

Functional Magnetic Resonance Imaging Evaluation of Bilateral Brain Activation in Chinese Speech

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Abstract

Objective: To investigate the cerebral hemispheric representation of Chinese subjects employing functional magnetic resonance imaging during verbal fluency tasks.

Patients and Methods: Healthy subjects were presented stimuli of the word categories animals, fruit, occupations. Each had to respond by saying aloud in Chinese any item which belonged to the category. Subjects' speech responses were recorded during functional magnetic resonance imaging. The blood oxygen level-dependent response was averaged and data analysed using statistical parametric mapping.

Results: Verbal fluency tasks spoken in Chinese were associated with bilateral fronto-temporal lobe activation.

Conclusion: These results provide preliminary support for bilateral cerebral hemispheric representation of Chinese speech.

Key words: Brain mapping, Chinese, Language, Magnetic resonance imaging, functional

Introduction

The concept of left cerebral hemisphere dominance for language from a young age is well established.^{1,2} Much

of the evidence for left cerebral hemisphere dominance for language is derived from experiments using alphabetic languages. Whether the concept can be regarded as universal can be tested by reference to non-alphabetic language systems, such as Chinese.

Chinese is a logographic language system, composed of characters or strokes positioned within a square. Neuroimaging experiments using Chinese language have traditionally employed silent reading tasks. These have shown left inferior-frontal and left middle frontal activation when Chinese characters³⁻⁵ and sentences⁶ were read but additional right inferior occipital gyrus activation during visuo-spatial analysis of Chinese characters.⁷ A study conducted by Tan et al suggests that reading aloud in Chinese is associated with strong *bilateral* cerebral activation.⁸ Since reading aloud requires the effective integration of speech and hearing, it is likely that a more widely distributed or bilaterally represented function is needed for Chinese speech.

To investigate this further, the authors selected the verbal fluency (VF) task.^{9,10} In alphabetic languages, VF is known to be associated with strong left cerebral hemisphere activation, activating brain regions which control executive function and semantic processing — the left prefrontal cortex, left superior temporal cortex, and left cingulate cortex.¹¹⁻¹³ Thus, if a Chinese VF task activated both hemispheres it would provide convincing evidence that the brain representation of executive and semantic processing for Chinese is bilateral. This is a novel and empirical approach since to our knowledge, no previous study has used VF to investigate cerebral lateralisation for Chinese speech.

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Patients and Methods

Subjects

Ten healthy Chinese volunteers were recruited from the community. All spoke Chinese as their first language. None had a history of neurological disease, alcohol or substance use, electroconvulsive therapy, head injury or loss of consciousness, or attendance at a special school. None had any history of ferromagnetic material *in situ*. All ten had normal hearing. Myopic subjects used plastic and titanium goggles to rectify visual acuity during magnetic resonance imaging (MRI). All gave written informed consent to participate after a full description of the study was provided. Participants were reimbursed for travel expenses only. Approval for the study was obtained from the Queen Mary Hospital Ethics Committee.

Clinical Assessments

On the day of the MRI scan, each subject was assessed by a trained rater using a sociodemographic interview, the Information and Digit Span subtests of the Wechsler Adult Intelligence Scale-Revised Manual¹⁴ (Cantonese version, Hong Kong Psychological Society 1989), for handedness,¹⁵ and using the Mini-Mental State Examination.¹⁶ Subjects generated normal scores on VF task,⁹ previously validated in Chinese adults.^{10,17} Subjects named items belonging to the categories of animals, or fruits or occupations. The latter category was chosen rather than “vegetables” since it is a common category and not semantically related to the category fruits.

