Neurohemodynamic Correlates of Antonym Generation in Bilinguals

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Abstract

Objectives: Bilingualism and multilingualism are the norms of the society. The study was undertaken to assess the neural systems of language in bilinguals by means of antonym generation in Tamil to Tamil (TT) language, English to English (EE) language, and code-switching between Tamil to English (TE) using functional magnetic resonance imaging (fMRI). **Methods:** Proficient 16 Tamil-native speakers from rural Tamil Nadu, South India, participated in the study. Tamil (L1) was the first language and English (L2) was the second language in Cognitive Neuro Centre, NIMHANS. Single assessment design was used. Antonym generation task was used for the study with fMRI. **Results:** TT task uniquely activated right frontotemporal gyrus along with left caudate and lentiform nucleus. TE activated left parahippocampal and right cerebellar tonsil. Using conjunction analysis, it was found that during TT task, robust activations were present in multiple bilateral prefrontal areas, premotor area, bilateral insula, bilateral lingual gyrus, claustrum, and bilateral cerebellum. Common areas for TT and EE are precentral gyrus, cingulate gyrus, and right dentate. However, EE and TE activated bilateral parietal gyrus, cingulate gyrus, bilateral fusiform gyrus, angular gyrus bilateral thalamus, bilateral culmen, and right inferior semilunar lobule on the blood oxygenation level dependent of fMRI. **Conclusions:** The nature of the language produces unique neural circuits. The language processing in the brain requires executive processes and cognitive controls. The study has implications for cognitive network pattern analysis which could possibly aid in rehabilitation.

Keywords: Antonym generation, bilinguals, code-switching, cognitive processes, functional magnetic resonance imaging

Introduction

Language is a system of brain circuits.[1] Localization of language processes comes from anatomical studies of language,[2] studies of lesions in human patients,[3] studies of brain stimulation in awake human patients, and[4] brain-imaging studies. The concept of "bilingualism" is termed as an equal ability to communicate in two languages. The term "bilinguals" refers to people who can use two languages selectively and effectively in their everyday life. According to Bloomfield, "those who have native-like control of two or more languages are considered as bilinguals."[4] On the contrary, Haugen mentions that when he/she observes a speaker of one language producing complete meaningful utterances in the other language, he/she can call him a "bilingual."[5] A person who might have no productive control over a language but be able to understand utterances in it is also considered as bilingual by other researchers.[6] From the psycholinguistics point of view, bilingualism aims at studying the processes involved in production, perception, and memorization of the bilingual's languages (spoken, written, or signed).[7] The are several dimensions involved to the measure of bilingual abilities (degree of proficiency, accuracy, context of acquisition and/or learning, age of appropriation, degree of motivation, context of use, and structural distance between the two languages). The one who acquires two languages, at the same time, from infancy is considered as the early bilingual and the one who acquires second language after the age of 7 years is the late bilingual.[8] The literature pertaining to brain processing of bilingualism is about whether spatially overlapped or segregated neural substrates subserve two reciprocal languages, or are there functional areas or networks responsible for language switching.[9]

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Code-switching is defined as the practice of selecting or altering linguistic elements in interaction.[10] Research in code-switching began in the 1970s, involving syntactic or morphosyntactic constraints on language alteration.[11,12] Later research examined the cognitive mechanisms underlying the bilingual's ability to integrate and separate two languages during the communicative process.[13]

India is widely known for its cultural diversity and the languages spoken. English is the secondary official language. The term "bilinguals" refers to the use of two languages in everyday life. In spite of an abundance of literature on bilingualism, questions remain to be addressed regarding the neural basis of language processing and switching in Indian languages. Our aim was to explore the cognitive network associated with language mechanism of Tamil and English (Dravidian language [Tamil] and Indo-European [English]); Tamil is considered as Proto-Dravidian language.[14]

Methods

Subjects

After the approval of ethics committee (NIMHANS), participants were recruited for the study with written informed consent. Participants for this study were 16 males, right-handed native Tamil speakers. Their mean age was 22 years, with mean education of 15 years of education. All participants had normal or corrected to normal vision. There was no significant history of any medical, neurological, or psychiatric illness as per the clinical interview.

All participants learned English (L2) in school as a second language from the age of 8 years, i.e., from the 3rd year of formal schooling. Tamil was the medium of instruction up to high school, i.e., 10 years of formal schooling. At the college level, i.e., from the 11th year of education, seven volunteers had Tamil and nine volunteers had English as their medium of instruction. Their preferred language for communication with family, friends, and superiors was Tamil. Exposure to English was limited to watching TV news for half an hour per day as well as reading their college lessons in English (the information was obtained from interview). Proficiency in English was average, with the mean score ranging from 2 to 3. This result indicates that they are comparatively less proficient in English. Language proficiency was tested through Language Proficiency Test[15] containing subjective report of proficiency. Subjective report was obtained about the age of acquisition, perceived proficiency in each language on a three-point scale, medium of instruction, and usage of language in different settings. The objective assessment of proficiency was conducted using Picture Narration and Verbal Comprehension Tests. The performance on each of these two tests was scored on a five-point scale.

Task

Silent antonym generation in each of the two languages, i.e., from Tamil to Tamil (TT) (L1 to L1) and from English to English (EE) (L2 to L2), as well as code-switching from Tamil (L1) to English (L2) (TE), was used as the tasks. The rationale for using silent generation was to decrease the movement artifact and the language choice was due to unavailability of the data for the language Tamil.

Choice of stimuli

The stimulus in each language was derived from 100 Tamil and 100 English nouns, verbs, and adjectives. In each language, the common list of words contained 2–6 letters and a syllable length of 2–4. To ensure similar levels of ease to generate antonyms for the words to be chosen as stimuli, the following procedure was adopted. Twenty native Tamil speakers generated antonyms for these 100 Tamil words. A total of 80 words were chosen as stimuli whereas difficult 20 words were omitted from the list both in English and in Tamil to ensure uniformity level in both the languages for the task. From the corpus of the 80 Tamil words, 40 words were chosen randomly for TT antonym generation and the remaining 40 words were chosen for code-switching from TE; Similar method was followed to choose antonym generation words in English as well (40 /80 words). The details of TT antonym generation words are as follows: 18 (45%) were nouns, 6 (15%) were verbs, and 16 (40%) were adjectives. In English, it was 19 (47%) were nouns, 7 (18%) were verbs, and 14 (35%) were adjectives. Among the set of 40 Tamil words used for TE antonym generation, 21 (52%) were nouns, 6 (15%) were verbs, and 13 (33%) were adjectives. A total of 80 simple black–white antonym words were used in the present study (40 each language). The images were presented using ESys functional magnetic resonance imaging (fMRI) presentation system with each patient viewing the images on magnetic resonance (MR) compatible display through a mirror attached to the head coil. All participants were comfortably padded around the head to reduce head motion artifacts. Participants were monitored visually using MR compatible video system [Figures 1 and 2].

