Brain imaging studies of bilingualism and second language acquisition

Christophe Pallier

Cognitive neuroimaging lab.

INSERM-CEA, Gif/Yvette, France

Many brain imaging studies of bilingualism have focused on just one question:

Does a bilingual use the same or different cerebral resources to process the first and the second language ?

Neurologists (e.g., Pitres, 1890) have described various patterns of recovery in bilingual aphasic patients, e.g. simultaneous, successive and selective.

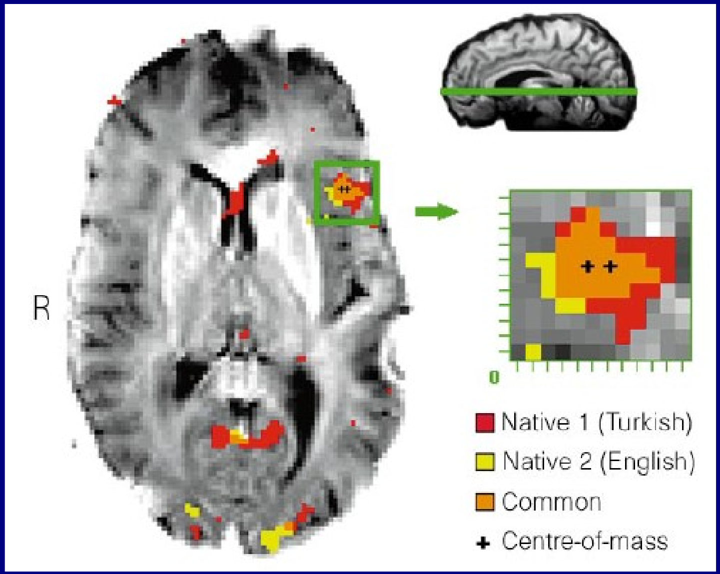
Some early studies reported (partially) distinct activations for L1 and L2.

(e.g. Kim et al. *Nature*, 1997)

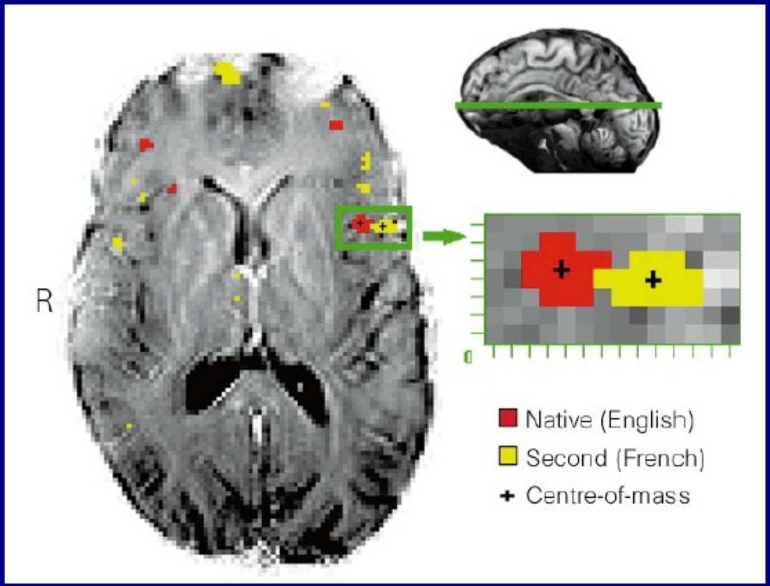
Participants: 8 early and 8 late bilinguals (AOA >6 years)

Task: free covert speech (inner discourse), in L1 or L2 (control = rest)

Early bilingual:



Late bilingual:



Remark:

- The bilinguals were described are having a high level of proficiency in L2, but no formal test was performed.

Some studies reported distinct activations for L1 versus L2.

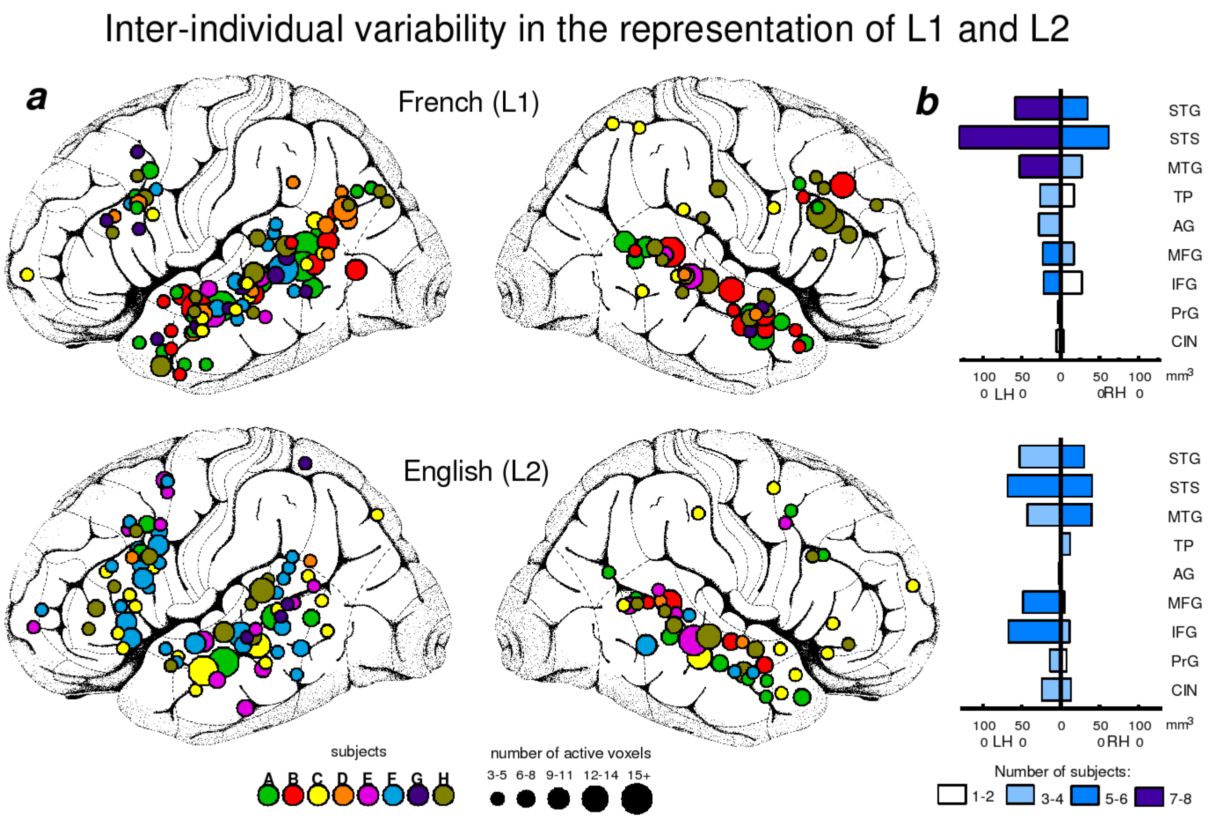
(e.g. Dehaene et al. *NeuroReport,* 1997)

Participants: 8 French speakers **with an intermediate level in English**.

Task: Listening to sentences, either in French or in English.

Results:

- The areas activated by L2 and L1 do not completely overlap.
- The areas activated by L2 are spatially more variable (from one individual to another) than those activated by L1.



Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Paulesu, E., Perani, D., et al. (1997). Anatomical variability in the cortical representation of first and second languages. *NeuroReport*, *8*, 3809-3815.

Question: Is this due to age of acquisition, level of proficiency, type of acquisition ?

Remark: no test/retest to check the stability of the patterns within individuals.