Experimental Design

All subjects were trained to perform the VF task satisfactorily before the scan. A blocked periodic design lasting 180 seconds was employed, meaning a periodic or repeating cycle of A-B-A-B-A-B where A is the active condition and lasted for a 30-second “block” followed by the baseline condition B which also lasted for 30 seconds. There were 3 stimuli categories for condition A: A1 = animal, A2 = fruit, A3 = occupation. These were presented in the order A1-B-A2-B-A3-B. Each category was presented at a rate of one every three seconds. Thus, for A1, the characters for animal (動物) were presented as 10 cues in succession over 30 seconds. Each time, the subject had to give an overt response of one item belonging to that category (eg, 狗 “dog” in Chinese).

The subject was instructed not to repeat any item for a given category. During passive condition B, the instruction “rest” (休息) was likewise presented as a cue every three seconds for 30 seconds, and the subject was required to repeat this word in response to the stimulus. The term 休息 was selected because it means no occupation and thus represented a control term for the category A3 occupation. Each subject performed the VF task twice, once with visual presentation of cues, the other with auditory presentation of cues. This was done because processing of speech is a socially dynamic process which depends on tuning into

different sensory modalities, especially auditory and visual; eg, the cocktail party phenomenon when one selectively tunes in to immediate stimuli while ignoring all other environmental interference. Accordingly, this kind of mixed event design permitted investigation of whether VF activates brain regions with a *common* processing component.^{6,18} Auditory VF task cues were delivered via headphones and visual VF task cues were back-projected on a screen via a computer. The order of stimulus presentation was counter-balanced across subjects — half the subjects had the auditory stimuli first and then the visual stimuli, and *vice versa*. During the auditory presentation of stimuli, the subject was instructed to close his or her eyes to eliminate extraneous environmental stimuli. In response, the subject was required to give an overt speech response, and this was recorded on an MRI-compatible microphone during the scan.

Magnetic Resonance Imaging Acquisition

MRI brain images were obtained using a 1.5 T superconducting magnet (Signa Horizon Echospeed, General Electric, Milwaukee, USA) and a transmit-receive head coil. The anterior AC-PC line was located using sagittal localiser images. A total of 7 contiguous oblique scans of the brain 10 mm thick were obtained starting from 7 mm below the AC-PC line in order to visualise the inferior and middle frontal gyri, superior and middle temporal gyri, and the cingulate gyrus. Using echo planar imaging gradient echo pulse sequence and blood oxygen-level-dependent technique (in which endogenous oxygenated blood is treated as the imaging contrast medium), functional MRI (fMRI) scans were acquired once every 3 seconds for 180 seconds (60 scans per cycle) giving a total of 420 T2*-weighted images per cycle. In plane resolution was 3 mm; imaging parameters were: TE = 40 ms; TR = 3 s; no. signal averages = 1. Each subject performed the VF task twice, yielding 840 T2*-weighted images per subject. T1-weighted structural MRI data were also acquired at the same location as the T2*-weighted images to facilitate co-registration of fMRI images. The subject’s head was restrained within a convex, padded head-rest and Velcro tabs were employed to secure the forehead and chin in order to limit head movement during scanning.

Magnetic Resonance Imaging Processing and Analysis

Data were analysed using Statistical Parametric Mapping (SPM-99, Wellcome Department of Cognitive Neurology, London, UK) using the general linear model^{19,20} running in MatLab 6.0 (Mathworks Inc., Sherborn, Massachusetts, USA) on a SUN Ultrasparc 10 workstation. The first four images were discarded to avoid saturation effects. To correct for motion, all remaining data were spatially realigned within SPM-99, using a least-squares approach, to estimate a six-parameter rigid body transformation for each data set. Thus, for each subject, all T2* images were successfully realigned with the middle volume of the imaging session and motion was less than 2 mm. Normalisation to standard

MNI (Montreal Neurological Institute) space within SPM-99 was performed, whereby the standard space is based on a template T1-weighted dataset closely corresponding to Talairach space. An isotropic Gaussian filter kernel having a full-width half maximum of 14 mm was used to smooth the data in order to increase signal-to-noise. Statistical parametric maps were generated using the general linear model²¹ to characterise regionally specific effects in the imaging data. The term in the model was the active task condition (VF task).