Functional magnetic resonance imaging paradigm

There were one fMRI paradigms, with three experimental block designs. Silent antonym generation from TT was scanned in the first set, EE in the second set, and TE in the third set. In each paradigm, four blocks of rest condition alternated with four blocks of active condition, with 10 words. In the active condition, one word was displayed per dynamic. There were no repetitions of words across the blocks in any of the three experimental conditions: Tamil (L1) nonswitching, English (L2) nonswitching, and forward switching (from L1 to L2) and control trials. In the rest condition, the volunteers passively viewed four crosshairs (####). Participants were asked to fixate their eyes on the cross silently and no response was required.

Data acquisition

Functional magnetic resonance imaging scanning

MRI scanning was conducted in a 3 Tesla Siemens Magnetom Skyra Scanner. Stimuli, programmed with a computer, were projected onto a translucent screen. Participants viewed the

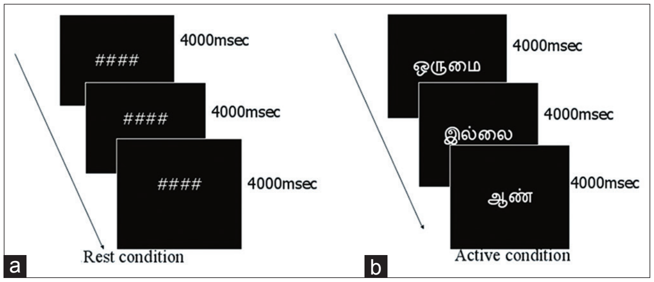

Figure 1: Sample of Tamil antonym generation

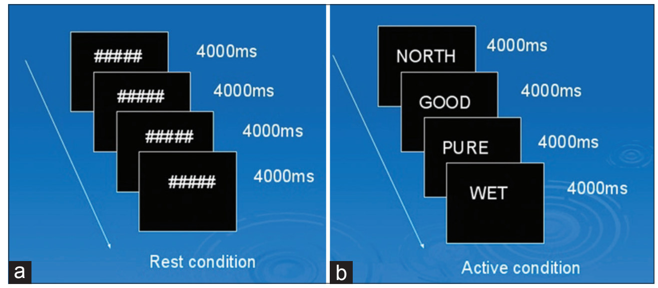

Figure 2: Sample of English antonym generation

Table 1: Functional magnetic resonance imaging activations for Tamil to Tamil/English to English antonyms generation

Common Areas		Unique Areas	
TT	**EE**	**TT**	**EE**
Left PG (BA 4), bilateral PG (BA 6)	Right PG (BA 4), left middle and MFG (BA 6)	Right transverse temporal gyrus (BA 41)	Right thalamus (LDN)
Bilateral middle and MFG (BA 9), right middle frontal gyrus (BA 46)	Left middle frontal gyrus (BA 9), right IFG (BA 9)	Right lingual gyrus (semantic processing)	Left anterior lobe (culmen)
Right IFG (BA 44), left IFG (BA 13)	Right IFG (BA 9), left insula (BA 13)		Right inferior semilunar
Left insula (BA 13	Left insula (BA 13)		Lobule
Bilateral cingulated gyrus (BA 24, BA 32)	Right cingulated gyrus (BA 24), left cingulate gyrus (BA 32)		Left angular gyrus (BA 39), left IPL (BA 40)
Left MOG (BA 18), left fusiform gyrus (BA 19)	Left MOG (BA 18), right IOG (BA 18), bilateral fusiform gyrus (BA 37)		Left SPL (BA 7)
Left claustrum, left declive of cerebellum, right dentate of cerebellum, left midbrain (SN)	Left claustrum, left declive of cerebellum, right dentate of cerebellum, left midbrain (SN)		

MFG: Medial frontal gyrus; PG: Precentral gyrus; SPL: Superior parietal lobule; IFG: Inferior frontal gyrus; MOG: Middle occipital gyrus; IOG: Inferior occipital gyrus; IPL; Inferior parietal lobule; LDN: Lateral dorsal nucleus; SN: Substantia nigra; BA: Broadman area; TT: Tamil to Tamil antonym; EE: English to English antonym generation

stimuli through a mirror attached to the head coil. Anatomical scan was acquired with a T1 MPRAGE sequence. The field of view (FOV) was 240 mm, slice thickness was 0.9 mm, and the number of slices/slab was 176, with the voxel size of 0.9 mm × 0.9 mm × 0.9 mm. fMRI was acquired with an SE EPI sequence. Repeat time was 4 s, echo time was 3 s, FOV was 192 mm, slice thickness was 4 mm, number of slices obtained was 36, voxel size was 3 mm × 3 mm × 4 mm, and the matrix was 64 × 64. For each participant, the first five volumes in each scan series were discarded because they were collected before magnetization reached the equilibrium state.

Functional magnetic resonance imaging data analysis

We used SPM8[16] (Welcome Department of Cognitive Neurology, London, UK) for image preprocessing and subsequent statistical analysis. The image preprocessing steps included echo planar imaging (EPI), functional image realignment, anatomic–functional image coregistration, and normalization.[17] The motion artifacts were corrected (maintained below 3 mm), normalization was done to fit the EPI template of MNI, and smoothing step to arrive at voxel (8 mm × 8 mm × 8 mm). First-level analyses for individual participants were done with family-wise error (FWE), threshold of $P < 0.05$, and a voxel cluster size of 5. Significant changes in hemodynamic response for each participant and condition were assessed using t-statistics in using general linear model (GLM). The group averaged effects were computed with a random-effects model. For group analysis, clusters with more than five voxels activated above a threshold of $P < 0.001$ (uncorrected) were considered as significant. Second-level analysis for group activation was derived for with family-wise $P < 0.0001$ and threshold value of 5. Using GingerALE,[18] Talairach coordinates were obtained.[19] Individual activation maps were parametrically estimated by the following contrasts: language nonswitching minus fixation, language switching minus language nonswitching, language nonswitching minus language switching, and (forward switching minus L2 nonswitching) minus (backward switching minus L1). Conjunction analysis, a technique that could identify several activations, in a series of subtractions, each performed in a different context, was jointly significant. The activation conjunction is identified by the conjoint testing of several hypotheses, each pertaining to individual subtractions or effects; this identification thus helps in identifying the areas of common activation that could be associated with the regional effects with the common processing component.[19] The present application of conjunction analysis was to evaluate the significant difference among two different languages for antonym generation. The study relied on whole-brain analyses and not region of interest analysis.[20]