Most studies have reported similar (i.e., essentially overlapping) brain activations when processing L1 and L2

Word repetition, Word generation, Translation.
English-French and English-Chinese bilinguals.
PET (Klein et al. 1994, *PNAS*, 1995 *Neuroreport, 1999*)

Semantic Decision on visually presented words.
English-Spanish bilinguals
fMRI (Illes et al., 2001 *Brain & Language*).

Picture naming.
Spanish/English bilinguals
fMRI (Hernandez et al., 2001 *Neuroimage*).

Stem completion. Sentence reading.
English-Chinese bilinguals (Singapore)
fMRI (Chee et al., 1999, *J. Cog. Neurosci.* & *Neuron*).

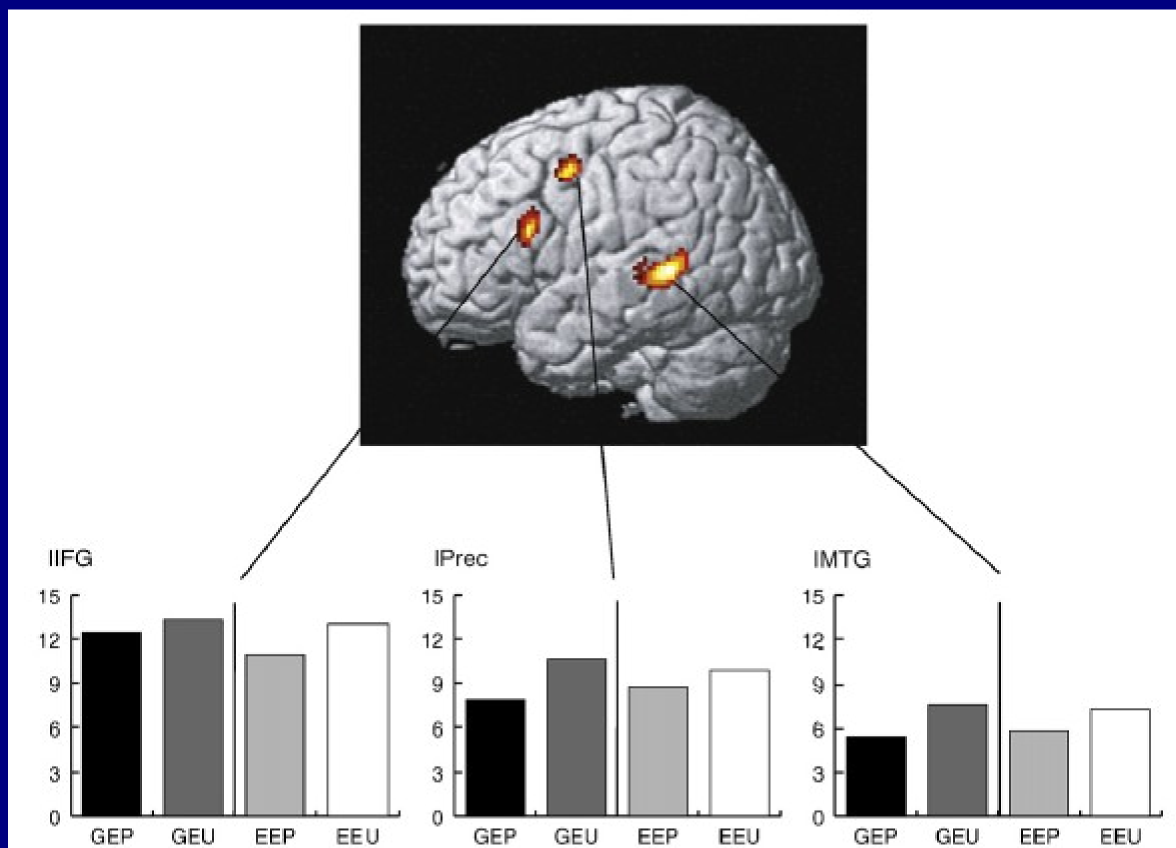
Word and Sentence reading.
English-French fluent bilinguals (half early/half late)
fMRI (Frenck-Mestre et al. *Neuroreport*, 2005)

Cross-linguistic syntactic priming

(Weber & Indefrey, Neuroimage, 2009)

16 German Ss with medium proficiency in English (AOA~10 years)

Condition	Prime/no-prime	Target
1. English–English	The tree was painted by the artist. The artist painted the tree.	The moon was painted by the girls.
2. German–English	Der Baum wurde von dem Künstler gemalt. Der Künstler malte den Baum.	The moon was painted by the girls.



Distance between L1 and L2 activations and L2 proficiency

(Golestani, Alario, Meriaux, Dehaene, LeBihan & Pallier, 2006, *Neuropsychologia*)

Aim: perform an experiment similar to Kim et al. (1997):

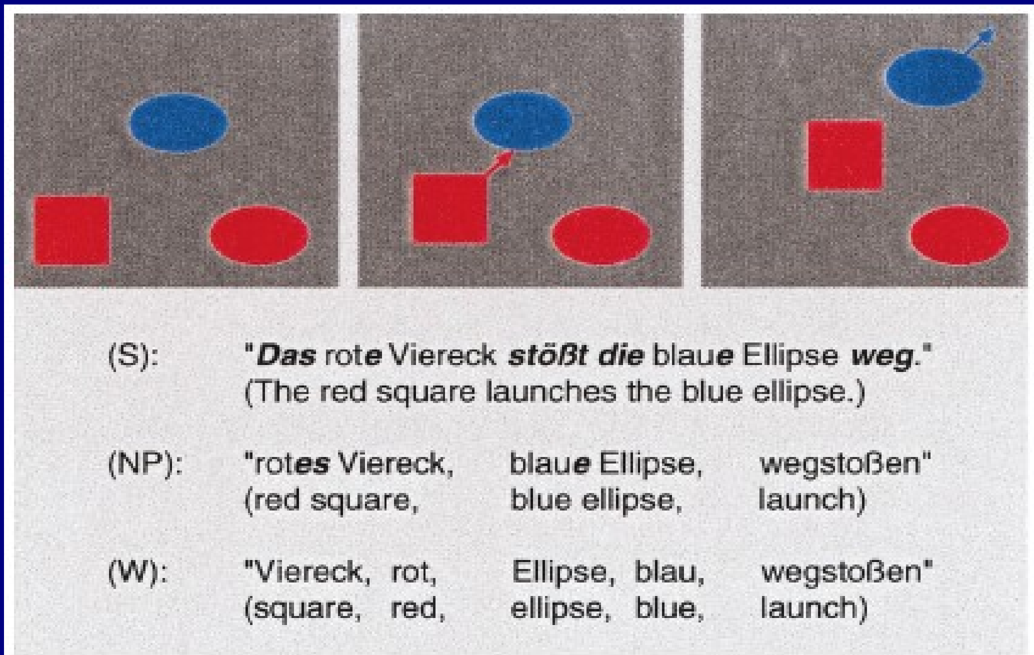
- with subjects of varying proficiency in L2 syntax.

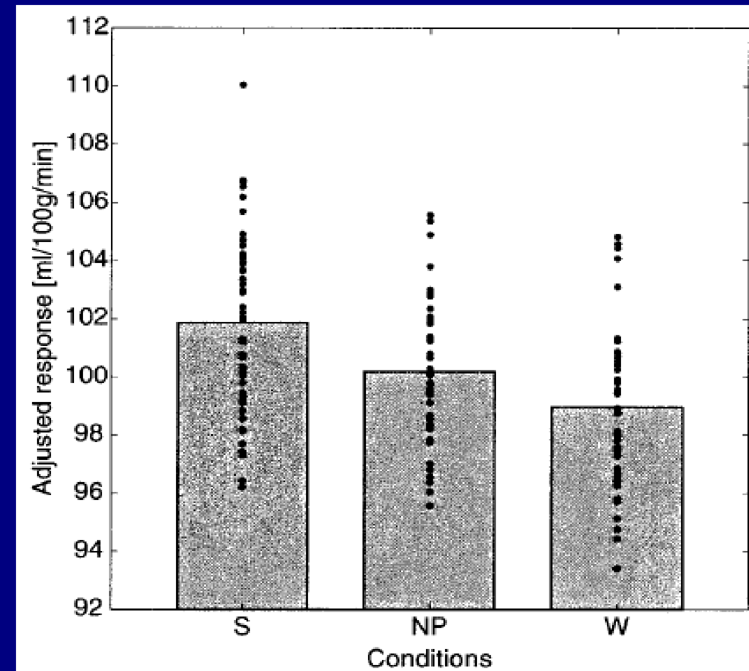
- using a better controlled task, tapping syntactic processes in speech production.

