Jikeikai Med J 2006 ; 53 : 81-6

Rational Speech Therapy on the Basis of Differences in Functional Magnetic Resonance Activation

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ABSTRACT

We have previously reported that two patients who showed complete recovery from Broca's and Wernicke's aphasia exhibited activation of only compensatory areas of the right hemisphere during repetition tasks. In the present study we compared functional magnetic resonance imaging (fMRI) findings obtained with repetition tasks in healthy subjects. When subjects silently repeated sentences, the only recognized areas of activation in the right hemisphere were the superior temporal gyrus, middle temporal gyrus, and precentral gyrus. When sentences were repeated aloud, recognized areas of activation in the right hemisphere were the superior temporal gyrus, middle temporal gyrus, superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, and precentral gyrus. Activated areas in the left hemisphere were similar when sentences were repeated aloud or silently : the superior temporal gyrus, middle temporal gyrus, superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, and precentral gyrus. If the extent of recovery from severe aphasia is related to activation in the right hemisphere, as suggested by previous reports, speech therapy for patients with aphasia should aim to activate the right hemisphere.

(Jikeikai Med J 2006 ; 53 : 81-6)

Key words : functional magnetic resonance, speech therapy, right hemisphere, repetition task, stroke

INTRODUCTION

Adult patients who recover from aphasia after a left-hemisphere stroke show the three following major changes[1-8] : 1) recovery of damage in the left hemisphere language region, 2) perilesional reorganization of the left hemisphere, and 3) a significant shift of activation areas into homologous areas of the right hemisphere. Rather than focusing on the importance of each of these three changes, perhaps we should envisage a system in which the most effective mechanism operates according to the degree of brain injury and the patient's condition.

Whether speech therapy helps recovery from aphasia remains controversial. Recent studies using functional brain imaging have demonstrated that the right hemisphere plays an important role in patients who recover from aphasia[1,4-8]. Depending on the perilesional reorganization in the left hemisphere, significant shifts of activation areas to homologous areas in the right hemisphere may be beneficial in patients who have showed little improvement[2,3].

We have reported that recovery from Broca's and Wernicke's aphasia involves reorganization and neuromodulation in the right hemisphere[1]. Functional magnetic resonance imaging (fMRI) in healthy subjects repeating words aloud showed activation in the superior temporal gyrus, the middle temporal gyrus,

Received for publication, February 27, 2006
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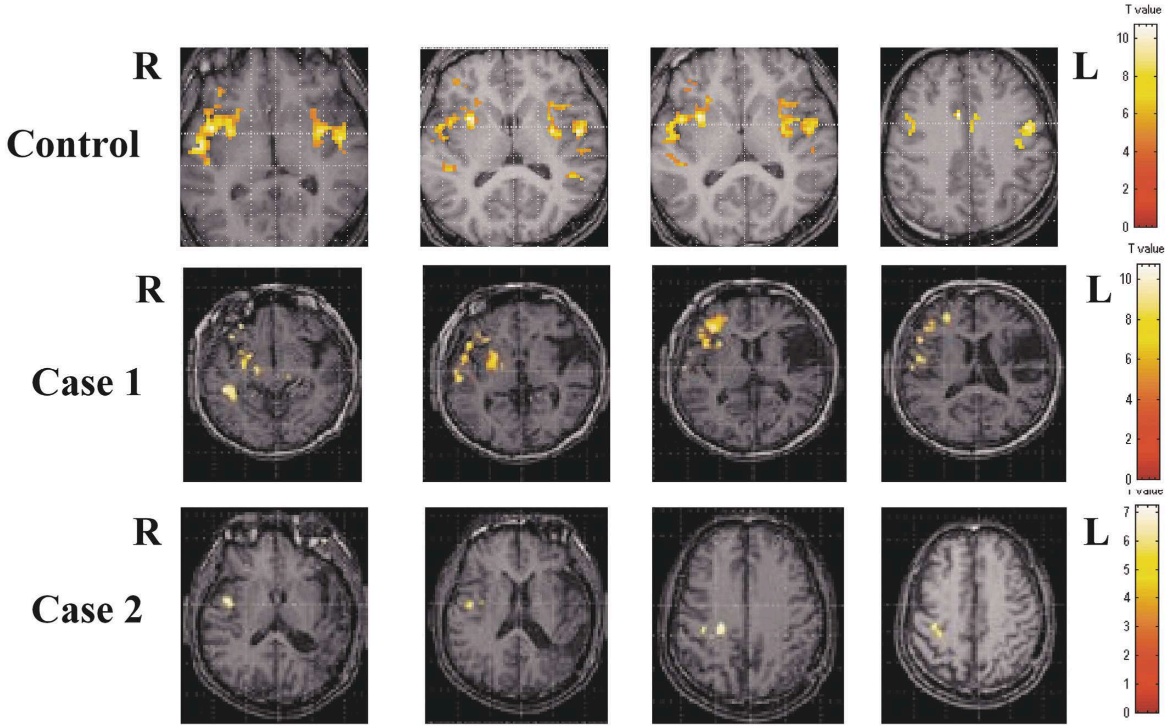