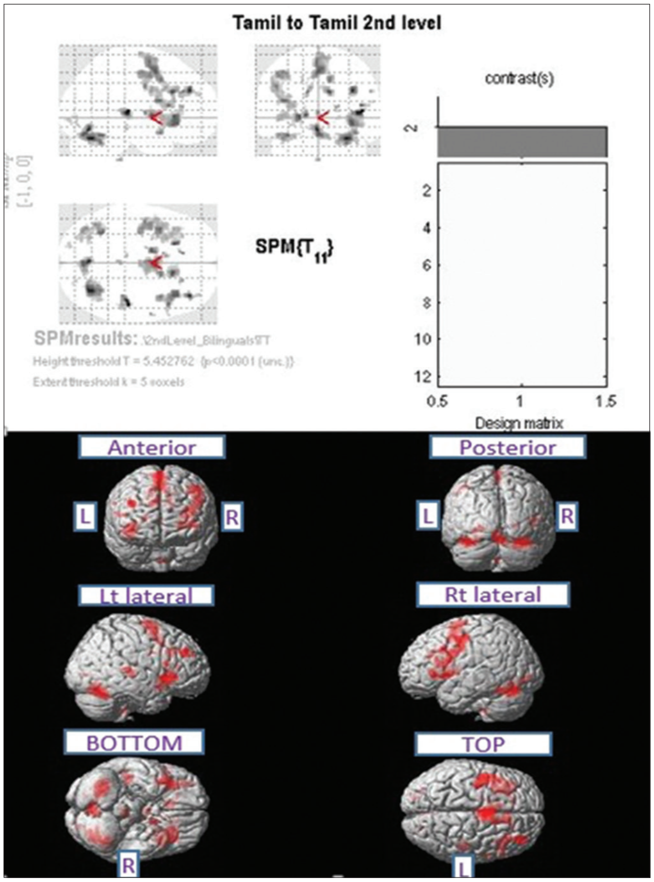

Figure 3: Glass brain view of the Tamil to Tamil activation

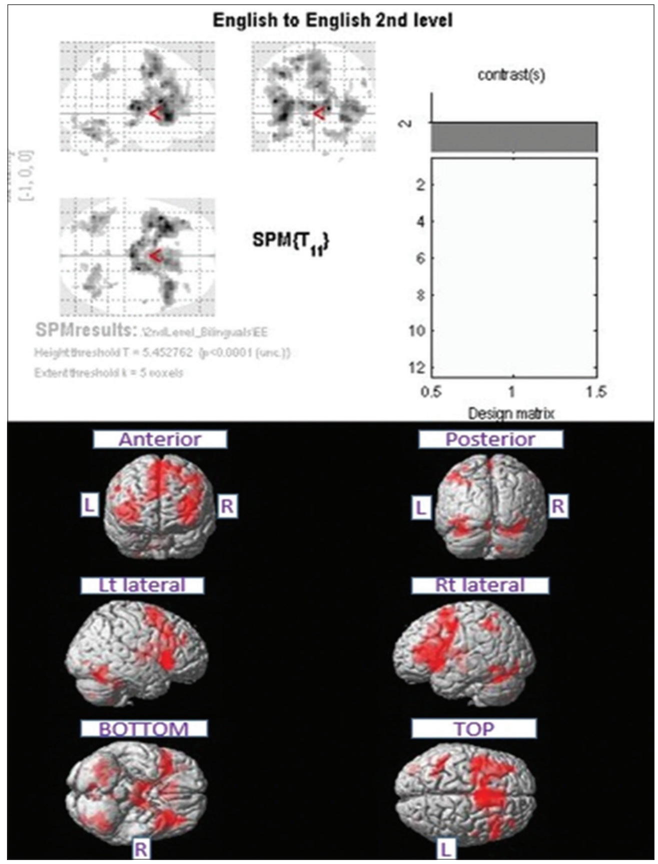

Figure 4: Glass brain view of the English to English activation

Results

Verbal comprehension and picture description were administered to obtain an assessment of proficiency in each language. Subjective report of the volunteers regarding the proficiency in speaking, understanding, listening, and writing in each of the two languages was obtained. By the end of the second-level analysis using SPM8 for uncorrected FWE, $P < 0.0001$, cluster threshold value of 5, and average activation for the different antonym generation task were tabulated. Regions were combined using conjunction analysis. The present study revealed the activation pattern for the silent word reading and generating antonyms to the presented words in all the three tasks (TT, EE, and TE). Unique areas were seen in both the tasks (TT and TE). TT task uniquely activated right frontotemporal gyrus along with left caudate and lentiform nucleus. TE activated left parahippocampal and right cerebellar tonsil. In bilingual, mother tongue (L1) has activated cortical areas. Code-switching has activated both cortical and subcortical regions. Using conjunction analysis, it was found that during TT task, robust activations were present in multiple bilateral prefrontal areas, premotor area, bilateral insula, bilateral lingual gyrus, claustrum, and bilateral cerebellum. Common areas for TT and EE are precentral gyrus, cingulate gyrus, and right dentate. However, EE and TE activated bilateral parietal gyrus, cingulate gyrus, bilateral fusiform gyrus, angular gyrus, bilateral thalamus, bilateral culmen, and right inferior semilunar lobule [Tables 1-4]. The pattern of activations indicates utilization of executive functions of central executive of working memory (BA 9, 46), semantic fluency (BA 44, 13), prosody (BA 41), error monitoring and cognitive control (BA 24, 32), subvocal speech (4, 6, claustrum, caudate, putamen, cerebellum), and auditory rehearsal (insula). Multiple cognitive processes are involved during TT antonym generation. During EE task, activations were presented in multiple right prefrontal areas (BA 9); right precentral areas (BA 4); left anterior cingulate gyrus (BA 32); right anterior cingulate gyrus (BA 24); left insula (BA 13); right fusiform gyrus (BA 37); right inferior occipital gyrus (BA 18); left middle occipital gyrus (BA 18); right thalamus (lateral dorsal nucleus); left claustrum, left cerebellum (anterior lobe, declive); and right cerebellum (dendate). The pattern of activations indicates the executive functions of central executive of working memory (BA 9); error monitoring and cognitive control (BA 24, 32), subvocal speech (BA 4, claustrum, cerebellum), auditory rehearsal (BA 13), visual processing (BA 37, 18). The semantic regions involved in TT are right inferior frontal gyrus (BA 44) and right middle frontal gyrus (BA 46). Visual recognition and processing of the word form of the Tamil script is attributed to activations in the right lingual gyrus and left fusiform gyrus (BA 19). The activation of left fusiform gyrus (BA 19) was also seen in TE