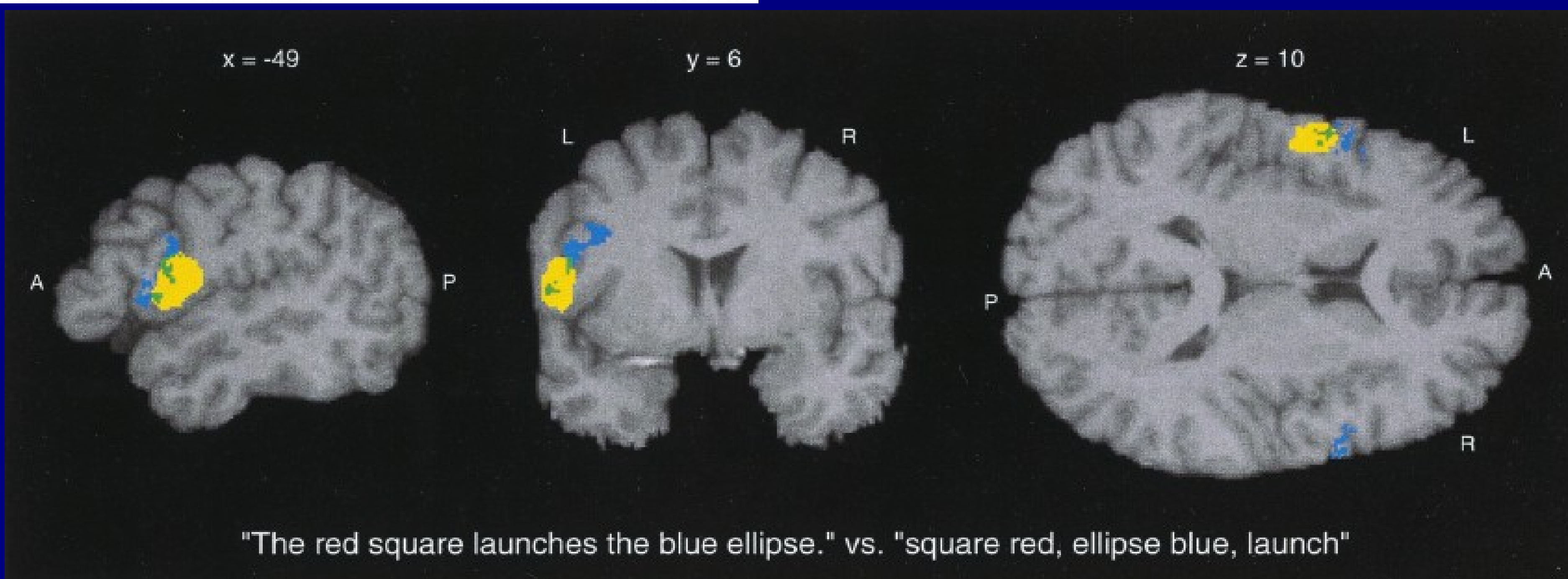
Subjects: 10 young French adults (age ~ 23 years) who had learned English in school after 12 years of age.

Their grammatical knowledge, assessed with the structure subtest of the "Test of English as a Foreign Language" (TOEFL), ranged from low- to mid-intermediate.

A study of syntactic production (Indefrey et al.; 2001)

