resections spared the identified language cortex with a margin of at least 1 cm (Table 2). All patients were seizure free after surgery, except for patient 2 who had a seizure reduction of 60% postoperatively.

An intracarotid amobarbital procedure was performed on all patients before surgery, according to the well-established protocol of our center [21]. This includes assessment of spontaneous speech, auditory comprehension, naming, repetition, and reading. All language items are quantified and assigned scores repre-

sented correct, partially correct, or failed responses. In each of the cases reported here, some capacity for language function in the right hemisphere was identified based on one of the following criteria: (1) correct responses in at least one language modality following the left injection during the period of maximum drug effect (complete contralateral hemiparesis), (2) an initial period of speech arrest without loss of awareness following both injections, or (3) paraphasic errors following the right injection during maximum drug effect. In all cases, the patients also demonstrated language functions, in the left hemisphere following right injection prior to motor recovery. Language responses during the intracarotid amobarbital procedure are summarized in Table 3. Only responses occurring prior to initial motor recovery are presented in this table because it is only these responses that are counted in our conservative method of determining language dominance. For example, patients with the designation of no language errors (-), may have actually produced paraphasic responses later in the recovery period.

2.2. Electrocortical stimulation for language mapping

The patients had been implanted with an 8 x 8-cm subdural electrode array (SEA) over the right frontotemporal region for recording of seizure activity and for functional mapping of language and motor cortex through ECS. Mapping sessions were performed in the patient's room on the epilepsy unit. Stimulations were

Table 3
IAP
results

Patient	Left Injection			Right Injection		
	Speech arrest	Language errors	Correct responses	Speech arrest	Language errors	Correct responses
1	+	-	+	-	-	+
2	+	+	+	+	-	+
3	+	-	-	+	+	-
4	+	-	-	-	+	+
5	-	+	+	-	-	+
6	+	+	+	-	+	+

^a No speech prior to motor return

delivered to the cortex through platinum/iridium electrode pairs embedded in Silastic (Model Radionics, or Adtech) using a stimulator (Model S12, Grass instruments, Quincy, MA, USA). Stimulation parameters consisted of a constant current of a biphasic square waveform pulse; intensity varied between 2.5 and 17.5 mA, 0.5-ms pulse widths at 50 Hz of frequency. Concomitantly, afterdischarges were monitored with each stimulation trial. Current levels used were determined to be just below the threshold for afterdischarge responses to minimize seizure production during stimulation. Each language map was based on at least two stimulation sessions.

The language protocol for each stimulation trial included tasks of automatic speech (counting), confrontation naming in response to drawings of common objects, auditory comprehension (one-step commands), repetition (short phrase), and reading (single words). Language items were administered in quick succession over an 8- to 12-second period. When speech arrest was produced in the frontal lobe, subsequent stimulation trials determined that the speech arrest was not attributed to general paralysis as patients were able to perform repeated orofacial movement of a nonverbal

nature (i.e., open and close mouth repeatedly or rapidly move tongue from side to side). Electrode sites where stimulation resulted in a change in motor or sensory functions or language errors were noted. These sites were anatomically verified using direct visual assessment of colored photographs taken before and after SEA placement and post-SEA MRI.

3. Results

3.1. Language maps

In five of six patients, language cortex was identified in the right hemisphere during ECS. Language errors recorded were elicited during at least one mapping session in these patients (Fig. 1).

3.1.1. Patient 1

Stimulation of the posterior part of the right inferior third convolution of the frontal lobe identified consistent naming and reading errors with few comprehension and repetition errors. The surface area of the frontal language cortex is estimated to be about 1 x 1 cm². As the

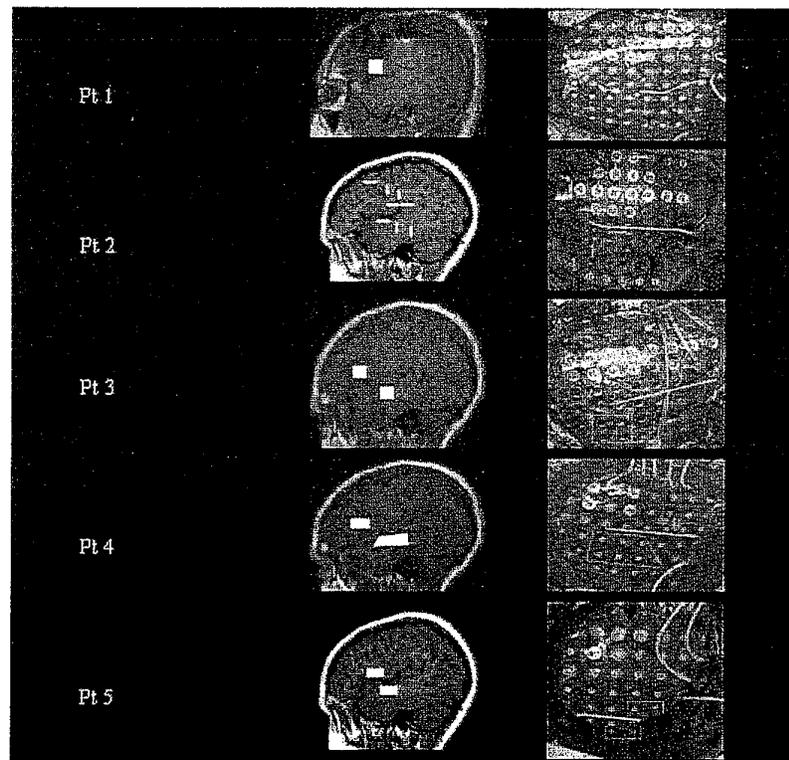


Fig. 1. Schematic representation of the language cortex over the right hemisphere on an MRI scan and on a direct photograph of the SEA implanted, taken intraoperatively in five patients. In the grid pictures, the yellow line represents the sylvian fissure, and green boxes represent language areas over the frontal and/or the temporal lobes. Patient 2 demonstrated single sites of language errors represented by green arrows. Similarly to the grid pictures, the MRI scans have white boxes for the language areas in the frontal and the temporal lobes. The white arrows in patient 2 represent the single-site errors found. Grid pictures have the anterior direction on the right side of the figure and the superior direction on the top of the figure.

