

# Articulation in early and late bilinguals' two languages: evidence from functional magnetic resonance imaging

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Received 5 February 2005; accepted 2 March 2005

The network of cortical and subcortical regions that contribute to articulation was examined in bilinguals using functional magnetic resonance imaging. Participants were all fluent in French and English: half were bilingual from birth and half were 'late bilinguals' who had learned French after the age of 12. Overt articulation resulted in the bilateral activation of the motor cortex, basal ganglia and cerebellum, and also the supplementary motor area, independent

of the language spoken. Furthermore, the threshold and extent of the network involved in articulation was identical for the two bilingual groups with the exception of greater variation in the left putamen for the late bilinguals. These data challenge claims that age of acquisition results in fundamental differences in the neural substrates that subserve language in bilinguals. *NeuroReport* 16:761–765 © 2005 Lippincott Williams & Wilkins.

**Key words:** Articulation; Early bilinguals; Functional magnetic resonance imaging; Late bilinguals; Putamen

## INTRODUCTION

Advances in imaging technology have allowed us to gain a far better understanding of the interactions involved between different regions of the brain when we engage in even highly automated tasks such as articulating speech. Evidence from monolinguals suggests that articulation involves a network of cortical and subcortical structures including the premotor and primary motor cortex, the supplementary motor area (SMA), the basal ganglia and the cerebellum [1,2]. The role of the anterior insula has also been suggested [3,4]. The extent to which these different regions are involved during speech varies as a function of several factors. Overt speech produces bilateral activation of the motor cortex, cerebellum and basal ganglia, whereas covert speech produces unilateral activation of the left motor cortex and comparatively reduced activation of the basal ganglia [5–7]. At slow rates of speech, the cerebellum is apparently not actively involved in a simple articulation task, whereas at rates that approximate normal speech it is [8]. When a particular rhythm is imposed upon simple sequences, the left putamen is involved in articulation, whereas for monotonic sequences (compared with a perceptual baseline) it is not systematically active [9].

Given the presence of such variability in brain activation during articulation in monolinguals, one might expect as much or more variability in the neural regions associated with articulation in bilingual speakers, particularly for those who learned a second language 'late' and who still bear the phonological mark of their first-learned language. Several dozen neuroimaging studies of language processing in

bilinguals have been published [10]. Only a handful, however, have examined the motor aspects of speech. Klein and colleagues [11] reported a positron emission tomography (PET) study in which proficient English–French late bilinguals overtly repeated and translated words. Highly similar patterns of cortical and subcortical activation were found across the two languages with the exception of the left putamen [12], where higher activation was found in the second language than in the native language. The authors attributed this difference to greater articulatory demands in the second, later learned language. Three subsequent PET studies, however, did not support this claim. No difference in putamen activation across languages was found in Chinese–English late bilinguals on a repetition task [13], or in German–English late bilinguals on a translation task [14]. Klein *et al.* [15] later reported that variation in putamen activation was bound to particular word properties (associated with articulating French), rather than specifically a second language effect. These PET studies thus concur in showing overlapping areas of activation across languages during speech, with the possible exception of the left putamen. Most functional magnetic resonance imaging (fMRI) studies in bilinguals also show overlapping rather than spatially distinct regions activated during language tasks; however, these studies have not looked specifically at articulation. Where differences are found, they appear to be associated with late onset of bilingualism and/or less proficiency in the second language; however, here too there is opposing evidence [16]. Thus, currently, no clear consensus exists about whether neural activation linked to

articulation differs for the first and second language of bilinguals.

The present study examined the cerebral structures underlying articulation by comparing two populations of bilinguals. We wished to establish whether the involvement of the brain during speech in 'early' bilinguals, who learn two languages from birth and are able to produce both with native prosody, would differ from that in 'late' bilinguals, who generally lack native prosody in their second language. No such comparison has been made as concerns articulation insofar as we are aware. A parallel, however, is provided in the domain of musical expertise, showing that early learning of complex motor skills affects cerebral organization. Violinists who learned to play from early childhood show an increase in the somatosensory representation of the fingers of their left hand compared with that of their right hand and compared with those who learned to play later in life [17]. Other evidence shows increased gray matter in skilled musicians compared with less-skilled ones [18], and a review of imaging studies of musicians supports these conclusions [19].

Our aim was twofold. First, we tested whether the hypothesis of increased putamen activation reflecting greater articulatory effort in a less dominant language proposed by Klein *et al.* has empirical support. Unlike previous studies, we tested this hypothesis by examining patterns of activation linked to articulation in the first and the second language at two levels of difficulty of articulation – individual words versus entire sentences. Second, we compared the cerebral network involved in speech in early versus late bilinguals, to establish the impact of early, simultaneous learning of two systems compared with late, successive learning.