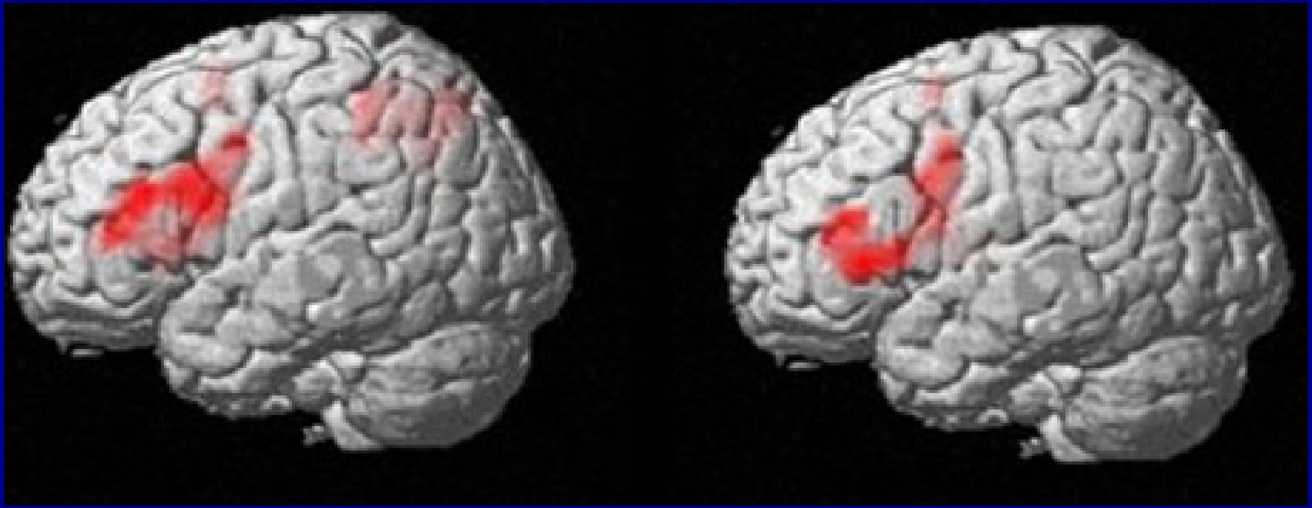






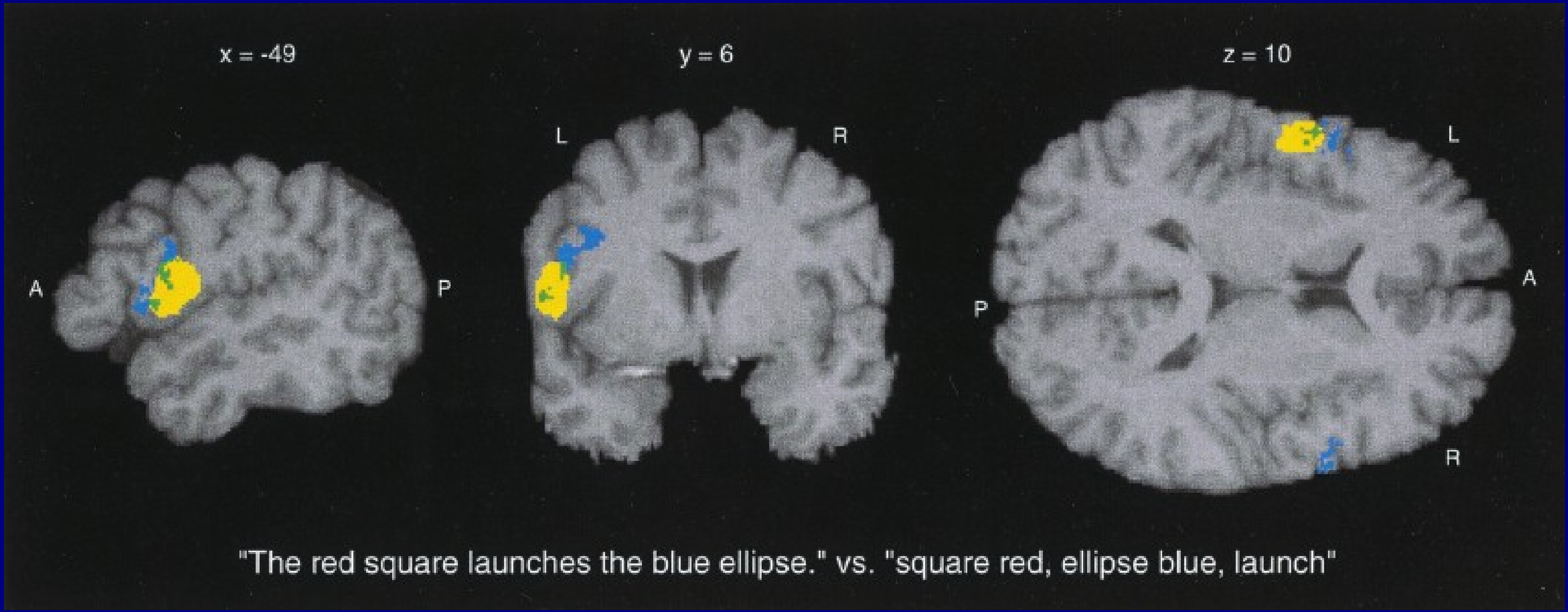
Group Results

English sentences>English words French sentences>French words



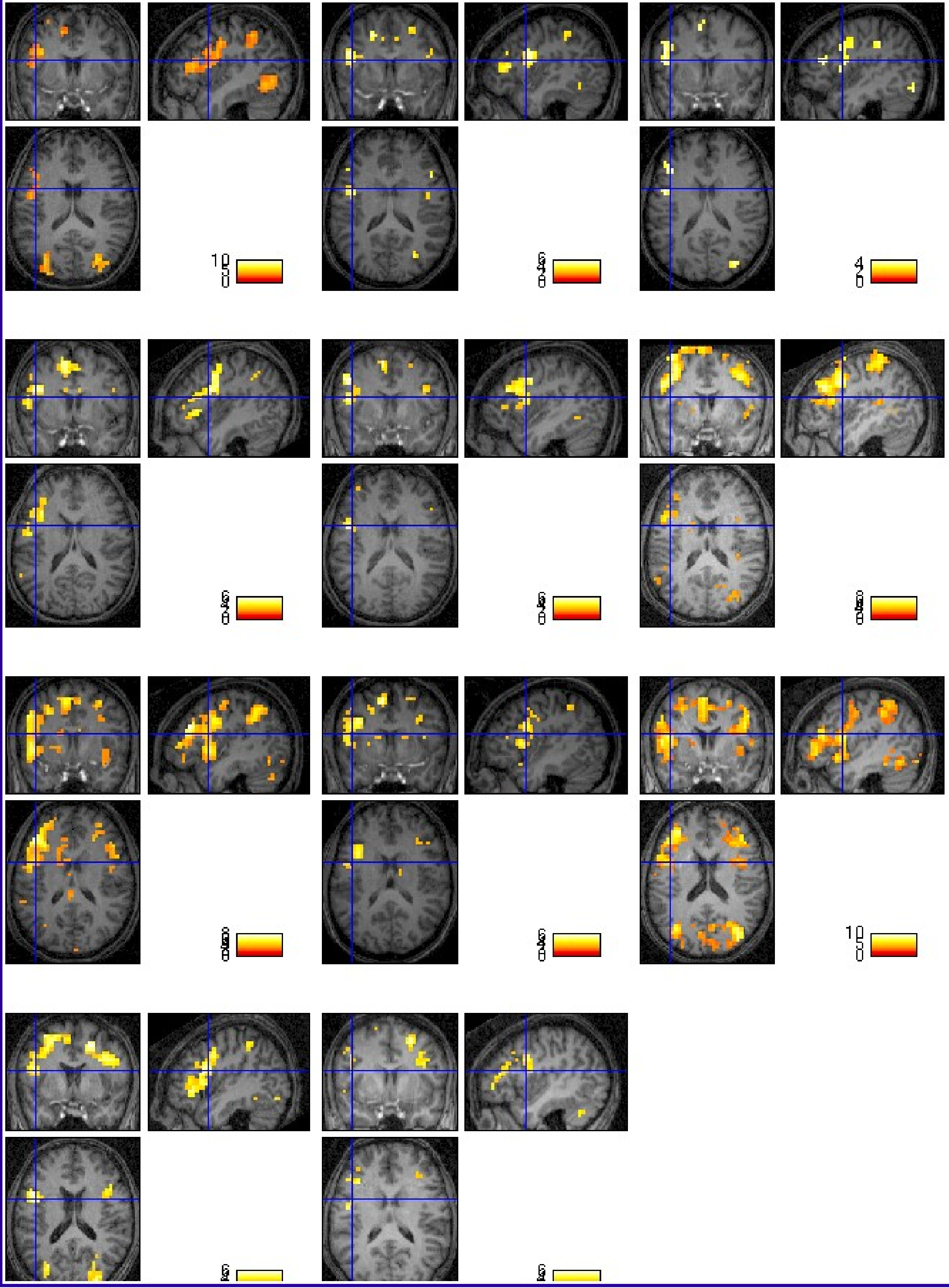
(RFX; p<.001 voxel-based; p<.05 corrected extent)

Compare with the results of Indefrey (2001) which inspired our study:



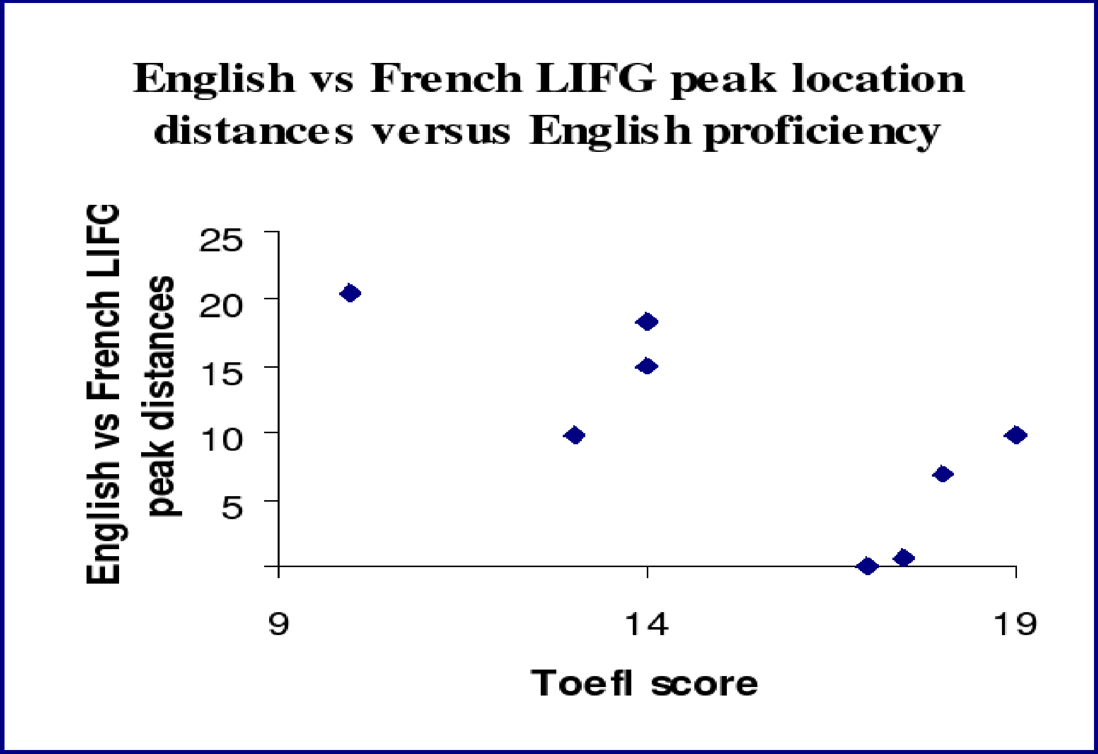
Individual results in the contrast between producing English sentences versus reading English words

(threshold: p<0.001 voxel-based)



Analysis of the “distance” between L1 and L2 in the left inferior frontal region

For each subject, the peaks of activity for the French and English “sentence>words” contrasts were determined.



