The neural representation of the languages of the polyglot speaker has been highly controversial. We used positron emission tomography (PET) to investigate whether production in a second language (L2) involves the same neural substrates as that of a first language (L1) in normal bilingual subjects who learned L2 after the age of 5 years. Comparison of cerebral blood flow (CBF) when repeating words in L2 and repeating words in L1 yielded only a single significant CBF change: an increase in the left putamen. We hypothesize that this region plays a specific role for articulation in L2. The role of the putamen in articulation is supported by foreign accent syndrome (FAS), which can occur after left putaminal damage. The increased articulatory demands imposed by speaking a second language may require complex motor control for speech production in L2.

**Key words:** Positron emission tomography; Bilingualism; Basal ganglia; Putamen; Speech

**Introduction**

The neural representation of multiple languages has been investigated by electrical stimulation, experimental studies, and by examining polyglot aphasics, but it has proven difficult to determine conclusively whether different languages share the same neural substrate. Penfield denied that separate neuronal mechanisms existed for each language, whereas others have proposed that partially distinct cerebral areas may be involved, especially when L2 is learned after the normal period of language acquisition, and some have gone so far as to suggest a contribution from right-hemisphere mechanisms to L2 processing.

We used positron emission tomography (PET) to investigate whether performance in a second language involves the same neural substrates as that of a first language in normal bilingual subjects who learned L2 after the age of 5 years. Understanding and speaking a language requires the interplay of a complex, and highly specialized network of distinct parts of the brain. Repeating a heard word is likely to engage many if not all portions of such a network. We took advantage of this seemingly simple task to investigate whether comprehension and production of L2 learned after the age of 5 would activate identical regions to those involved in the repetition of a word in the native language. If L2 is represented differently from L1, then this should be demonstrable in a comparison of the two conditions.

**Materials and Methods**

Twelve right-handed subjects (equal sex distribution, mean age 22 years) gave informed consent to participate in this study approved by the Montreal Neurological Institute Review Committee on the Use of Human Subjects. The subjects had learned English as their native language (L1), but had acquired proficiency in French (L2) after the age of 5 (mean age 7.3 years) and were actively using both languages in their daily lives. Proficiency was established by a prescreening test.

During the experiment, the subjects underwent two separate PET scans to measure CBF during word repetition. In the first condition, they were presented with single English words binaurally over insert headphones (Eartone type 3A) at the rate of one every 4.2 s, and were required to repeat the words aloud. The second condition was identical to the first, except that subjects heard and repeated French words. Although these conditions are part of a broader study on bilingual subjects, the two repeat conditions were always presented first, counterbalancing for order of language presentation. There were 22 stimuli in each list, presented in a fixed order to each subject. The words were those that occur commonly in the respective languages and the lists were matched for frequency, length, syllable number, part-of-speech and imageability. Each task commenced 30 s before scanning and continued until after the scanning period had finished. Latency of response was recorded through a voice-onset microphone. Subjects kept their eyes closed during scanning and lights were dimmed. Ten practice examples were given prior to each scan.

The paired-image subtraction method was used to identify significant task-dependent differences between the conditions. PET scans were obtained using the Scanditronix PC-2048 system, which produces 15 image slices at an intrinsic resolution of 5.0 × 5.0 × 6.0 mm. Using the bolus H2O methodology, without
blood sampling, the relative distribution of CBF was measured in each of the two conditions. Individual high-resolution MRI studies (160 slices, 1 mm thick) were obtained from a Philips ACS (1.5T) and co-registered with the PET data. An orthogonal coordinate frame was then established, based on the anterior-posterior commissure line as identified in the MRI volume. These coordinates were used to apply a linear re-sampling of each matched pair of MRI and PET data sets into a standardized stereotactic coordinate system. PET images were reconstructed using a 20 mm Hanning filter to overcome residual anatomical variability; they were then normalized for global CBF value, averaged across subjects for each activation state, and the mean state-dependent change image volume obtained. This volume was converted to a t-statistic volume by dividing each voxel by the mean standard deviation in normalized CBF for all intracerebral voxels. Individual MR images were subjected to the same averaging procedure, such that composite-image volumes sampled at approximately 1.5 mm in each dimension were obtained for both t-statistic and MRI volumes. Anatomical and functional images were merged to allow direct localization on the MR images of regions with a high t-value.

