CHAPTER 16

Cerebral imaging and individual differences in language learning

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The majority of the brain imaging studies on bilingualism have focused on the question of the separation or overlap of the neural regions involved when a bilingual brain is working with one language or the other. Researchers have been especially interested in the roles of factors such as age of acquisition of the second language and level of proficiency. In recent studies, however, new questions about the bilingual brain have started to be explored. For example, are there anatomical and/or functional differences between the brains of bilinguals and monolinguals? Do the interindividual differences in the ability to learn a second language correlate with brain differences? We will present recently published and ongoing work about these questions.

1. Introduction

One intriguing observation about second language acquisition concerns the large interindividual variability in second language attainment. The quality of production (accent), for example, varies much more from speaker to speaker in a second language than in the native language. Many factors are likely to be involved, including motivation, age of acquisition, amount of use, etc. (Ellis 1997; Skehan 1989). Some biological factors might also play a role. In this chapter, we describe a few studies conducted in our laboratory that aimed to explore the cerebral correlates of performance in second language.

During the first decade of brain imaging (1995–2005), most studies on the bilingual brain have focused on the issue of whether the two languages of a bilingual recruit the same brain areas or, instead, some language-specific areas as suggested by evidence from brain stimulation (Ojemann & Whitaker 1978). Experiments using positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) compared patterns of cerebral activation associated with the processing of the first (L1) and second (L2) languages as bilingual individuals accomplished tasks such as reading, repetition or translation of isolated words, naming of images or the comprehension of written or spoken sentences. The majority of such studies described very similar activations for both languages (see Pallier & Argenti (2003) and Perani & Abutalebi (2005) for a summary of the literature involved), a result which is generally interpreted to mean that the same circuits are employed in the processing of either language.[1] Yet, a few studies have described partially distinct activation patterns for L1 and L2, particularly when participants had an intermediate level in the second language (Dehaene, Dupoux, Mehler, Cohen, Paulesu, Perani, van Moortele, Léhericy & LeBihan 1997) and/or had learned it after childhood (Kim, Relkin, Lee & Hirsch 1997).

These observations suggest that the cortical representation of L2, that is to say the areas recruited during use of L2, may progressively overlap with those used by L1 as the learning of L2 progresses. To test this hypothesis, Golestani, Alario, Meriaux, LeBihan, Dehaene & Pallier (2006) used fMRI with ten native French participants who had an intermediate proficiency level in English according to the Test of English as a Foreign Language (TOEFL), and a range of scores on the grammatical subpart of this test (They had learned English in schools between the ages of 11 and 17 and were not using it regularly). While being scanned, the participants had to read lists of words or to construct sentences from the same lists. Subtraction between the activations associated with both conditions confirmed the implication of the left inferior frontal gyrus, Broca's area, in sentence construction (Indefrey, Brown, Hellwig, Amunts, Herzog, Seitz & Hagoort 2001). Within this region, in each participant we localised the point where the cerebral activation linked to sentence construction was at a maximum, in English on the one hand and French on the other. The spatial distance between these activation peaks then served to define the distance between the representations of L1 and L2. Corresponding to the hypothesis of the confluence of Ls 1 and 2, there was a significant correlation between individual scores on the TOEFL test and the distance between activation maxima in English and French: the subjects with the highest scores had the closest maxima. This result suggests that the higher the level of mastery of the second language, at least as far as grammar is concerned, the more similar the cerebral activations associated with sentence construction in L1 and L2 become. Yet, a limitation of this study was that it was based on a comparison between participants having different levels in L2 (cross-sectional approach). To definitely prove that L1 and L2 representations become more similar within the brain of a single individual in the course of language learning, it would be necessary to carry out a longitudinal study in which second language learners would be tested at different time points.

A longitudinal study has been performed by Stein et al. (2009), who scanned foreign exchange students at two time points, 1 and 5 months after their arrival. The task was word reading in L1 and L2. The authors report that, in the first scanning session, L2 words elicited stronger activations than L1 words in frontal regions and that this difference is largely reduced on the second session. This result likely reflects a diminution of frontal control as L2 word identification is becoming more automatized (Hernandez, Li & MacWhinney 2005). Unfortunately, only group analyses are reported and the distances between L1 and L2 activations in individuals were not analysed. Yet, another promising longitudinal study is currently under way at the Max-Planck Institute for Psycholinguistics in Nijmegen where a group of Chinese learners of Dutch are scanned at regular intervals while processing sentences (Indefrey et al. 2004).

The participants in the study by Golestani et al. (2006) described above had learned English in school and did not use it regularly. They had certainly not reached their ultimate attainment in English: should they resume learning it, they would certainly improve in proficiency. By contrast, in the next study, the participants had probably reached their maximum level of proficiency; they were born in a multilingual society (Singapore) and had strong motivations to become highly-proficient in two languages: English and Mandarin Chinese. Nevertheless, there were still non negligible differences in their level in L2, allowing us to compare two groups of people who had grown up in the same bilingual environment but differed in their mastery of the second language (Chee, Soon, Lee & Pallier 2004).