## MATERIALS AND METHODS

**Study participants:** Twelve right-handed proficient English–French bilinguals (five women) with no history of neurological disorders participated. The early bilinguals ( $N=6$ ) had acquired their two languages from birth. All had lived in both French- and English-speaking countries, had received education in both languages and had native prosody in both languages as judged by a panel of naïve listeners. The late bilinguals ( $N=6$ ) were native English speakers. All had learned French after age 12, had moved to France as adults and had been living in France for over 15 years at the time of participation. All late bilinguals could be identified as nonnative French speakers by a panel of naïve listeners. The two groups also differed in age (early: mean 24 years,  $SD=1.4$  years; late: mean 41 years,  $SD=2.8$  years). (Various studies have shown age-related threshold differences as concerns hemodynamic response. Therefore, comparisons between the early and late bilinguals will be made by comparing patterns of activation obtained in each group rather than direct comparison through subtraction.) All participants gave informed consent and were paid for taking part in the study. The study was approved by the Timone hospital ethical committee.

**Stimulus materials:** Two articulation tasks were administered, one at word and one at sentence level. In the word task, there were 225 French and 225 English words, and 225 nonpronounceable consonant strings for the baseline con-

dition. The words contained a sampling of all phonemes of each language, in all positions. They comprised nouns, adjectives and verbs, were of medium to high frequency, and ranged in length between 1 and 3 syllables. Syllable length, complexity and word frequency were matched by item across languages. Consonant strings were randomly generated, but excluded repetitions and acronyms. In the sentence task, 75 English and 75 French sentences were generated from the above set of words, and 75 nonpronounceable strings made up of consonant strings served as baseline. All sentences were simple declarative sentences and were matched in length across languages. Prior to scanning, participants were acquainted with the materials and task.

**Recording:** Participants lay supine in a 3T scanner, with their heads restrained by a soft strap. They read aloud the visually presented words and sentences with occluded jaws, and visually scanned the consonant strings. Materials were retroprojected onto a screen outside the scanner and a head-mounted apparatus in the scanner. In both articulation tasks, three 7.5-min runs were performed in a counter-balanced order across participants. In each run, there were five blocks per stimulus condition (English, French, consonants) for a total of 15 (30 s) blocks presented in a fixed random order. Each block began with a fixation cross for 5 s, followed by a lead-in (i.e. 'English', 'français' or 'XRPNZ' in the word task, and 'Please read the following sentences', 'Veuillez lire les prochaines phrases' or 'XRDT PNJVZ QLW FNRB' in the sentence task) and the stimuli of that condition (14 words and four sentences for the respective tasks) for 25 s.

Imaging was performed using a 3T whole-body imager MEDSPEC 30/80 AVANCE (Bruker, Ettlingen, Germany) equipped with a circular polarized head coil. High-resolution structural T1-weighted images covering the whole brain were acquired from all participants for anatomical localization. Functional images were acquired using a T2-weighted echo-planar sequence at 30 axial slices parallel to the AC–PC plane ( $TR/TE=2.5\text{ s}/35\text{ ms}$ , flip angle  $60^\circ$ , interleaved acquisition,  $3 \times 3 \times 3\text{ mm}$  voxels, 1 mm gap, field of view= $192 \times 192\text{ mm}$ ,  $64 \times 64$  matrix).

**Data analysis:** SPM99 (Wellcome Institute of Cognitive Neuroscience, London) was used for image processing and analysis. The functional images were interpolated in time to correct phase advance during volume acquisition and were spatially realigned to the first image of each session using sinc interpolation. Movement correction was further performed by applying six regressors (right, forward, up, pitch, roll and yaw). To allow multiparticipant analysis, the anatomical references and the realigned functional images of all participants were transformed to a common standard space (echo-planar imaging template). The functional data were spatially smoothed (three-dimensional Gaussian kernel, 6 mm) and temporally filtered (Gaussian low-pass filter with a 4 mm full-width at half maximum). A general linear effects model was applied to the time course of the functional signal at each voxel using a boxcar waveform function convolved with a canonical hemodynamic response function.

Results are expressed as statistic parametric maps (SPM  $t$ ) constituted by the calculated  $t$  values in each voxel of the

**Table 1.** Activation levels as a function of type of bilingual and language spoken in the two articulation conditions, and in the left putamen for each participant.