A boxcar reference waveform convolved with a kernel that approximates the haemodynamic response curve was used to test specific hypotheses, resulting in a t value at each voxel. Within SPM, each SPM $\{t\}$ statistic is transformed to the unit normal distribution to give an SPM $\{Z\}$ statistic. For each subject, brain images from the VF task performed using visual and auditory presentation were combined using a standard approach^{6,22} to permit brain regions of activation common to both modalities of stimulus presentation to be identified. This was achieved using a cognitive conjunction analysis, because this permits the identification of areas of common activation associated with a common processing component. The null hypothesis was that at any given voxel, no common brain areas are involved in the performance of VF. Group analysis was performed based on voxels which achieved statistically significant activation at a threshold of $p < 0.05$ (corrected for multiple comparisons), and 150-voxel spatial extent threshold applied for cluster size at $p < 0.05$ (corrected for multiple comparisons). The MNI coordinates in standard parametric space were automatically converted by means of a standard conversion algorithm to Talairach and Tournoux coordinates.

Results

Inspection of movement files of 4 subjects showed greater than 2 mm movement during the scan, so the data from these subjects was excluded from analysis. The final sample comprised 6 subjects (3 men and 3 women), all right-handed, mean age 37 years (SD 9.9), years of education 9 years (SD 3.1), verbal IQ 100, mean Mini-Mental State Examination¹⁶ score 29/30.

Verbal Fluency Performance

Subjects performed VF task equally proficiently, and the mean number of items generated for each category was 19–20 per minute, which is accepted as normal.¹⁰ There was no significant difference between the total number of items generated in the active condition compared to the passive condition. In addition, the total number of Chinese characters in each condition, which can potentially give rise to jaw movement, revealed no significant difference.

Brain Regions Activated During Verbal Fluency

Bilateral fronto-temporal cortices were strongly activated during VF task. Strongest activation was noted in the right inferior frontal gyrus (BA 47), right middle temporal gyrus

(BA 39), and right superior temporal gyrus (BA 22). The left middle frontal gyrus (BA 10) and left middle temporal gyrus (BA 39) also showed significant activation (Figure 1). The height and extent of clusters reported were significant at the level of $p < 0.05$ corrected (Table 1). Excluding female subjects did not substantially alter these findings.

Discussion

This paper presents the first description of VF task during Chinese speech associated with bilateral fronto-temporal activation. Classically, the VF task has been regarded as a robust left fronto-temporal hemisphere task, whether or not verbal responses are produced silently or aloud.^{23,24} The majority of Chinese language tasks evaluated to date have involved silent reading or generating Chinese words and these have also yielded strong left prefrontal activation.^{25,26} Thus, the bilateral cerebral representation observed in this study is not explained by the use of Chinese *per se*. It also cannot be accounted for by the auditory and visual nature of VF task stimuli, because these are known to activate left fronto-temporal gyri predominantly.⁶ It is interesting to note that Tan and coworkers reported that reading Chinese words *aloud* resulted in bilateral cerebral activation involving the left infero-middle frontal cortex, left motor cortex, right infero-frontal gyri, bilateral anterior superior temporal areas, and the anterior cingulate cortex.²⁷ Tan and colleagues suggest

Figure 1. Significant brain regions activated on Chinese verbal fluency task (axial view of brain images; left side of image corresponds to left side of brain).