Table 2: TT Functional magnetic resonance imaging activations for Tamil to Tamil antonyms generation

Cluster equivk	Peak T	MNI Co-ordinates			Lobe	Gyri/sulcus	Brodmann Area
		x, y, z {mm}	x, y, z {mm}	x, y, z {mm}			
86	10.5905	47	-24	8	R. Temporal	Transverse Temporal Gyrus	41
340	9.734167	31	-64	-22	R. Posterior	Declive	*
	7.816748	31	-54	-28	R. Anterior	Culmen	*
	6.751443	21	-66	-26	R. Anterior	*	Dentate
73	9.366196	37	42	32	R. Frontal	Middle Frontal Gyrus	9
179	9.257313	-3	-66	-12	L. Posterior	Declive	*
97	8.589966	11	24	30	R. Limbic	Cingulate Gyrus	32
118	8.520151	-21	26	2	L. Sub-lobar	Caudate	Caudate Head
	6.703815	-37	30	4	L. Frontal	Inferior Frontal Gyrus	13
492	8.465748	1	4	54	L. Frontal	Medial Frontal Gyrus	6
	7.62696	13	10	44	R. Limbic	Cingulate Gyrus	24
319	8.371746	37	26	-6	R. Sub-lobar	Insula	13
	6.391443	39	12	-8	R. Sub-lobar	Claustrum	*
51	8.321925	-13	2	4	L. Sub-lobar	Lentiform Nucleus	Putamen
544	8.101967	-39	10	20	L. Frontal	Precentral Gyrus	6
	7.589292	-39	-10	52	L. Frontal	Precentral Gyrus	4
22	8.052954	45	20	14	L. Frontal	Middle Frontal Gyrus	46
	5.96878	55	18	14	R. Frontal	Inferior Frontal Gyrus	44
208	7.99575	-33	-54	-20	L. Anterior	Culmen	*
	7.262045	-39	-70	-22	L. Posterior	Declive	*
9	7.776439	-11	34	30	L. Frontal	Medial Frontal Gyrus	9
14	7.408343	-1	-6	6	L. Sub-lobar	Thalamus	*
11	6.919011	19	34	12	R. Limbic	Anterior Cingulate	32
22	6.917975	-9	16	34	L. Frontal	Cingulate Gyrus	32
	6.504282	-35	8	2	L. Sub-lobar	Claustrum	*
7	6.330881	-9	-26	-12	L. Midbrain	*	Substania Nigra
5	6.297094	-17	-4	42	L. Limbic	Cingulate Gyrus	24
12	6.039987	-21	-90	-2	L. Occipital	Middle Occipital Gyrus	18
11	5.94693	-29	-80	-8	L. Occipital	Fusiform Gyrus	19

code-switching. In EE task, left angular gyrus (BA 39) was involved in semantic processing along with bilateral fusiform gyrus activation along the region attributed to the visual task (BA 37). We see that the regions for visual processing of the word form followed by the semantic processing are different for both languages. Both languages activated cerebellum and basal ganglia regions. Common activations in the substantia nigra for all TT, EE, and TE tasks are attributed to the eye movements involved in the visual word processing. Cerebellar activation of the right inferior semilunar lobule was present in EE as well as TE code-switching, but not for TT task. This region is reported to be involved in phonological assembly[21] also phonological processing of code-switching.[22] It indicated that participants had done the translation between English (L2) to Tamil (L1) and later TE, i.e., L2→L1||L1→L2. Subjective oral report also confirmed it. We infer from this that a process of phonological mapping to Tamil also takes place in the EE antonym generation task. The previous studies on working memory suggested that it is a two-storage buffer: the phonological loop for storing verbal information and the visuospatial sketchpad for the storage of visual information. Because working memory resources are limited, an executive system assigns and coordinates these limited resources for storing and manipulating information.[23-25] Left middle frontal gyrus (BA 6), left superior parietal lobule (BA 7), and left inferior parietal lobule (BA 40) were not seen in TT antonym generation, but it was commonly seen in EE antonym generation and TE code-switching. This clearly indicates that the participants faced the difficulty to produce the opposite. The disassociation of function in left BA 6 for task difficulty and right BA 6 for response correctness and the involvement of a more diffuse network involving the left cerebellum in response correctness extend the knowledge about contributions of classic motor and premotor areas supporting higher-level cognition.[26] It is evidenced that TT antonym generation was much easier for them because of their fluency. Activation pattern with angular gyrus in BA 39 is also seen only in TE and EE tasks but not in TT. This result suggests the reading ability involved phonological processing[27] which requires further analysis [Figures 3 and 4] and [Tables 1-3].

Language switching (2) code-switching

The analysis revealed several regions significantly activated by language switching relative to language nonswitching. The results indicate code-switching from TE is mediated by

Table 3: Functional magnetic resonance imaging activations for English to English antonyms generation