Their distance was significantly correlated with the TOEFL score ($r=-0.71$; $p<.05$)

The “distance” between L1 & L2 decreases when grammatical skills (as attested by the TOEFL) increase (between subjects).

L1/L2 activation studies

The similarity between L1 and L2 activations increases with proficiency.

Caveats:

- difficulty to equate performance in L1 and in L2
- lack of tests of the reliability of activations (within-subject)
- the spatial resolution of typical fMRI is about 3x3x3mm. Future experiments with better resolution may uncover L1/L2 differences.
- FMRI does not distinguish between inhibition and excitation.
- Data from direct electrical stimulations in bilinguals reveals language-specific speech arrest areas (Roux et al, 2002, 2004; Lucas, McKahn & Ojemann 2004). Is this in contradiction with fMRI results?

Part II

They are important individual differences in the ability to learn a second language.

Many factors probably play a role (e.g. motivation).

Can we find some cerebral correlates of these differences?

Second language attainment and phonological working memory

(Chee, Soon, Lee, Pallier (2004) Left insula activation: a marker for language attainment in bilinguals. *Proceedings of the National Academy of Science.)*

- Background: Phonological working memory span predicts the success in L2 learning in children (Service, 1992).

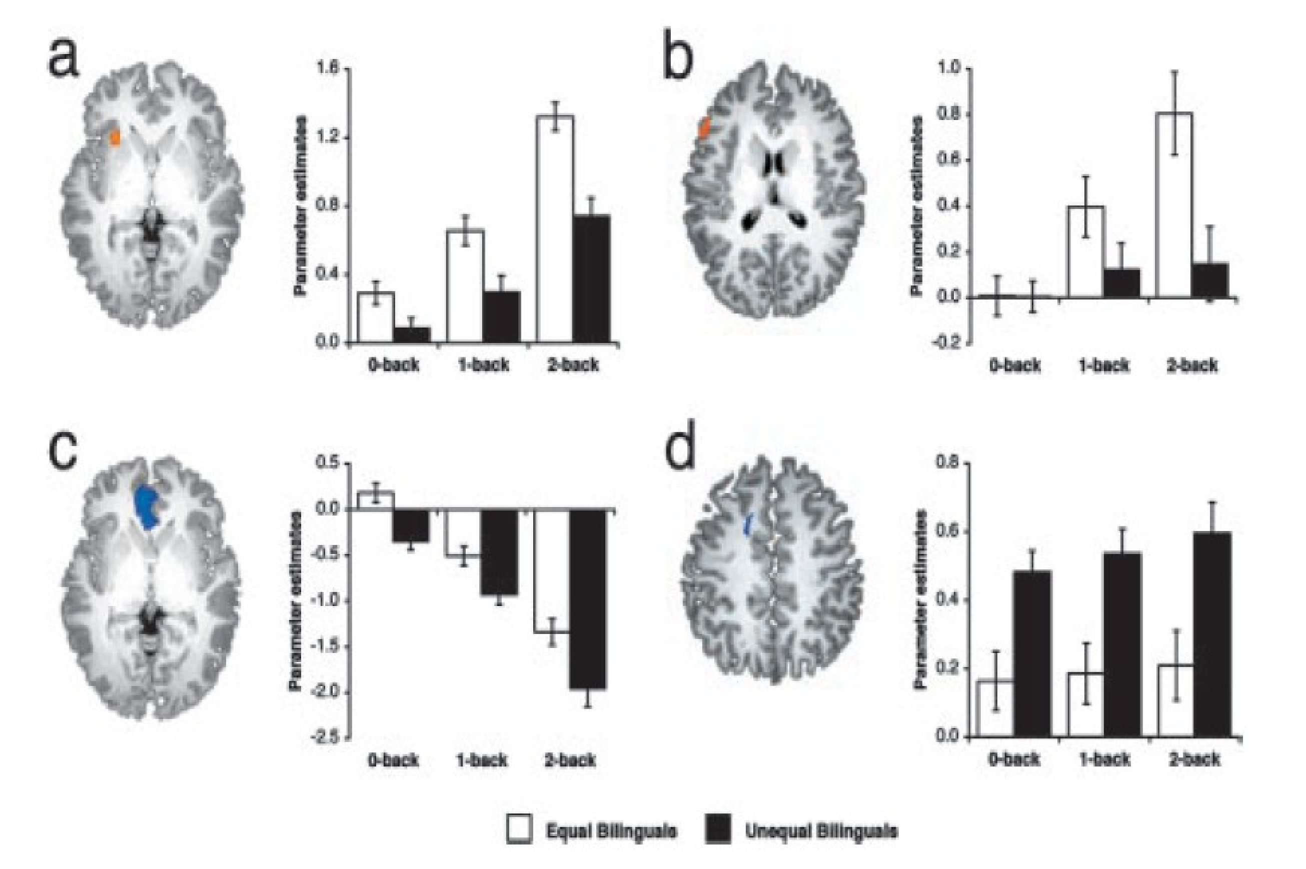
- Participants: 30 English/Chinese bilinguals raised in Singapore, who all had a strong impetus to learn Chinese.
  - 15 “equal” bilinguals (high scores in Chinese exams)
  - 15“non-equal” bilinguals (low scores in Chinese exams)

- Task (chosen to tap phonological working memory): Detection of repetitions in lists of foreign words (n-back task)

Results

Equal bilinguals recruited more the insula and the left inf. frontal gyrus (part of the phonological working memory circuit (rehearsal))

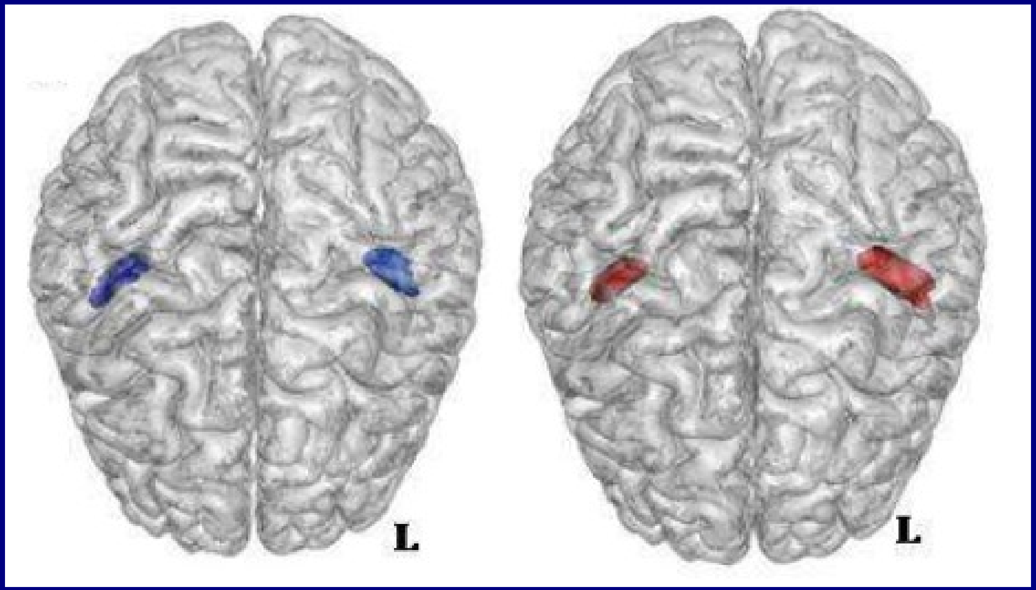
Unequal bilinguals showed greater activation in anterior cingulate and greater deactivation in the anterior medial frontal region.