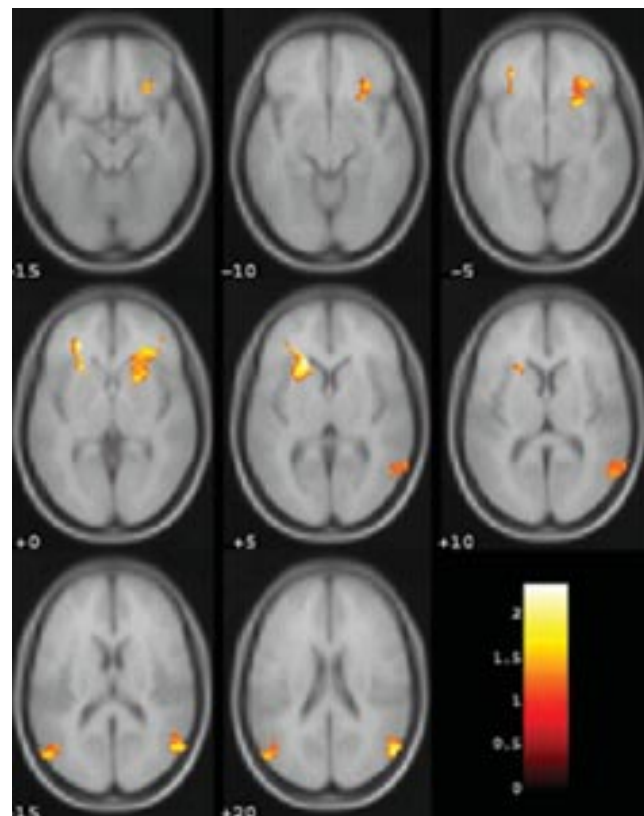


Table 1. Significant clusters on verbal fluency task in healthy subjects.

Cluster level ($p < 0.05$ corrected)	Voxel level ($p < 0.05$ corrected)				Brodmann area	Brain region
	x (mm)	y (mm)	z (mm)	z score		
536	28	35	0	6.04	47	R. inferior frontal gyrus
	36	33	0	5.97	47	R. inferior frontal gyrus
404	53	-67	24	6.75	39	R. middle temporal gyrus
	51	-57	18	5.11	22	R. superior temporal gyrus
	63	-56	10	5.05	22	R. superior temporal gyrus
305	-26	35	-2	6.81	47	L. inferior frontal gyrus
	-26	21	-3	6.27	47	L. inferior frontal gyrus
157	-51	-71	22	5.68	39	L. middle temporal gyrus
	-46	-63	18	4.90	39	L. middle temporal gyrus

that as with other languages, speaking in Chinese not only recruits the left fronto-temporal cortex but also a distributed brain network incorporating the right cerebral hemisphere. Our preliminary finding of bilateral fronto-temporal activation during Chinese VF task provides additional support for their proposition. It also is consistent with neurophysiological evidence from magneto-encephalography suggesting that words spoken in Chinese result in more bilateral cerebral activity compared with English or Spanish.²⁸ Indeed, processing and learning tones, which is essential for Chinese speech, has been shown to involve activation of the right middle and inferior frontal gyrus, respectively.²⁹

A limitation of this study is that the final sample size was small due to high data attrition, a particular disadvantage of overt language tasks. Accordingly, these findings are preliminary. The conjunction analysis approach attempted to minimise the possibility of Type I errors. This permitted the exploration of core brain regions which are common to both auditory and visual speech processing,²² a method superior to traditional cognitive subtraction analysis since it can combine any number of tasks, all of which differ only by one component. Finally, our subjects were all ethnic Chinese, a possible confounding factor.

It is plausible that learning a language with complex tonal and orthographic rules may result in a widely distributed set of brain language systems and our study supports the position that bilateral cerebral activation may be important to Chinese speech. This pattern is likely to be observable from a young age, as the brain shows a striking capacity to adapt to vocal cues very early in life.³⁰ Future research will focus on how brain maturational development determines which brain regions are involved in orthographic and tonal processing of Chinese language.

Conclusion

This is to the authors' knowledge the first study to use fMRI and a VF task to examine Chinese speech. It provides preliminary evidence of bilateral fronto-temporal lobe activation, suggesting that in keeping with other languages, speaking in Chinese recruits not only the left fronto-temporal cortex but also a distributed brain network involving the right cerebral hemisphere.

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