Cluster equivk	Peak T	MNI Co-ordinates			Lobe	Gyri/sulcus	Brodmann area
		x, y, z {mm}	x, y, z {mm}	x, y, z {mm}			
2789	14.25327	-33	20	-2	R. Sub-lobar	Claustrum	*
	14.03463	-43	12	14	L. Sub-lobar	Insula	13
	12.36086	-29	16	10	L. Sub-lobar	Claustrum	*
1968	12.98124	1	-20	8	L. Sub-lobar	Thalamus	*
	12.89941	15	-12	6	R. Sub-lobar	Thalamus	Ventral Lateral Nucleus
	10.93184	13	-16	14	R. Sub-lobar	Thalamus	Lateral Dorsal Nucleus
2009	10.47601	3	14	32	R. Limbic	Cingulate Gyrus	24
	10.37865	-17	6	62	L. Frontal	Middle Frontal Gyrus	6
	8.616605	-31	-68	-24	L. Anterior	Culmen	*
61	9.809093	-11	-18	-12	L. Midbrain	*	Substania Nigra
	7.021689	-5	-26	-12	L. Midbrain	*	Red Nucleus
372	9.082474	37	-70	-18	R. Posterior	Declive	*
	8.117363	15	-60	-24	R. Anterior	*	Dentate
	7.63103	45	-60	-10	R. Temporal	Fusiform Gyrus	37
109	8.702861	-43	-54	-10	L. Temporal	Fusiform Gyrus	37
36	8.047215	55	22	34	R. Frontal	Middle Frontal Gyrus	9
177	7.569046	-43	-48	50	L. Parietal	Inferior Parietal Lobule	40
	6.614387	-29	-58	44	L. Parietal	Angular Gyrus	39
8	7.447751	53	-6	52	R. Frontal	Precentral Gyrus	4
13	6.699526	-3	-46	-20	L. Anterior	Culmen	*
15	6.499015	-33	-58	62	L. Parietal	Superior Parietal Lobule	7
18	6.437856	11	-70	-48	R. Posterior	Inferior Semi-Lunar Lobule	*
26	6.423661	-3	-72	-12	L. Posterior	Declive	*
6	6.370822	61	14	26	R. Frontal	Inferior Frontal Gyrus	9
9	6.219115	19	6	30	R. Limbic	Cingulate Gyrus	24
7	5.938213	35	-80	0	R. Occipital	Inferior Occipital Gyrus	18
5	5.914238	-15	30	24	L. Limbic	Cingulate Gyrus	32
5	5.646809	-41	-84	-4	L. Occipital	Middle Occipital Gyrus	18

executive processes (BA 8, 9); cognitive control (BA 32); visual attention (BA 7); semantic processing (BA 39, 40); memory retrieval (BA 36); emotional processing (BA 13); visual processing (BA 18, 19, 37); motor programming (BA 6, bilateral cerebellum); and arousal (bilateral thalamus); activations in visual processing areas are attributed to seeing the words; in motor programming areas to subvocal speech; and in semantic processing and emotional processing areas to processing the meaning of the words. Code-switching requires activations of the executive processes (BA 8, 9) and cognitive control (BA 32). The bilateral thalamic activations could have arisen due to task difficulty. Code-switching in rural bilingualism requires functional and executive process to perform the task in the other language. Moreover, its complex phenomenon for the memory recalls. Hence, when language is processed by an individual, it is always intermingled with cognitive and affective processes. Right insula was only seen in TE code-switching. Anterior cingulate (BA 32) was present in both the code-switching and EE antonym generation suggested that the working memory involved in the execution of the task. Working memory serves simultaneous information, storage, and processing functions.[28] The previous study by Venkatraman *et al*.[29] on code-switching from English to Chinese for a numerical addition and approximate percentage calculation task showed the activation in left inferior frontal gyrus and left inferior parietal gyrus extending to angular gyrus. The left inferior frontal gyrus activations were attributed to code-switching. Another study by Chee *et al*.[30] for translating visually presented sentences from Mandarin to English as well as from English to Mandarin showed activations in both languages in the middle prefrontal cortex (left BA 9, parts of 8 and 6), left temporal (BA 21, 22 and 38), bilateral superior parietal (BA 7), left angular gyrus (BA 39), anterior supplementary motor area (BA 8), and occipital regions. The activations of the middle prefrontal cortex were attributed to code-switching between the languages. A striking point in our results is bilateral thalamic activity and bilateral culmen observed in TE code-switching whereas no thalamic activation was observed in the TT (L1) task. We attribute bilateral activity to simultaneous lexical processing and translating from L1→L1/L2||L2/L1→L2. Right thalamic activity was observed only in the EE (L2) antonym generation task indicating the mediation of an L2→L1||L1→L2 process. In either case, our results indicate an executive control that involves L1 processing for L2 tasks. Consistent with the previous studies, a face localizer contrast (faces-objects) revealed bilateral activation in the fusiform gyrus (BA 37) for EE, left temporal fusiform gyrus (BA 37) and left occipital fusiform gyrus (BA 19) for

Table 4: Functional magnetic resonance imaging activations for Tamil to English antonyms generation

Cluster equivk	Peak T	MNI Co-ordinates			Lobe	Gyri/sulcus	Brodmann Area
		x, y, z {mm}	x, y, z {mm}	x, y, z {mm}			
3406	14.75418	-31	-6	52	L. Frontal	Precentral Gyrus	6
	12.59526	-35	26	22	L. Frontal	Middle Frontal Gyrus	9
982	11.70623	31	-64	-20	R. Posterior	Declive	*
	9.071198	33	-54	-26	R. Anterior	Culmen	*
133	11.1873	11	-12	-2	R. Sub-lobar	Thalamus	*
	5.722264	19	-12	4	R. Sub-lobar	Thalamus	Ventral Lateral Nucleus
1044	10.44448	1	8	56	L. Frontal	Medial Frontal Gyrus	6
	8.91507	13	24	36	L. Limbic	Cingulate Gyrus	32
	8.027737	11	26	28	R. Limbic	Cingulate Gyrus	32
93	10.1641	-27	-56	-26	L. Anterior	Culmen	*
524	9.998851	35	22	6	R. Sub-lobar	Insula	13
	7.661178	29	24	-2	R. Sub-lobar	Claustrum	*
	5.48248	47	18	6	R. Sub-lobar	Insula	13
286	9.601188	-25	-78	-6	L. Occipital	Lingual Gyrus	18
	6.549486	-41	-70	-12	L. Occipital	Fusiform Gyrus	19
332	9.475987	-29	-60	42	L. Parietal	Angular Gyrus	39
	8.252487	-39	-50	44	L. Parietal	Inferior Parietal Lobule	40
125	8.968073	-7	-20	14	L. Sub-lobar	Thalamus	*
	6.164597	-7	-4	2	L. Sub-lobar	Thalamus	Ventral Anterior Nucleus
48	7.972794	15	-70	-46	R. Posterior	Inferior Semi-Lunar Lobule	*
13	7.765791	-11	-20	-10	L. Midbrain	*	Substania Nigra
133	7.359931	-37	-48	-20	L Anterior	Culmen	*
	6.569908	-41	-54	-16	L. Temporal	Fusiform Gyrus	37
5	7.049703	-43	-36	-10	L. Limbic	Parahippocampal Gyrus	36
74	7.035115	37	42	26	R. Frontal	Superior Frontal Gyrus	9
15	6.797206	-33	-60	60	L. Parietal	Superior Parietal Lobule	7
6	6.053941	31	-68	-38	R. Posterior	Cerebellar Tonsil	*
7	5.711086	-35	26	44	L. Frontal	Middle Frontal Gyrus	8