The presence of significant focal changes was tested by a method based on three-dimensional Gaussian random-field theory. Values of t ≥ 3.5 were deemed statistically significant (p < 0.0002, one-tailed, uncorrected). Correcting for multiple comparisons, a t-value of 3.5 yields a false positive rate of 0.58 in 200 resolution elements (each of which has dimensions 20 × 20 × 7.6 mm), which approximates the volume of grey matter scanned.

Results and Discussion

On a behavioural level, all subjects performed the repetition task with high rates of accuracy (99% and 96% in L1 and L2, respectively), and with equal speed of response (1156 ms and 1222 ms in L1 and L2, respectively).

The PET results demonstrated that the pattern of CBF was strikingly similar across the two conditions, with only a single significant CBF change (t = 3.5) in the vicinity of the left putamen (Fig. 1). No other significant increases or decreases were detected, strongly suggesting that repetition in the two languages makes demands on almost completely overlapping neural substrates. The activation of the left putamen, however, indicates that additional neural processes within this structure are required for production of L2 compared with L1. This finding is confirmed by results of additional conditions in which subjects were required to translate from L1 into L2, and vice versa. Subtraction of these translation conditions from repetition tasks also revealed a focus of activation in the left putamen (stereotaxic coordinates x = −15, y = 10, z = −6; t = 4.13) when translating into L2 (compared with repeating L1), but not when translating into L1 (compared with repeating L1). Thus, the left putamen is involved specifically when production of L2 is required (as in repetition of L2, or translation from L1 to L2), but not when comprehension of L2, without production, is required (as in the case of translation from L2 to L1).

Previous PET studies of language-processing in unilinguals have demonstrated functional specialization for specific left-hemisphere regions in the performance of various linguistic tasks. Tasks involving speech output have consistently been shown to activate motor cortex bilaterally, together with other areas, such as the SMA, but not the putamen. The lack of subcortical activation sites in these studies does not necessarily mean that there was no subcortical contribution to language output in unilinguals however, since previous studies may not have been designed to elicit this particular component.

The findings of this study allow us to postulate that activation of the left putamen is a function of the increased articulatory demands imposed by speaking a language learned later in life. Lesion studies of basal ganglia function concur with the interpretation that these structures subserve complex motoric processes involved in articulation and fine motor skills. A complementary role for the right putamen in the motor control of prosody has also been suggested.

Our interpretation of left putaminal involvement in articulatory processes in L2 finds support from studies of foreign accent syndrome (FAS). Rarely, subsequent to left hemisphere damage, unilingual individuals develop articulatory difficulties which mimic a foreign accent, a symptom clearly distinct from dysarthrias or apraxias of speech. Although lesion sites in FAS vary, the left basal ganglia can be selectively implicated. However, strokes of the basal ganglia are not sufficiently focused to discriminate between cortical disconnection and direct putaminal involvement. The observation of putaminal activation in our L2 repetition task adds support for the specific contribution of this structure in articulation, particularly in the precise timing of motor output. Our findings thus help to explain why lesions to the left basal ganglia may produce an FAS.

Conclusion

The present study examined only a single aspect of linguistic processing; it will be interesting in future to see if similar results are obtained for other linguistic tasks. It will also be important to study languages that are structurally more distinct than are English and French, and which may therefore require differential neural mechanisms. Despite these constraints, our data provide no support for the hypothesis that a language learned later in life is represented differently from the
native language; nor do we find evidence in favour of a right-hemisphere contribution to bilingual processes. With regard to the question of the functional representation of multiple languages, speaking in L1 and L2 may differ in cognitive demands, but from this initial experiment, we conclude that the same specialized cerebral regions are active in both cases, except for the articulatory demands of L2, which may require additional processing in the left putamen.

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