Reading in the brain

1. The visual word form area: myth or reality?

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Early art forms

Chauvet Cave, Ardèche, France
~32,000 years ago

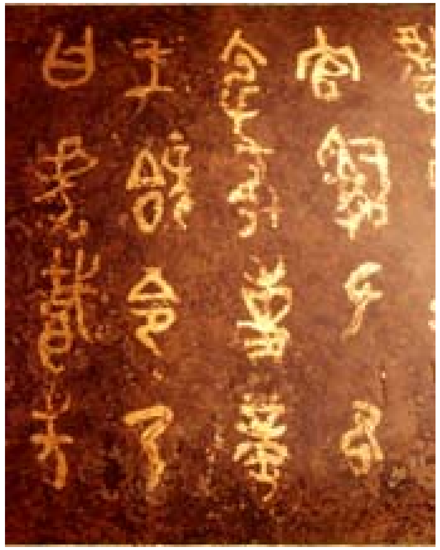
Lascaux cave
~18,000 years ago

Emergence of symbolic writing

Egyptian hieroglyphs

Cuneiform

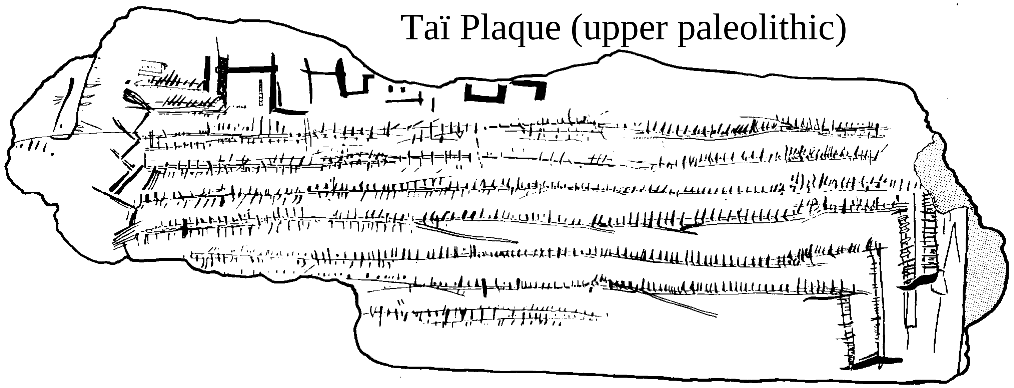
Chinese



Maya

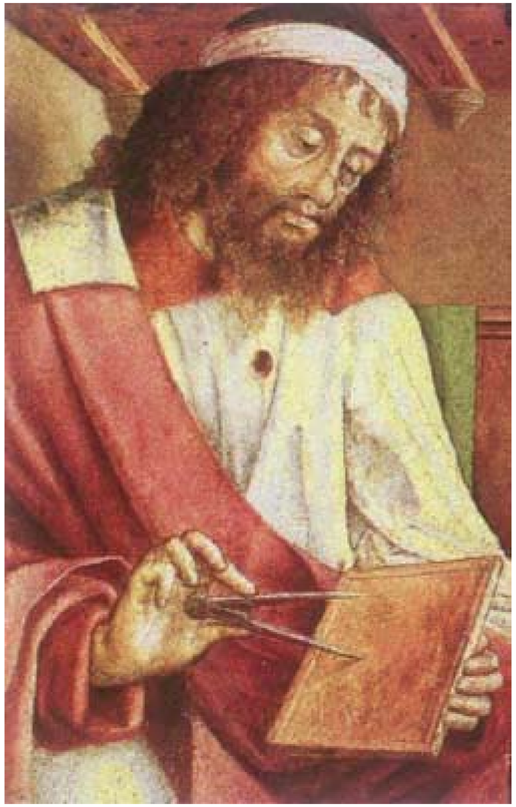
Emergence of symbolic mathematics

Taï Plaque (upper paleolithic)