Fig. 1. fMRI activation results during word repetition the aloud in heatlhy subjects, case 1, and case 2. In cases 1 and 2, the recovery from aphasia was complete. The threshold for activation was set at $p<0.05$.

the medial frontal gyrus and the precentral gyrus, insula, the cingulate gyrus of the left hemisphere, and the cingulate gyrus, the middle frontal gyrus and the superior frontal gyrus of the right hemisphere (Fig. 1). In a patient with aphasia and infarct lesions in the left inferior frontal gyrus, insula, white matter in the middle and superior frontal gyri, posterior limb of the internal capsule, and the inferior area in the precentral gyrus activated areas were limited to the unaffected hemisphere, the external temporopolar area, and the anterior superior temporal area of the superior temporal gyrus, precentral gyrus, putamen and the inferior frontal gyrus. In another patient with aphasia and posthemorrhagic atrophy and degeneration in the left temporal lobes, activated areas were limited to the unaffected hemisphere, the superior temporal gyrus of the temporal region, the posterior supramarginal gyrus of the parietal region and inferior parietal lobule of the parietal region. Both patients, who showed complete recovery from aphasia, used only the right hemisphere during repetition tasks despite both hemispheres being used in healthy subjects.

If the right hemisphere is important in the recovery from aphasia, a training method to stimulate the right hemisphere should be started at an early stage. The present study compared fMRI findings obtained during two repetition language tasks, repeating sentences aloud and silently, and examined the validity of using these tasks to train the right hemisphere.

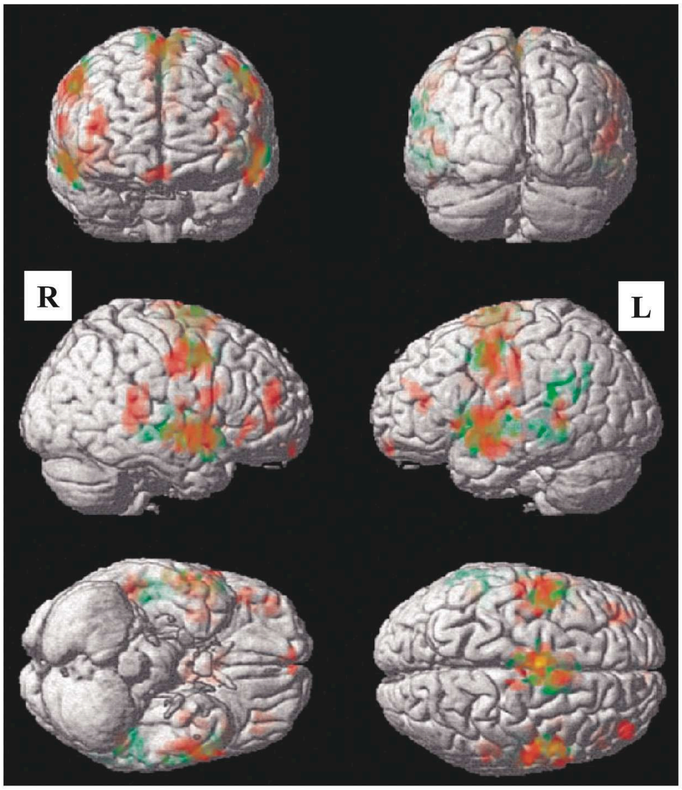
Methods

1. *Subjects*

The subjects were 6 healthy, right-handed male college students aged 20 to 23 years (mean±SD, 21.7±1.2 years).

2. *fMRI*

All MRI examinations were performed with a 1.5-T scanner (23 mT/m maximum amplitude, 77 mT/m/msec slew rate). The subject's head was immobilized within a circularly polarized head coil. fMRI was performed with an echo-planar imaging



RED

Left side	x	y	z	F-value
Superior temporal gyrus	−54	−45	12	22.01
Middle temporal gyrus	−51	−6	−15	45.4
	−57	0	−15	38.45
	−48	−45	0	33.68
Superior frontal gyrus	−6	−3	66	35.32
Middle frontal gyrus	−36	45	21	17.8
	−33	39	12	17.55
Inferior frontal gyrus	−42	39	9	13.81
Precentral gyrus	−54	0	6	46.14
Right side	**x**	**y**	**z**	**F-value**
Superior temporal gyrus	57	−39	12	34.29
Middle temporal gyrus	60	−6	−9	35.93
	54	0	−12	34.18
Superior frontal gyrus	6	9	66	35.95
Medial frontal gyrus	6	−6	57	28.94
	12	60	−18	14.29
Middle frontal gyrus	39	48	18	21.39
	45	45	−3	43.33
Inferior frontal gyrus	63	9	18	21.81
	48	33	0	14.5
Precentral gyrus	54	−6	51	43.26
	60	−12	42	34.55
	51	3	45	22.78
Insula	57	−30	21	17.88