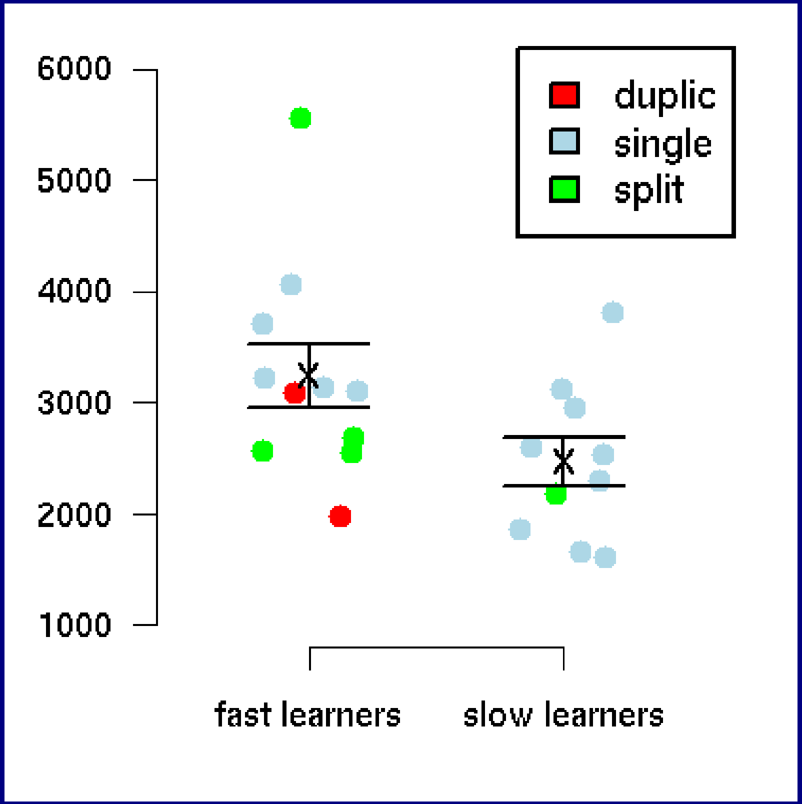


The pattern in the unequal bilinguals may reflect a less efficient processing strategy that correlates with poorer second-language attainment.

Correlates of individual differences of the ability to learn to perceive foreign speech sounds

70 **monolingual** speakers of French were trained to distinguish a subtle Hindi dental/retroflex phonetic contrast.
Structural MR scans of the 10 fastest and the 10 slowest learners.
Voxel-based morphometry (VBM) and direct measurements of Heschl gyri (auditory cortex) were performed.





The left Heschl gyrus is larger on average in fast-learning subjects (red) than in slow-learning subjects (blue).

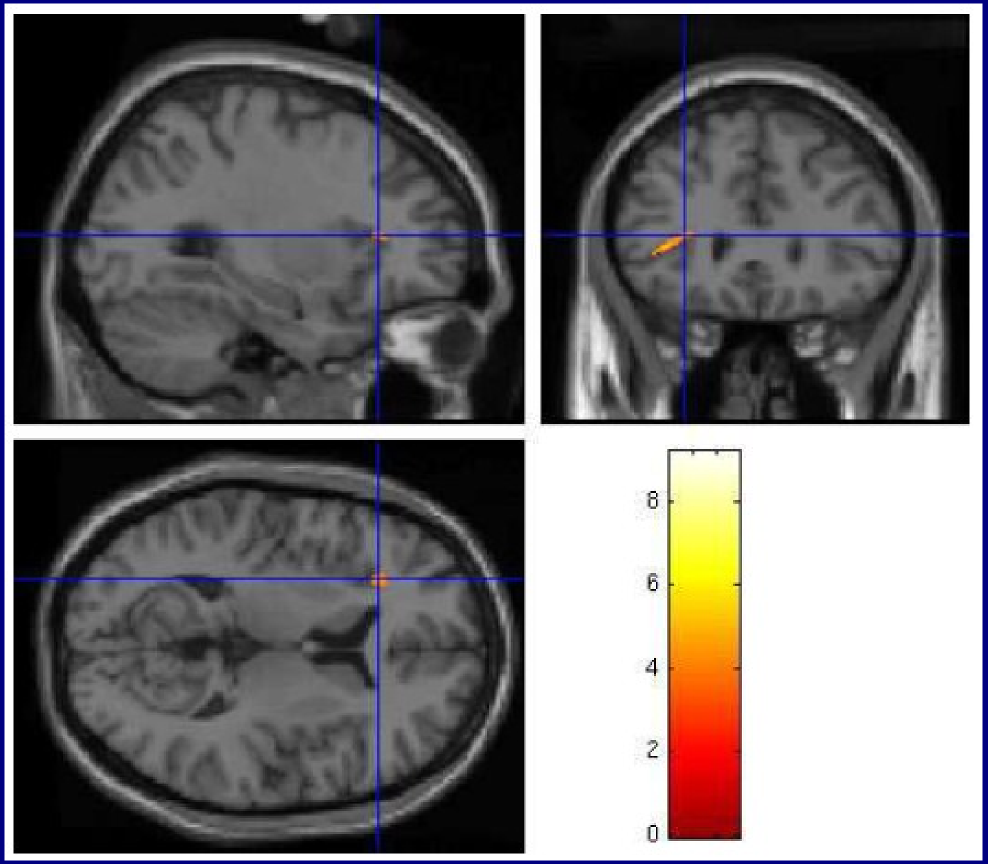
(Golestani, Molko, Dehaene & Pallier (2007) *Cerebral Cortex)*

Correlates of the ability to **imitate** a foreign speech sound

- The same subjects were asked to produce the Farsi uvular stop in various phonetic contexts.
- Two native Farsi speakers rated the quality of their productions.

A voxel-based morphometry analysis (correlation) shows higher white matter density beneath the anterior insula/prefrontal cortex in individuals who produce more accurate exemplars of the non- native /q/ phoneme.

(P<.001 voxel-based uncorr.; p<0.05 extent corr. 20 Ss)



Golestani & Pallier (2007) *Cerebral Cortex*

Discussion

- Correlations exist between brain anatomy and performance with foreign speech.