TE, and left fusiform gyrus (BA 19) for TT tasks.[31] Proverbio *et al*.[32] reported bilateral response for Italian (L1) and left side response for L2 (Slovenian). In our result, also right lingual gyrus which is responsible for semantic processing has only seen in TT task (L1). Parahippocampal gyrus (BA 36) was only seen in TE code-switching. Neural responses are specific to speech components or voice production clearly observed in the left-sided area of the brain.[22] This is confirming that the recollection of associative information but was not related to old item recognition.[33] Our results are in agreement with the previous studies in which code-switching has activated areas mediating executive processes and cognitive control. To conclude, Tamil and English languages activated overlapping and unique areas of brain regions involved in higher level cognitive and executive control. L1 (TT) showed bilateral activation and L2 (EE) consistently activated most of the left-sided brain regions which is in agreement with the previous studies on bilinguals. Code-switching in normative bilingualism requires executive processes and cognitive control. It is noteworthy that switching from Dravidian language to an Anglo Saxon language activates similar brain areas as when switching from a Chinese language to an Anglo Saxon language [Figure 5, Tables 4 and 5].

Discussion

Neuropsychological and psycholinguistic work has focused on the macrorepresentation such as semantic processing, syntactic, phonological, and other processes, which aids in cognitive framework of language processing. Research in bilinguals indicate that semantic processing in two languages is mediated by a common neural system.[34] In a study by Price *et al*.,[35] proficient German-English bilinguals were asked to perform a word reading task and a translation task, and the results revealed increased activity for translation in areas involved in articulation (anterior insula and supplementary motor area) and in attentional control (anterior cingulate gyrus). Switching resulted in increased activity in the Broca's area and the supramarginal gyrus.[36] Bilinguals studies reveal the recruitment of an attentional network and few studies have found increased activity of brain areas involved in cognitive control when bilinguals are switching between languages.[37-39] One of the studies demonstrated that there is multiple cognitive processing involved in bilinguals using a picture naming paradigm; the results revealed increased activity in the dorsolateral prefrontal cortex (DLPFC) and the superior parietal lobule during language switching compared to naming of pictures in a single language.

Table 5: Summary of brain regions acquired for the uncorrected *P*<0.0001 with Threshold value of 5

BA no	Task		
	TT	EE	TE
4	L. Precentral Gyrus	R. Precentral Gyrus	*
6	B. Precentral Gyrus	L. MFG	L. MFG, L. PG, L MFG
7	*	L. SPL	L. SPL
8	*	*	L. MFG
9	B. MFG	R.IFG, R. MFG	R.SFG, , L. MFG
13	L.Insula, L IFG	L. Insula	R. Insula
18	L.Middle Occipital Gyrus	L. MOG, R. IOG	B. Lingual Gyrus
19	L. Fusiform Gyrus	*	L. Fusiform Gyrus
24	B. Cingulate Gyrus	R. Cingulate Gyrus	*
32	B. Cingulate Gyrus	L. Cingulate Gyrus	R. Anterior Cingulate
#	*	*	R. PCT
36	*	*	L. Parahippocampal Gyrus
37	*	B. Fusiform Gyrus	L. Fusiform Gyrus
39	*	L. Angular Gyrus	L. PAG
40	*	L. IPL	L. IPL
41	R. Temporal Gyrus	*	*
44	R. IFG	*	*
46	Right Middle Frontal Gyrus	*	*
#	L. Claustrum	L. Claustrum	R. Sub Lobar Claustrum
#	Left Caudate	*	*
#	L. Lentiform Nucleus (Putamen)	*	*
#	*	R. Thalamus (LDN)	B. Thalamus
#	L. Mid Brain (SN)	Left Mid Brain (SN)	Left Mid Brain (SN)
#	*	L. Tuber	*
#	*	L. Brain Stem	*
#	L. Declive	B. Declive	R. Declive
#	R. Dentate	R.Dentate	*
#	*	L. Anterior (Culmen)	B. Culmen
#	*	R. ISLL	R. ISLL

TT: Tamil to Tamil antonym generation; EE: English to English antonym generation; TE: Tamil to English antonym generation; generation; BA: Broadman area. *No activation; #No BA. MFG: Medial frontal gyrus; PG: Precentral gyrus; SPL: Superior parietal lobule; IFG: Inferior frontal gyrus; SFG: Superior frontal gyrus; MOG: Middle occipital gyrus; IOG: Inferior occipital gyrus; PCT: Posterior cerebellar tonsil; PAG: Parietal angular gyrus; IPL: Inferior parietal lobule; LDN: Lateral dorsal nucleus; SN: Substantia nigra; ISLL: Inferior semilunar lobule

This study also suggested that there was increased activity observed between early learned first and second languages. In addition, differences in areas devoted to language processing such as the superior temporal gyrus were found. In nutshell, the study showed increased activity in brain areas devoted to memory, somatosensory processing, and emotion.[9]

Our study implies that cognitive processes are involved in the silent antonym generation in bilinguals. The relevance