SEA covered only the frontal lobe, the temporal lobe was not mapped for language in this patient.

3.1.2. Patient 2

Four single-language-error sites were identified over the right superior and middle temporal gyri. In three sites a single error occurred in each of the following modalities: repetition, comprehension, and naming. At one site, language errors in both comprehension and repetition were noted. No language cortex was identified in the frontal lobe. However, stimulation of the area behind the precentral gyrus at 1 cm above the sylvian fissure produced some speech arrest. Initially, the patient had stopped counting, but with prompting, she was able to start again.

3.1.3. Patients 3 and 4

Both cases showed a clear, well-defined representation of language cortex roughly analogous to the classic essential language areas usually found in the dominant left hemisphere. Stimulation of the temporal language cortex produced errors of comprehension, repetition, and naming, whereas stimulation of the frontal cortex produced naming, reading, and some repetition errors. Temporal language areas in both patients involved the superior and middle temporal gyri; in patient 3, language is represented in the posterior part at 6.5 cm from the temporal tip, whereas in patient 4, language extended anteriorly to 4.5 cm from the temporal tip. The surface area of both the frontal and temporal language cortex was estimated to be 2 x 2 cm² in patient 3, however, in patient 4, there were surface areas of 2 x 1 cm² in the frontal lobe and 4 x 3 cm² in the temporal lobe.

3.1.4. Patient 5

The language map showed naming and repetition errors in the frontal lobe in two different sites anterior to the motor strip. At each site, the speech area was estimated to be 1 x 1 cm².

3.1.5. Patient 6

No language cortex was found. The absence of language responses in this case is believed to be due to the misplacement of the SEA such that it did not cover the classic language areas.

4. Discussion

These data describe the configuration of right hemisphere language cortex in patients classified with bilateral language based on the intracarotid amobarbital procedure (IAP), who underwent epilepsy and/or tumor surgery involving the right hemisphere. Left hemispheric language mapping was not considered in this population because the pathology was found in the right hemi-

sphere. The pattern of language distribution identified in the five patients is varied. Most patients displayed language cortex analogous to that seen in the dominant left hemisphere as reported by Penfield, Ojemann, and co-workers using ECS [16-19]. In addition, anterior localization of temporal lobe language as previously described [20] was noted in one patient of our population.

Language errors found were mainly of the motor speech type in the frontal lobe and involved the following of commands and repetition in the temporal language cortex. The absence of language in response to ECS mapping inpatient 6 was unexpected and may be attributed to the placement of the SEA, which, in this particular case, may not have covered the classic language areas.

In these cases, right cortical language mapping confirmed a right hemisphere role in language that was clearly predicted by the TAP results. For example, automatic speech elicited from the right hemisphere during the IAP in patient 1 matches the demonstration of an expressive language area in the right frontal lobe on mapping. Of note, patient 2 demonstrated speech arrest following both amobarbital injections. In our center, we do not typically use this criterion for classifying bilateral language because speech arrest may have other causes that are not language related [21]. However, the TAP raised concerns regarding the possibility of bilateral language, and this was later confirmed by the language map.

In each patient with well-defined language areas in the right hemisphere, the age at seizure onset was less than 10 years. Based on this observation, the anatomical representation of language in the right hemisphere does not seem to have been affected by seizure onset during early childhood, as these patients' seizures originated from the right side. On the other hand, most of these patients had family history of left-handedness (Table 1), supporting the likelihood that a tendency for language to develop in the right hemisphere was genetically predetermined [22]. In addition, the fact that five of these patients are right-handed may reflect transfer of hand dominance secondary to early right hemisphere pathology [23].

The clinical significance of the right hemisphere language areas remains to be determined. In each of these cases, there is also evidence of language function in the left hemisphere based on the IAP. However, because we were unable to perform language mapping on the left hemisphere using ECS, the relative contributions of the two sides to functional language are unclear. In most cases, it appears that the right language cortex is a duplication of functions that are well established in the left hemisphere. Whether these duplicated language areas are necessary for normal language behavior is unknown because, to date, these areas have been spared in the surgical resection. It is also possible that some interaction

between the two sides is necessary to produce normal speech or language processing such that each hemisphere is necessary but not sufficient to support normal language independently. Previous research has suggested that the division of language functions into clearly defined language modalities divided between the hemispheres is rare, although occasionally amobarbital studies appear to indicate expressive speech in one hemisphere and receptive language in the other [20]. In these instances, not only is the language cortex in both hemispheres necessary, but also the interhemispheric connections through the corpus callosum and the anterior commissure and, perhaps, subcortical connections through the thalamic nuclei may be critical for normal function. We speculate that these right hemisphere language areas might have an accessory role in language production as suggested by the IAP results. Further focused studies are needed, particularly in this group of bilateral language patients with right hemisphere seizure onset, to clearly understand the physiological role of the right language cortex and its contribution to language processing and production.

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