We wondered whether difference in phonological working memory could partly explain the different ultimate proficiencies between the two groups. One expects that an efficient phonological working memory may help in acquiring a second language. The best evidence for this comes from a study by Elizabeth Service, performed on Finnish children starting to learn English in primary school (Service 1992). Scores on phonological memory tasks (memorisation and repetition of Finnish pseudo-words) were measured before the pupils began to learn English; two years later, it turned out that these scores predicted their performance in this new language.

Our Singaporean participants (the high L2-proficient group and the less L2-proficient group) did not differ on measures of phonological memory. However, when we scanned them while listening to a series of French words (a language none of the participants knew) in which they had to detect repeated items, the patterns of cerebral activations of the two groups were different. The group of high L2-proficiency relied relatively more on the regions of the insula and left inferior

1. It should nevertheless kept in mind that present-day resolution of fMRI images is about 3 mm since it may well be that, at a higher resolution, partial separation between the networks of these languages exist.

gyrus, part of the network involved in phonological working memory, while the less proficient manifested stronger activations in medial frontal areas suggesting a greater attentional effort. A possible interpretation is that those with a better level in their second language used the circuits of phonological memory in a more effective manner. Yet, we cannot be sure that this characteristic was present before they started learning the second language. Again, to obtain a firm conclusion, it would be nice to run a longitudinal study in which subjects were scanned before and after learning the second language.

The experiment we have just described highlighted functional cerebral correlates of the level of bilingualism. Could anatomical characteristics also explain a greater or lesser ability to acquire a second language? We asked this question in the context of the perception and production of phonemes in a foreign language (Golestani, Molko, Dehaene, LeBihan & Pallier 2007 and Golestani & Pallier 2007). For example the contrast between dental and retroflex consonants in Hindi is quite difficult for a French speaker subject to learn. In our laboratory, Narly Golestani trained sixty French volunteers on this contrast and divided them into two groups depending on how quickly they learned to distinguish between syllables using these consonants. We then measured, in each subject, the volumes of the left and right Heschl gyri, structures lying on top of the temporal lobes and housing the primary auditory cortex. Analyses of these data showed that, on average, those subjects with the greatest ability to distinguish the Hindi syllables had a more voluminous left auditory cortex than those who had more difficulties. The volume of white matter differed significantly between the groups, potentially reflecting a greater number or higher myelinisation of the fibres of the auditory cortex in the group of fast learners versus the group of slow learners. It is conceivable that such parameters influence the precision of the temporal representation of sounds which is particularly useful for discriminating consonant contrasts associated with rapid acoustic transitions. A similar result was obtained by Wong et al. (2008) who taught English speakers to distinguish words based on pitch patterns, as occurs in some languages, e.g. Chinese. They report that subjects who were less successful in learning showed a smaller HG volume on the left, but not on the right, relative to learners who were successful. Together with our results, these data confirm that primary auditory regions are important for spoken language learning.

In a follow-up experiment, Golestani & Pallier (2007) assessed the ability of the same volunteers to articulate a foreign sound. We selected a uvular Farsi consonant, easily distinguishable from French phonemes. The subjects were required to produce it in different phonetic contexts and two Farsi speakers evaluated the quality of their pronunciation. Scores thus obtained were correlated with individual probability images of white or grey matter using the voxel-based morphometry technique. These analyses showed that the accuracy of the pronunciation correlated positively with white matter density in two areas classically associated to phonological memory and articulation, that is, the inferior parietal cortex and the insula (Paulesu, Frith & Frackowiak 1993; Becker, MacAndrew & Fiez 1999; Wise, Greene, Büchel & Scott 1999).

2. Conclusion

In sum, the studies we have presented demonstrate the existence of functional and anatomical cerebral correlates of abilities involved in second language acquisition. These experiments should be considered as first steps in the exploration of a domain which has yet received little attention: the cerebral bases of foreign language acquisition (see also Raboyeau, Balduyck, Gros, Démonet & Cardebat 2004; Golestani & Zatorre 2004; Callan, Tajima, Callan, Kubo, Masaki & Akahane-Yamada 2003). We hope that the future will see more longitudinal studies despite all the methodological difficulties involved (Poldrack 2000).

Finally, it is important to stress that the existence of brain differences between "good" and "bad" learners of foreign language does not imply that the latter should abandon trying to learn a second language. Indeed, even in adults, intensive training can induce cortical modifications which can be detected at a macroscopic level (Draganski, Gaser, Busch, Schuierer, Bogdahn & May 2004; Maguire et al. 2000). Moreover, one study demonstrated that bilinguals have higher grey matter density in an inferior parietal region which may be linked to vocabulary acquisition (Mechelli et al. 2004; Lee et al. 2007). This was true even when the second language had been learned after 10 years of age. One's own brain anatomy should not be an excuse to avoid learning languages! Indeed, analyses of language learning across the life span suggest that it is never too late to learn a foreign languages (Hakuta, Bialystok & Wiley 2003).

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