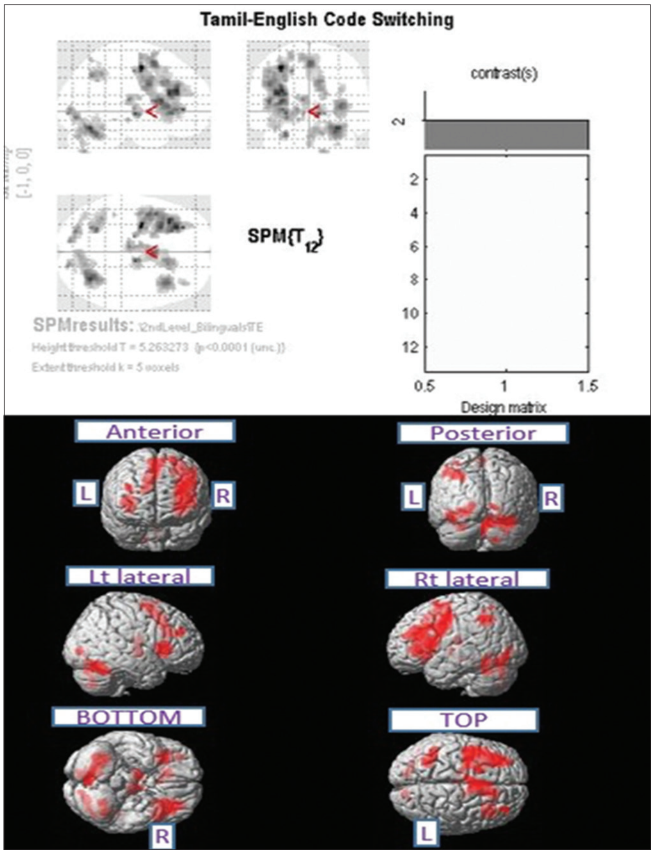

Figure 5: Glass brain view of the Tamil to English activation

of prefrontal cortex involvement and the associated areas is in accordance of the literature. Prefrontal cortex is conceptualized as a major cognitive control cortex which functions as top-down bias mechanisms that facilitate the processing of task-relevant representations even in the presence of prepotent, irrelevant ones.[40] Petrides[41] proposed two-stage hierarchical organization of prefrontal cortex according to which in the midfrontal areas 9 and 46 carry out sequential processing and self-monitoring functions while the inferior prefrontal areas 45 and 47 (DLPFC) are engaged in a lower-level function. The interconnections of the prefrontal cortex are involved in modulation. During word production, the left basal ganglia and the anterior cingulate cortex are expected to modulate activity in the prefrontal cortex mediating and inferior parietal cortex. The prefrontal cortex interconnects strongly with the parietal cortex and this circuit may be implicated in the selection of competing responses.[42] The prefrontal cortex along with cognitive control, organization, and modulation also guides response selection under conditions of response conflict or refreshes recently active representations within working memory. The prefrontal cortex implements control via top-down modulation of posterior cortex or the basal ganglia.[41] In summary, dynamic view of speech production in bilinguals involves cortical and subcortical structures which is primarily connected and interconnected with prefrontal areas.

There are two basic questions regarding brain processing of bilingualism, whether neural substrates subserve two reciprocal languages and the other is the functional areas or networks responsible for language switching. The studies suggested that there was no single region responsible for language switching. Studies to address the neural representation of late bilingual's language switching include left inferior frontal region,[43] bilateral supramarginal gyri,[35] left caudate,[44] left anterior cingulate cortex, and subcortical structures. However, in early bilinguals, the involvement of the left DLPFC,[45,46] right DLPFC,[47] and left prefrontal and lateral temporal regions[48] has been observed.

These findings suggest that different languages are represented in overlapping areas of the brain for early bilinguals; few models were proposed.[49] The language-specific model[50] assumes that only the target language is activated. The inhibitory control model[51,52] assumes that the selection of lemmas in one language is only achieved after the successful inhibition of the lemmas of the other; the amount of inhibition would depend on two factors: the activation level of the words that need to be suppressed and the speaker's proficiency level in the nonresponse language. Another model of cognitive processes and neural foundations of language switching has been proposed based on a "hodological" rather than a "localizationist" view of language processing. It suggests that language switching involves corticocortical and cortico-subcortical parallel and distributed networks that span lobes, with the superior longitudinal fasciculus as their edges and the supramarginal and angular gyri, Broca's area, posterotemporal areas, and fusiform gyrus as their nodes. Abutalebi and Green[37] proposed a left cortico-subcortical network for language switching which is also involved in cognitive control or executive control more generally. This network consisted of prefrontal cortex, anterior cingulate cortex, basal ganglia, and inferior parietal lobule. The hodological view is as it allows us treating widely spread regions in a coherent framework of interpretation for language.

The limitations of our study are that the proficiency of bilinguals was not similar. However, we have accounted for age of acquisition and background status and education which makes the sample homogeneous. Another limitation is the absence of behavioral data to support the imaging studies. The sample size is too limited to arrive at generalization of the findings. We have inferred from the brain activation about the cognitive process; our inferences have only been heuristic; however, it requires robust statistical analysis to further enhance the study variables. Advancement in the analysis such as the multivariate pattern analysis might be more useful for detecting some aspects of the corticocortical and cortico-subcortical networks that subserve the functions in bilingual language switching, while still being sensitive to the contiguous areas of homogenous activation that might be detected by the GLM methods.

Our study has implications for the language and cognitive network pattern analysis and use of the knowledge pool to create possible program for rehabilitation program with acquired language difficulties.

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Conflicts of interest

There are no conflicts of interest.

References

1. Kolb B, Whishaw IQ. Fundamentals of Human Neuropsychology. Amsterdam: Macmillan; 2009. p. 1.
2. Bialystok E, Martin MM. Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. Dev Sci 2004;7:325-39.
3. Stemmer B, Whitaker HA, editors. Handbook of the Neuroscience of Language. Amsterdam: Academic Press; 2008; p.79.
4. Bloomfield L. Language History: From Language (1933 ed.). Amsterdam: Holt, Rinehart and Winston; 1933.
5. Haugen E. The Norwegian Language in America. Vol. 2. Philadelphia: University of Pennsylvania Press; 1953.
6. Hockett CF. A Course in Modern Linguistics. New Delhi: Oxford and Ibh Publishing Co.; 1958.
7. Meuter RF, Allport A. Bilingual language switching in naming: Asymmetrical costs of language selection. J Mem Lang 1999;40:25-40.
8. Paradis M. Differential use of cerebral mechanisms in bilinguals. In: Banich MT, Mack M, editors. Mind, Brain, and Language: Multidisciplinary Perspectives. London: Lawrence Erlbaum; 2003. p. 351-70.
9. Hernandez AE, Martinez A, Kohnert K. In search of the language switch: An fMRI study of picture naming in Spanish-English bilinguals. Brain Lang 2000;73:421-31.
10. Nilep C. Code switching in sociocultural linguistics. Colo Res Linguist 2006;19:1-22.
11. Blom JP, Gumperz J. Social meaning in linguistic structure: Code-switching in Norway. In: Gumperz J, Hymes D, editors. Directions in Sociolinguistics. New York: Holt, Rinehart and Winston; 1972.
12. Halmari H. Government and Codeswitching Explaining American Finnish. Amsterdam: John Benjamins Publishing; 1997.
13. Heredia RR, Altarriba J. Bilingual language mixing: Why do bilinguals code-switch. Curr Dir Psycholo Sci 2001;10:164-8.
14. Dravidian Languages. Encyclopaedia Britannica. Available from: http://www.search.eb.com/eb/article. [Last accessed on 2017 May 09].
15. Shivashankar N. Language Proficiency Test. Amsterdam: NIMHANS Unpublished Clinical Test; 2010.
16. Available from: http://www.fil.ion.ucl.ac.uk/spm/software/spm8. [Last accessed on 2017 May 09].
17. Friston KJ, Holmes AP, Poline JB, Grasby PJ, Williams SC, Frackowiak RS, *et al.* Analysis of fMRI time-series revisited. Neuroimage 1995;2:45-53.
18. Available from: http://www.brainmap.org.ale. [Last accessed on 2014 Apr].
19. Available from: http://www.talairach.org. [Last accessed on 2014 Apr].
20. Price CJ, Friston KJ. Cognitive conjunction: A new approach to brain activation experiments. Neuroimage 1997;5:261-70.
21. Fulbright RK, Jenner AR, Mencl WE, Pugh KR, Shaywitz BA, Shaywitz SE, *et al.* The cerebellum's role in reading: A functional MR imaging study. AJNR Am J Neuroradiol 1999;20:1925-30.