	Early bilinguals				Late bilinguals			
	Word conditions							
	English versus baseline		French versus baseline		English versus baseline		French versus baseline	
	(X, Y, Z)	T values	(X, Y, Z)	T values	(X, Y, Z)	T values	(X, Y, Z)	T values
SMA	M (0, -3, 57)	11.02	(0, -3, 60)	8.41	L (-3, -3, 66)	7.18	(-3, -3, 66)	9.90
MC (BA 4, 6)	L (-51, -9, 42)	13.58*	(-48, -12, 36)	13.71*	L (-54, -9, 33)	14.30	(-54, -12, 36)	13.31
	R (57, -6, 36)	15.59*	(51, -9, 33)	13.55*	R (51, -12, 30)	11.50	(48, -12, 30)	11.73
STG (BA 22, 42)	L (-63, -12, 0)	10.15*	(-63, -27, 0)	9.88	L (-66, -27, 0)	14.66	(-66, -30, -3)	11.65
	R (63, -15, -6)	10.53*	(66, -21, -6)	10.74	R (51, -27, -3)	11.50	(51, -27, -3)	15.99*
Cerebellum	L (-18, -63, -24)	16.21*	(-21, -63, -24)	13.44*	L (-24, -66, -24)	15.62*	(-24, -66, -24)	15.89*
	R (18, -69, -21)	16.17*	(18, -69, -21)	14.46*	R (18, -63, -21)	16.96*	(18, -63, -21)	16.76*
	Sentence conditions							
	English versus baseline		French versus baseline		English versus baseline		French versus baseline	
	(X, Y, Z)	T values	(X, Y, Z)	T values	(X, Y, Z)	T values	(X, Y, Z)	T values
SMA	L (-3, -3, 63)	6.24	—	—	L (-3, -3, 66)	5.64	(-3, -3, 66)	5.82
MC (BA 4, 6)	L (-48, -15, 33)	7.38*	(-45, -15, 33)	7.96*	L (-54, -12, 39)	9.91	(-54, -12, 39)	9.35
	R (60, -6, 36)	6.59*	(51, -9, 36)	7.24	R (45, -15, 30)	7.80	(45, -15, 30)	8.20
STG (BA 22, 42)	L (-63, -30, -3)	8.87*	(-63, -30, -3)	7.23*	L (-63, -24, -3)	11.21*	(-66, -30, -3)	9.00
	R (57, -30, -3)	8.62*	(57, -27, -3)	6.55	R (48, -27, -6)	15.53*	(48, -27, -6)	15.00
Cerebellum	L (-15, -63, -21)	9.36*	(-15, -63, -21)	9.67*	L (-15, -63, -21)	13.74*	(-18, -63, -24)	11.88*
	R (21, -63, -24)	9.34*	(15, -63, -21)	8.68	R (21, -60, -24)	16.81*	(21, -60, -24)	15.50*
	ROI putamen							
	English versus baseline		French versus baseline		English versus baseline		French versus baseline	
	t stat	p value	t stat	p value	t stat	p value	t stat	p value
S1	1.16	0.12	3.64	0.001	-3.43	NS	-2.32	NS
S2	2.60	0.005	1.40	0.08	-0.25	NS	-0.65	NS
S3	2.60	0.005	4.41	0.001	0.42	NS	0.65	NS
S4	4.14	0.001	3.94	0.001	2.83	0.005	1.53	0.06
S5	5.19	0.001	5.21	0.001	2.88	0.005	2.59	0.005
S6	7.28	0.001	7.47	0.001	6.42	0.001	3.03	0.001

\*Asterisks indicate significant effects in the random effects analysis. Subtraction of the two articulation conditions revealed no significant activation at any region, in any analysis.

particular area of activation. The threshold of significance for active voxels, corrected at  $p < 0.001$ ,  $k=5$ , was set at  $T > 5.13$ . A second-order, random-effects analysis was also performed. All steps of statistical analysis considered a height threshold of  $T > 4.03$  ( $p < 0.005$ , uncorrected), and an extent of activation threshold was applied at cluster level ( $p < 0.05$ , corrected,  $k > 52$ ) to correct for multiple comparisons. The coordinates of the cluster maxima were transformed to fit in the Talairach space. In addition, the left putamen was delineated as a region of interest (ROI); it was anatomically determined for each participant (Anatomist and MARSBAR toolbox), and both individual statistical analyses and a one-way ANOVA were performed.

## RESULTS

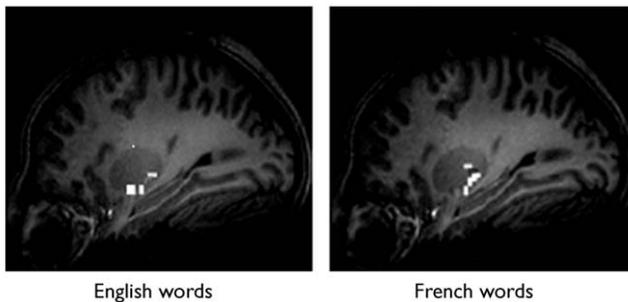
**Articulation of words: early bilinguals:** The overt articulation of both English and French words, compared with baseline, led to bilateral activation of the motor cortex, superior and middle temporal gyri and cerebellum, and also the SMA. The direct comparison of the two articulation conditions through subtraction revealed completely overlapping patterns with no significant differences (cf. Table 1).