Green

Left side	x	y	z	F-value
Superior temporal gyrus	−57	−39	18	47.13
	−42	−39	15	20.71
Middle temporal gyrus	−55	−27	−3	16.19
	−60	−6	−9	25.25
	−54	9	−15	18.85
Supramarginal gyrus	−55	−45	27	19.52
Superior frontal gyrus	−3	−3	66	26.35
Middle frontal gyrus	−48	3	48	38.47
	−57	6	42	22.19
Medial frontal gyrus	−6	−6	54	33.83
	−6	−15	66	26.35
Inferior frontal gyrus	−51	15	−6	30.07
	−45	33	−9	26.09
	−48	30	0	25.09
Precentral gyrus	−42	−3	36	22.85
Right side	**x**	**y**	**z**	**F-value**
Superior temporal gyrus	54	−3	3	28.63
Middle temporal gyrus	63	−6	−12	43.37
	60	−18	−9	25.9
Precentral gyrus	54	−3	39	28.09
	48	−6	57	25.57
	54	3	45	17.91

Fig. 2. Statistical parametric {t} maps of 3-D images co-registered with MRI images after normalization of MRI and fMRI data into Talairach space.
Red : repeating sentences aloud. Green : repeating sentences silently.

gradient-echo sequence (echo time = 90.5 ms, repetition time = 5,000 ms, field of view = 240 mm, flip angle = 90°, matrix size = 128 × 128, slice thickness = 6 mm, and oriented identical to the anatomical images). Each subject underwent fMRI under both repetition and resting conditions. The language comprehension paradigm consisted of 6 cycles with two conditions : 1) resting condition, 1 minute, and 2) repeating aloud the sentence heard though a set of stereo headphones (Hitachi Advanced Systems Corporation, Yokohama), 1 minute. Another language comprehension paradigm consisted of 6 cycles with two conditions : 1) resting condition, 1 minute, and 2) repeating silently the sentence heard though a set of stereo headphones, 1 minute. In the repetition task, the auditory stimulus consisted of a series of sentences (e.g., "please take the hat off") delivered every 5 seconds binaurally through earphones. Subjects were instructed to repeat the sentence aloud or silently.

The study protocol was approved by the ethics review committees of the participating institutions, and a signed consent form was obtained from each subject.

3. *Image analysis* : Motion correction was performed using the SPM2 software program (Wellcome Department of Cognitive Neurology, University College London, London, UK) implemented in the MATLAB environment (Mathworks Inc., Natick, MA, USA). Each of the MRI slices was automatically realigned and reoriented along the bicommissural line to correct for head movements. Statistical maps were overlaid on the Talairach space[9], and the threshold for activation was set at $p < 0.001$ in all cases.

RESULTS

1. *Three-dimensional images*

Fig. 2 shows statistical parametric {t} maps of three-dimensional (3-D) images co-registered with MRI images after normalization of MRI and fMRI data into the Talairach space.

2. *Repetition aloud* (Fig. 2, red)

Areas of activation were observed bilaterally in the superior temporal gyrus (BA22), the middle temporal gyrus (BA21), the superior frontal gyrus (BA6), the middle frontal gyrus (BA46), the inferior frontal gyrus, and the precentral gyrus (BA6), and in the medial frontal gyrus (BA11) and the insula (BA13) of the right hemisphere.

3. *Silent repetition* (Fig. 2, green)

Areas of activation were observed bilaterally in the superior temporal gyrus (BA22), the middle temporal gyrus (BA21), and the precentral gyrus (BA6) (Fig. 2, green). Areas of activation were limited to the left hemisphere, the supramarginal gyrus (BA40), the superior frontal gyrus, the middle frontal gyrus (BA6), the inferior frontal gyrus, and the medial frontal gyrus.