22. Démonet JF, Thierry G, Cardebat D. Renewal of the neurophysiology of language: Functional neuroimaging. Physiol Rev 2005;85:49-95.
23. Daneman M, Carpenter PA. Individual differences in working memory and reading. J Verbal Learn Verbal Behav 1980;19:450-66.
24. Engle RW, Tuholski SW, Laughlin JE, Conway AR. Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. J Exp Psychol Gen 1999;128:309-31.
25. Miyake A, Shah P, editors. Models of Working Memory: Mechanisms of Active Maintenance and Executive Control. Cambridge: University Press; 1999.
26. Kalbfleisch ML, Van Meter JW, Zeffiro TA. The influences of task difficulty and response correctness on neural systems supporting fluid reasoning. Cogn Neurodyn 2007;1:71-84.
27. Hampson M, Tokoglu F, Sun Z, Schafer RJ, Skudlarski P, Gore JC, *et al.* Connectivity-behavior analysis reveals that functional connectivity between left BA39 and Broca's area varies with reading ability. Neuroimage 2006;31:513-9.
28. Baddeley A. Working Memory: Oxford Psychology Series, No. 11. Oxford: Clarendon Press; 1986: p.289.
29. Venkatraman V, Siong SC, Chee MW, Ansari D. Effect of language switching on arithmetic: A bilingual FMRI study. J Cogn Neurosci 2006;18:64-74.
30. Chee MW, Caplan D, Soon CS, Sriram N, Tan EW, Thiel T, *et al.* Processing of visually presented sentences in Mandarin and English studied with fMRI. Neuron 1999;23:127-37.
31. Rossion B, Schiltz C, Crommelinck M. The functionally defined right occipital and fusiform "face areas" discriminate novel from visually familiar faces. Neuroimage 2003;19:877-83.
32. Proverbio AM, Cok B, Zani A. Electrophysiological measures of language processing in bilinguals. J Cogn Neurosci 2002;14:994-1017.
33. Yonelinas AP, Hopfinger JB, Buonocore MH, Kroll NE, Baynes K. Hippocampal, parahippocampal and occipital-temporal contributions to associative and item recognition memory: An fMRI study. Neuroreport 2001;12:359-63.
34. Francis WS. Bilingual semantic and conceptual representation. Handbook of Bilingualism: Psycholinguistic Approaches. Amsterdam: Oxford University Press; 2005. p. 251-67.
35. Price CJ, Green DW, von Studnitz R. A functional imaging study of translation and language switching. Brain 1999;122(Pt 12):2221-35.
36. Hernandez AE. Language switching in the bilingual brain: What's next? Brain Lang 2009;109:133-40.
37. Abutalebi J, Green DW. Control mechanisms in bilingual language production: Neural evidence from language switching studies. Lang Cogn Process 2008;23:557-82.
38. Abutalebi J, Annoni JM, Zimine I, Pegna AJ, Seghier ML, Lee-Jahnke H, *et al.* Language control and lexical competition in bilinguals: An event-related FMRI study. Cereb Cortex 2008;18:1496-505.
39. Wang Y, Xue G, Chen C, Xue F, Dong Q. Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. Neuroimage 2007;35:862-70.
40. Miller EK, Cohen JD. An integrative theory of prefrontal cortex function. Annu Rev Neurosci 2001;24:167-202.
41. Petrides M. The role of the mid-dorsolateral prefrontal cortex in working memory. Exp Brain Res 2000;133:44-54.
42. Petrides M, Pandya DN. Projections to the frontal cortex from the posterior parietal region in the rhesus monkey. J Comp Neurol 1984;228:105-16.
43. MacDonald AW 3rd, Cohen JD, Stenger VA, Carter CS. Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. Science 2000;288:1835-8.
44. Emmorey K, Borinstein HB, Thompson R. Bimodal bilingualism: Code-blending between spoken English and American sign language. In: Proceedings of the 4th International Symposium on Bilingualism. Somerville, MA: Cascadilla Press; 2005. p. 663-73.
45. Lehtonen MH, Laine M, Niemi J, Thomsen T, Vorobyev VA, Hugdahl K, *et al.* Brain correlates of sentence translation in Finnish-Norwegian bilinguals. Neuroreport 2005;16:607-10.
46. Crinion J, Turner R, Grogan A, Hanakawa T, Noppeney U, Devlin JT, *et al.* Language control in the bilingual brain. Science 2006;312:1537-40.
47. Hernandez AE, Dapretto M, Mazziotta J, Bookheimer S. Language switching and language representation in Spanish-English bilinguals: An fMRI study. Neuroimage 2001;14:510-20.
48. Kim KH, Relkin NR, Lee KM, Hirsch J. Distinct cortical areas associated with native and second languages. Nature 1997;388:171-4.
49. Costa A, Santesteban M, Ivanova I. How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. J Exp Psychol Learn Mem Cogn 2006;32:1057-74.
50. Green DW. Control, activation, and resource: A framework and a model for the control of speech in bilinguals. Brain Lang 1986;27:210-23.
51. Green DW. Mental control of the bilingual lexico-semantic system. Biling Lang Cogn 1998;1:67-81.
52. Duffau H. The anatomo-functional connectivity of language revisited. New insights provided by electrostimulation and tractography. Neuropsychologia 2008;46:927-34.