ROI analyses of the left putamen revealed that all early bilinguals showed activation of this region when articulating English or French words compared with baseline, and that the majority showed significant activation in both

conditions (cf. Table 1). An ANOVA carried out on the contrast values obtained per participant for each of the four contrasts (English vs. baseline, French vs. baseline, English vs. French and French vs. English) revealed a significant main effect [ $F(3,15)=7.80$ ,  $p < 0.005$ ]. Activation of the left putamen was greater for each of the articulation conditions minus baseline (English vs. baseline and French vs. baseline) than for either articulation condition minus the other (English vs. French and French vs. English), but did not differ as a function of the language articulated (cf. Table 1 and Fig. 1).

**Articulation of words: late bilinguals:** The overt articulation of both English and French words, compared with baseline, led to bilateral activation of the motor cortex, superior and middle temporal gyri and cerebellum, and also the SMA. The direct comparison of the two articulation conditions through subtraction revealed completely overlapping patterns with no significant differences (cf. Table 1).

The ROI analysis of the left putamen showed that half the late bilinguals showed significant activation of this region when articulating English and/or French words compared with baseline (cf. Table 1). An ANOVA carried out on the contrast values obtained per participant for each of the four contrasts (English vs. baseline, French vs. baseline, English vs. French and French vs. English), however, failed to show a significant main effect ( $F < 1$ ).



**Fig. 1.** Activation in the region of the left putamen during the articulation of English and French words for early bilingual participants.

**Articulation of sentences: early bilinguals:** The articulation of both English and French sentences, compared with baseline, led to bilateral activation of the motor cortex, superior and middle temporal gyri and cerebellum, and left lateralized activation of the SMA. The direct comparison of the two articulation conditions through subtraction revealed no significant differences. No significant activation was observed at the level of the putamen (cf. Table 1).

**Articulation of sentences: late bilinguals:** The articulation of both English and French sentences, compared with baseline, led to bilateral activation of the motor cortex, superior and middle temporal gyri and cerebellum, and left lateralized activation of the SMA. The direct comparison of the two articulation conditions through subtraction revealed no significant differences. No significant activation was observed at the level of the putamen (cf. Table 1).

## DISCUSSION

In both early and late bilinguals, overt articulation resulted in the activation of an established pattern of areas of the cortex, basal ganglia and cerebellum. This was true for both languages and whether single words or sentences were spoken, with very little variation between the two levels of articulation. No significant differences were found as a function of language. The only difference observed between the early and late bilinguals was the level of activation of the putamen during the articulation of single words, which reached threshold in the early bilinguals but failed to do so in the late bilinguals. However, neither group showed reliable activation of the putamen during sentence production.

The present results belie the hypothesis put forward by Klein *et al.* that 'additional neural processes within the left putamen are required for production of L2 compared with L1.' To the contrary, we found that, when significant, activation of the putamen was indistinguishable between the first and second language. Differences in activation of the putamen, in particular, may be linked more to properties of the articulated sequences than to the language in which they are produced. Recently, we reported that varying the length of stimuli produced a significant effect in putamen activation (and of the anterior insula and SMA) in monolinguals; trisyllabic pseudowords involved the putamen significantly more than monosyllabic ones [20]. This result underlines the necessity to rule out confounding variables when concluding on between-language differ-

ences in bilingual populations. Indeed, Mahendra and colleagues [21] report that the variability previously attributed to differences in native and second language representation is no greater than that observed in the same language between scanning sessions. Our results do not confirm a recent finding of greater left cerebellar activation in the second language of late bilinguals, although the task used in that study (rhyme judgement) was not an articulation task [22].

Our findings corroborate the general conclusion of Klein *et al.* and others [23,24] that there is little evidence to support the hypothesis that the neural substrates that underlie the native language differ from those for later learned languages. They suggest further that this conclusion may be extended to include the motor aspects of speech.

## CONCLUSIONS

The present results show that the motor loop involved in articulation is essentially identical for early and late bilinguals and for their two languages. This suggests that learning to execute new articulatory patterns specific to a second language does not involve recruiting new neural populations but requires, rather, the redeployment of existing ones.

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**Acknowledgements:** The present work was funded by a grant from the French ministry (IC 6), awarded to C.F.-M. The authors extend their thanks to Prof. H. Ackermann and Dr A. Rieckle for valuable discussions as concerns the present data, and to Drs N. Nguyen and C. Meunier for help in creating materials.