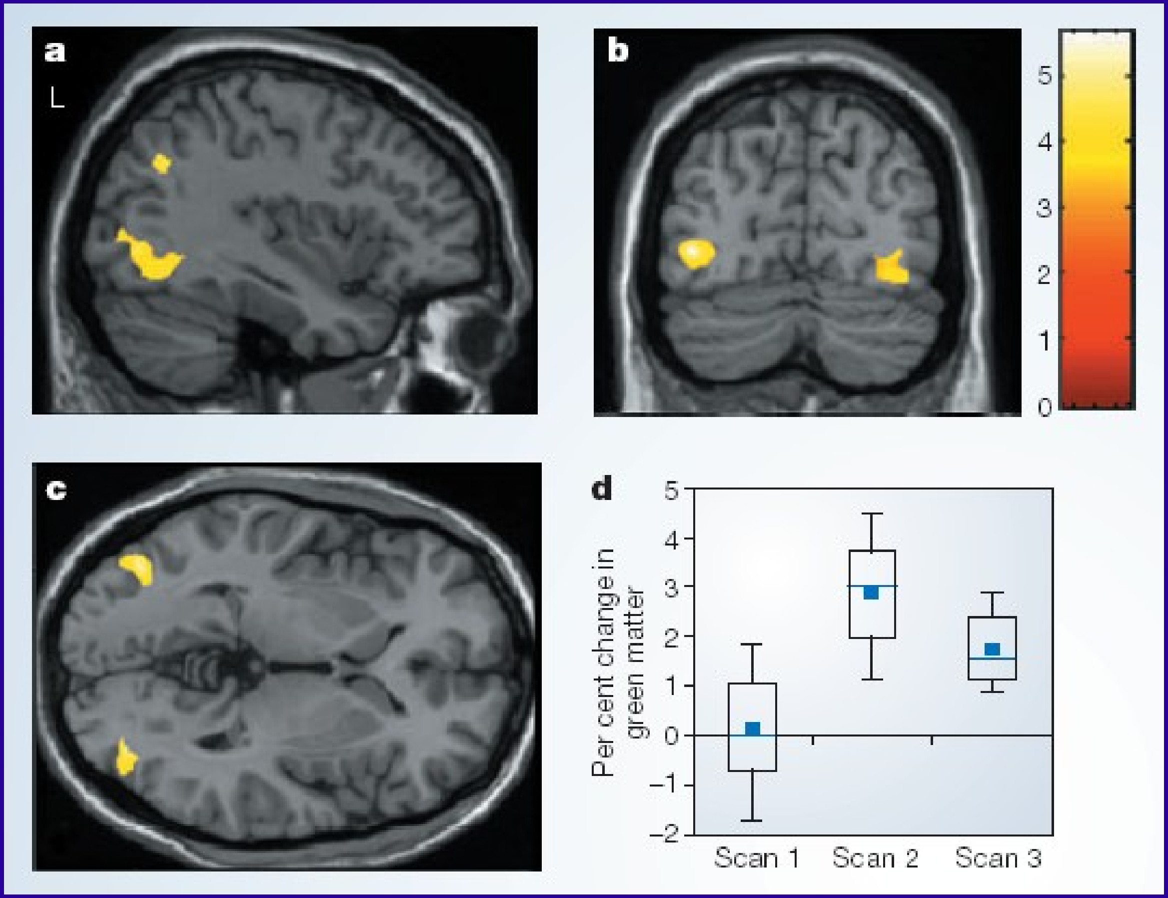
- Open questions:

  - Are these differences in brain anatomy due to innate differences or to different histories of stimulation?
    (see the differences between Musicians and non-Musicians, e.g., Pantev at al. 1998, Schneider et al. 2002; Gaser & Schlaug, 2005).
  - Are they specific to speech?
  - Could intensive training induce detectable morphological changes in these structures?

Learning a new skill can induce morphological modifications

Comparing (using VBM) anatomical scans of two groups of subjects, one of which learn to jungle for 3 months.

3 sessions: before, after, 3 months after the end of training.



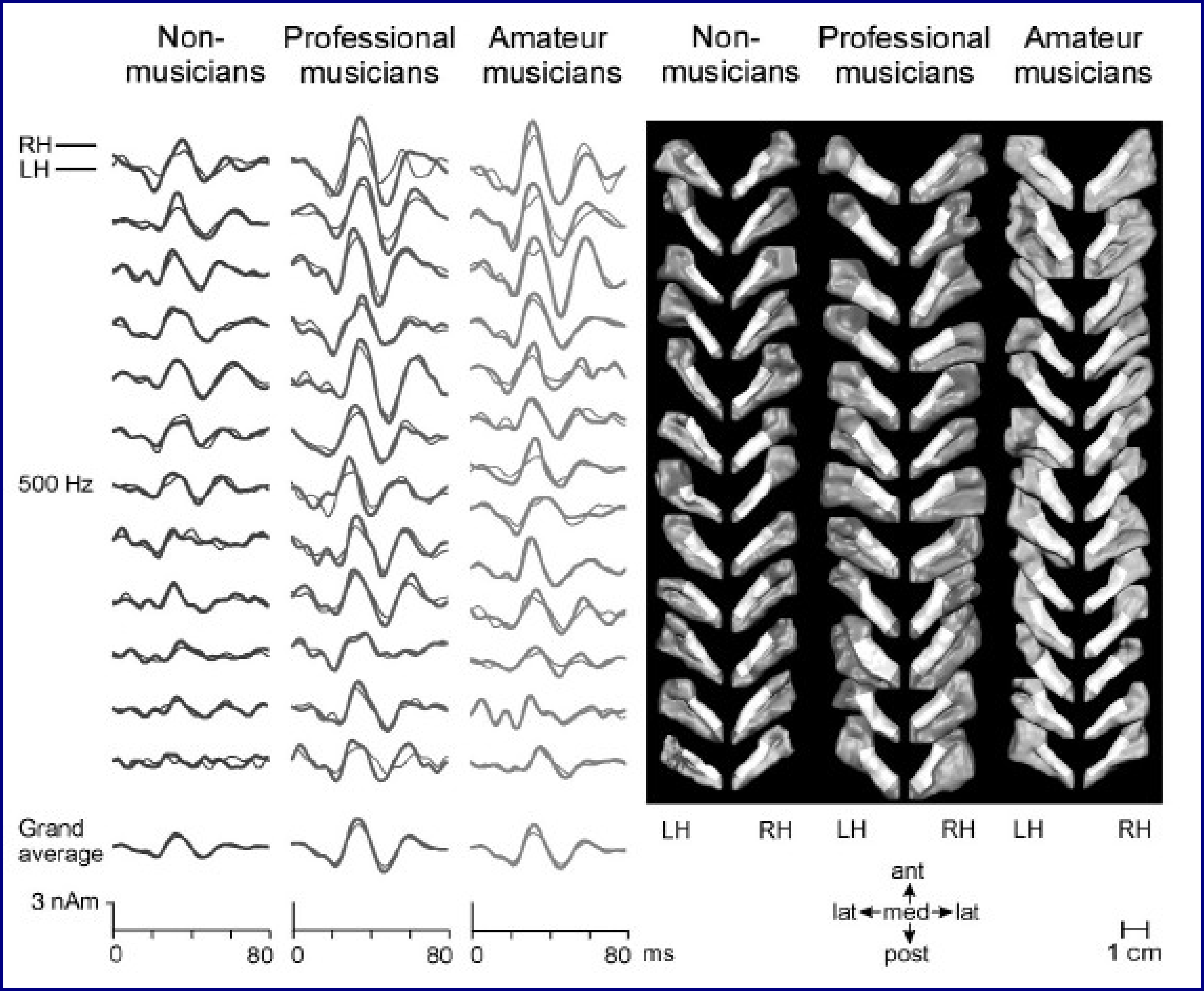
Draganski, Gaser, Busch, Schuierer, Bogdahn, May. *Nature*, 2004

Morphology of Heschl Gyrus in musicians vs. non musicians (Schneider et al. Nature Neurosci. 2002)

The volume of gray matter of HG is 37 % (se=15%) larger in musicians.

In the antero-medial portion, the difference is 130 % (se=23%).

The response to a pure tone in MEG is also stronger.