DISCUSSION

A recent positron emission tomographic study of regional glucose metabolism at rest and during word repetition in six patients with aphasia 1, 12, and 18 months after ischemic stroke showed a correlation between good recovery and activation of the left hemispheric speech areas surrounding the infarct, in particular, the left superior temporal gyrus[2]. In contrast, activation of right hemispheric regions is not correlated with recovery from aphasia[2,3]. Thus, the language-function area of the dominant hemisphere shows good recovery. There is no correlation between functional expansion involving the dominant hemisphere and good recovery from aphasia. However, other reports have indicated that the non-dominant hemisphere plays an important role in the recovery from aphasia[1,4–7]. Musso et al.[7] have demonstrated a correlation between right hemisphere activation and training-induced improvement in verbal comprehension. Furthermore, positron emission tomographic studies of adult patients recovering from aphasia after a left-hemisphere stroke have demonstrated right-sided activation of language processing[4]. We have also shown that patients with aphasia and left-hemisphere damage who completely recovered from aphasia exhibit activation of only compensatory areas in the right hemisphere during the repetition task[1].

These differential activation patterns suggest a hierarchy within the language-related network regarding the effectiveness for improvement of aphasia, i.e., areas in the right hemisphere contribute if regions in the left hemispheric have been destroyed. Both functional deactivation (diaschisis) and neuronal loss might also contribute to metabolic and perfusional changes in the neighborhood of the infarct, and the condition of the surrounding tissue may also affect recovery. Efficient restoration of language is usually achieved only if left temporal areas are preserved and can be reintegrated into the functional network. Many clinical reports support the notion that the right hemisphere participates in a long-term process of recovery. Speech-recognition and syntactic-processing functions in the right hemisphere, which are less developed than those of the left hemisphere, might begin to compensate for impaired language functions.

Although recovery from aphasia may be due to speech therapy, evaluating the effect of speech therapy on recovery is often difficult. Aphasic recovery depends on several factors, such as the severity of the disease process, the type of aphasia, the cause of the disease, and the latency between stroke onset and aphasia. Any treatment should be specifically tailored to individual patients. However, these standards are rarely adhered to. Designing a randomized clinical trial to evaluate the efficacy of speech therapy is, therefore, difficult. Speech therapy for aphasia is varied. In addition, considerable differences in the methods and characteristics of speech therapy result when therapy is tailored to the conditions of individual patients.

When our healthy subjects repeated sentences silently, areas of activation in the right hemisphere were the superior temporal gyrus, the middle temporal gyrus, and precentral gyrus. When subjects repeated sentences aloud, areas of activation in the right hemisphere were the superior temporal gyrus, the middle temporal gyrus, the superior frontal gyrus, the middle frontal gyrus, the inferior frontal gyrus, and the precentral gyrus, similar to a mirror image of the left hemisphere. If the degree of recovery from severe aphasia is related to activation in the right hemisphere, as suggested by previous reports[1,4–8], speech therapy to activate the right hemisphere should be started at an early stage in patients with aphasia. Therefore, stimuli, such as sounds that can be recognized as language, should be given so that reorganization may progress smoothly in patients with aphasia. Although melodic intonation therapy[10] is a useful for treating aphasia, it might be made more effective by adding stimuli using body movement and vibration, and, thus, aphasia therapy is defined as a concept of brain organization.

In patients with aphasia, the mirror regions of the left posteroinferofrontal area and posterosuperotemporal area in the nondominant hemisphere are important for performing word-repetition tasks[5]. Thulborn et al.[8] have demonstrated that improvements in language tasks were paralleled by shifts of activation areas to homologous brain areas in the right hemisphere. Our previous study has shown that repetition functions in patients who have recovered completely from Broca's aphasia caused by left hemisphere damage were possible by using only compensatory areas in the right hemisphere[1].

However, opinions about recovery from aphasia 1 year after onset are varied. Recovery of aphasia is considered to occur 1 year after onset. Patients who have undergone different methods of aphasia training after more than 1 year from onset should be evaluated. Patients receiving our speech therapy were evaluated with the Western Aphasia Battery and fMRI. By performing such evaluations, we may be able to examine the effects of language training. Further studies, especially those using fMRI, are necessary to confirm our findings and to compare the effects of long-term speech therapy, including the protocol used in the present study and other modes of speech therapy.

Conclusion

When sentences were repeated silently, areas of activation were recognized only in the superior temporal gyrus, middle temporal gyrus, and precentral gyrus of the right hemisphere. When sentences were repeated aloud, areas of activation were recognized in the right hemisphere in the superior temporal gyrus, the middle temporal gyrus, the superior frontal gyrus, the middle frontal gyrus, the inferior frontal gyrus, and the precentral gyrus, like a mirror image of the left hemisphere. If the degree of recovery from severe aphasia is related to activation in the right hemisphere, as demonstrated in previous reports, speech therapy to activate the right hemisphere should be started at an early stage in patients with aphasia. Therefore, using a stimulus, like sound, that allows recognition of language is important so that reorganization can progress smoothly in patients with aphasia.

Acknowledgement: This work was supported by grants from Animo Limited (Kanagawa, Japan)

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