Structural differences between monolinguals' and bilinguals' brains

Mechelli, Crinion, Noppeney, O'Doherty, Ashburner, Frackowiak & Price
(2004) Structural plasticity in the bilingual brain. *Nature*

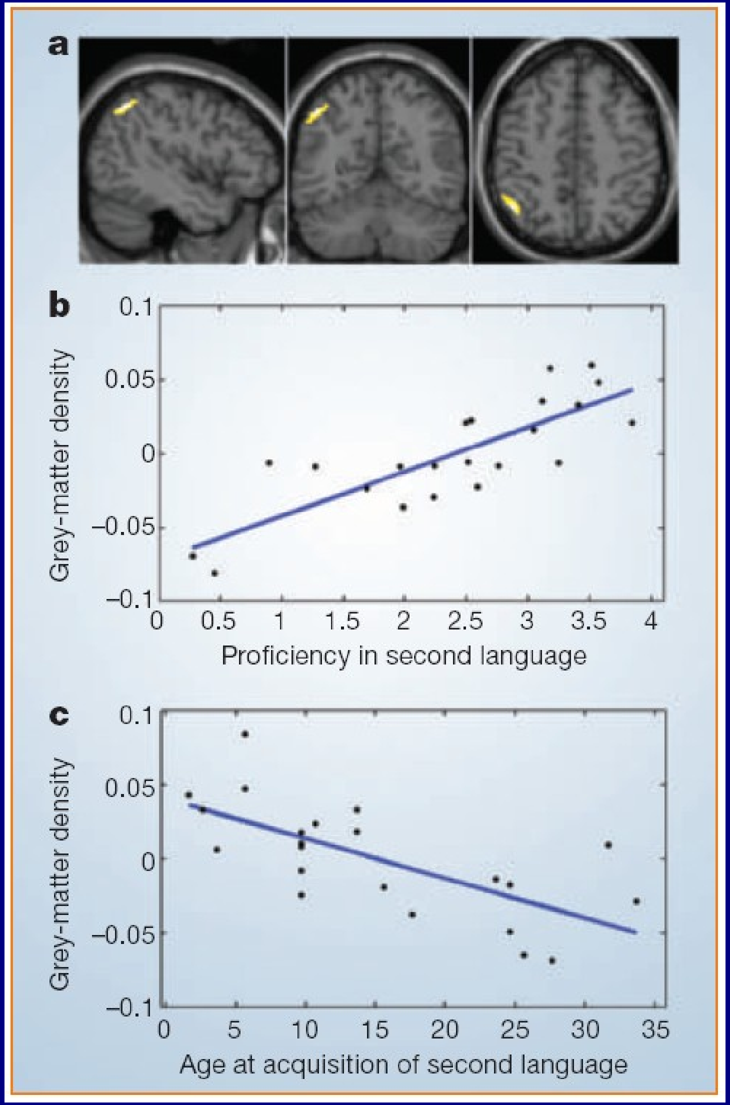
Method: Voxel-based-morphometry

Study 1: Comparaison of 25 monolinguals vs. 58 bilinguals.

Résult: bilinguals have a higher gray matter “density” in an area of the inferior parietal cortex (cf. figure 'a')

Study 2: 22 Italians having learned English between 2 and 34 years of age, with varying proficiency levels.

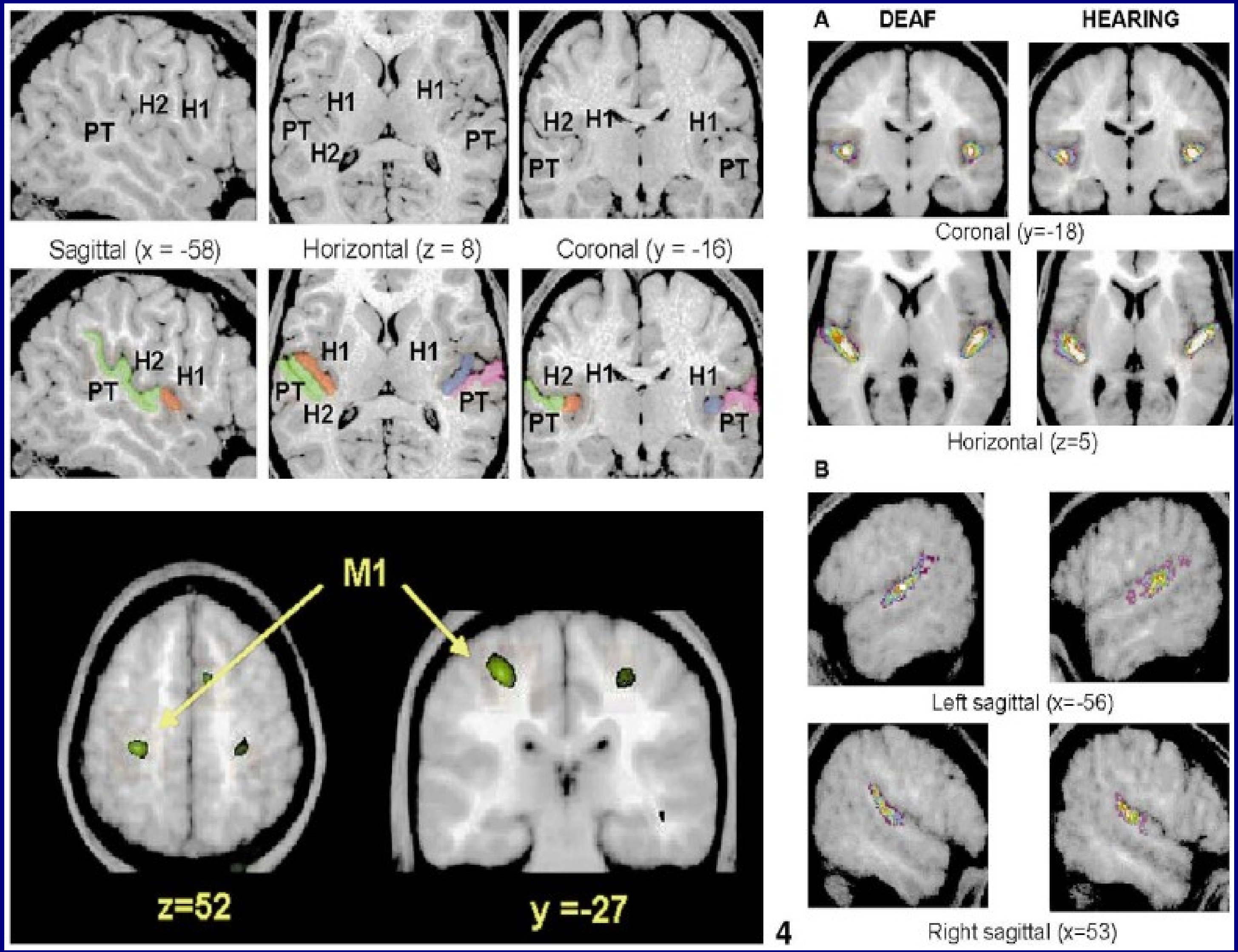
Result: in the same region, gray matter “density” correlates with the level reached in English (and inversely with age of acquisition) (see figures 'b' et 'c')



Morphometry of auditory cortex in the congenitally deaf
(Penhune et al. 2003)

No difference in volume of HG and PT of deaf and hearing subjects!

The only difference is in the grey matter volume of hand motor cortex



Perception of *native* contrasts in bilinguals

(Diaz, Sebastian-Gallès et al., 2009)

- Participants: 2 groups of Spanish(L1)-Catalan(L2) fluent bilinguals differing on their perception of Catalan phonemes (poor vs. good).
- Method: Evoked-potential/Mismatch-negativity (oddball paradigm)
- Stimuli: acoustic/native/non-native contrasts
- Results: relative to the “good” group, the poor group shows a *reduced MMN for native* contrasts (& non-native contrasts.
- Conclusion: innate (?) speech-specific perceptual limitations in the “poor” group.
- Question: are there anatomical brain correlates?

Conclusions

- Some markers of individual differences in the ability to acquire a foreign language have been identified.
- Yet our understanding is still very limited...
- The graal: find tools (behavioral and brain imaging) that provide reliable individual data and allow us to perform longitudinal studies.