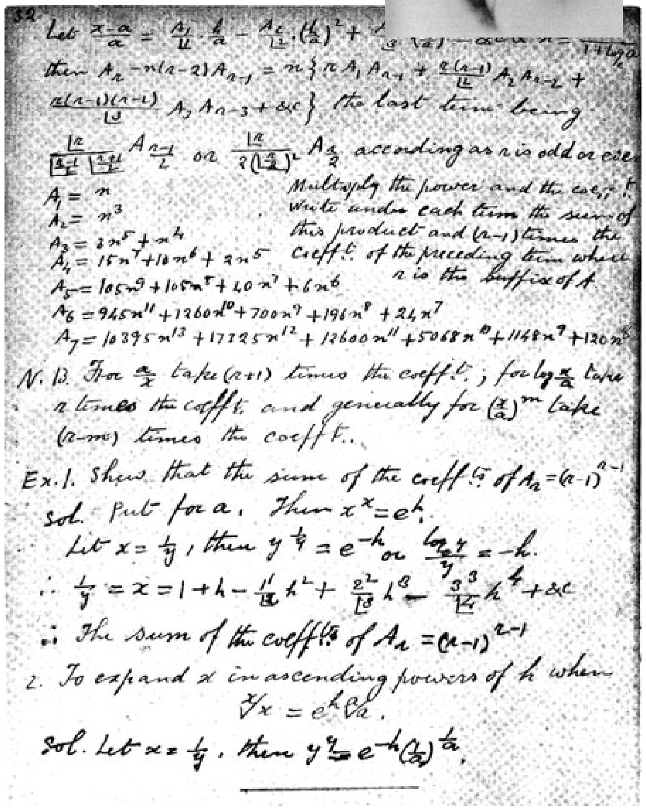


Rhind papyrus

Euclid's Elements



Ramanujan notebooks


then $A_n - n(n-2)A_{n-1} = n\{nA_1A_{n-1} + \frac{n(n-1)}{\underline{2}}A_2A_{n-2} + \frac{n(n-1)(n-2)}{\underline{3}}A_3A_{n-3} + \&c\}$ the last term being

$\frac{\underline{n}}{\underline{\frac{n-1}{2}}\,\underline{\frac{n+1}{2}}}A_{\frac{n-1}{2}}$ or $\frac{\underline{n}}{2(\underline{\frac{n}{2}})^2}A_{\frac{n}{2}}$ according as n is odd or even

$A_1 = n$
$A_2 = n^3$
$A_3 = 3n^5 + n^4$
$A_4 = 15n^7 + 10n^6 + 2n^5$
$A_5 = 105n^9 + 105n^8 + 40n^7 + 6n^6$
$A_6 = 945n^{11} + 1260n^{10} + 700n^9 + 196n^8 + 24n^7$
$A_7 = 10395n^{13} + 17325n^{12} + 12600n^{11} + 5068n^{10} + 1148n^9 + 120n^8$

Multiply the power and the coeff.t Write under each term the sum of this product and $(n-1)$ times the coeff.t of the preceding term where n is the suffix of A.

N.B. For $\frac{a}{x}$ take $(n+1)$ times the coeff.t; for $\log\frac{x}{a}$ take n times the coeff.t and generally for $(\frac{x}{a})^m$ take $(n-m)$ times the coeff.t.

Ex. 1. Shew that the sum of the coeff.ts of $A_n = (n-1)^{n-1}$

Sol. Put for a. Then $x^x = e^h$.

Let $x = \frac{1}{y}$, then $y^{\frac{1}{y}} = e^{-h}$ or $\frac{\log y}{y} = -h$.

$\therefore \frac{1}{y} = x = 1 + h - \frac{1}{\underline{2}}h^2 + \frac{2^2}{\underline{3}}h^3 - \frac{3^3}{\underline{4}}h^4 + \&c$

$\therefore$ The sum of the coeff.ts of $A_n = (n-1)^{n-1}$

2. To expand x in ascending powers of h when $\sqrt[x]{x} = e^h\sqrt[a]{a}$.

Sol. Let $x = \frac{1}{y}$. then $y^y = e^{-h}(\frac{1}{a})^{\frac{1}{a}}$.

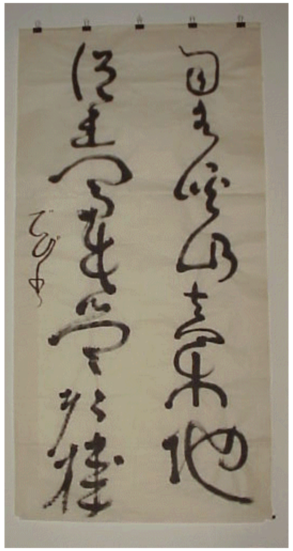
Reading in the brain

A series of 3 lectures:

1. **The visual word form area: myth or reality?**
   - → **What is the brain architecture for reading?**

2. **Masking, subliminal reading, and the mechanisms of conscious access**
   - → **Which stages of the reading process can unfold non-consciously?**
   - → **What is the nature of conscious access?**

3. **Symbol grounding: How the acquisition of symbols affects numerical cognition**
   - → **How do we link (number) symbols to semantic representations?**
   - → **How are our representations changed by learning symbols?**



Cultural tools and the brain

- **Non-invasive neuro-imaging techniques** now allow us to study the brain mechanisms underlying cultural tools.
- For both reading and arithmetic, in spite of cultural variability, we find **reproducible** and partially **specialized** brain regions.
- These findings raise an obvious **paradox**, as evolution did not have enough time to adapt brain architecture to these recent cultural objects.

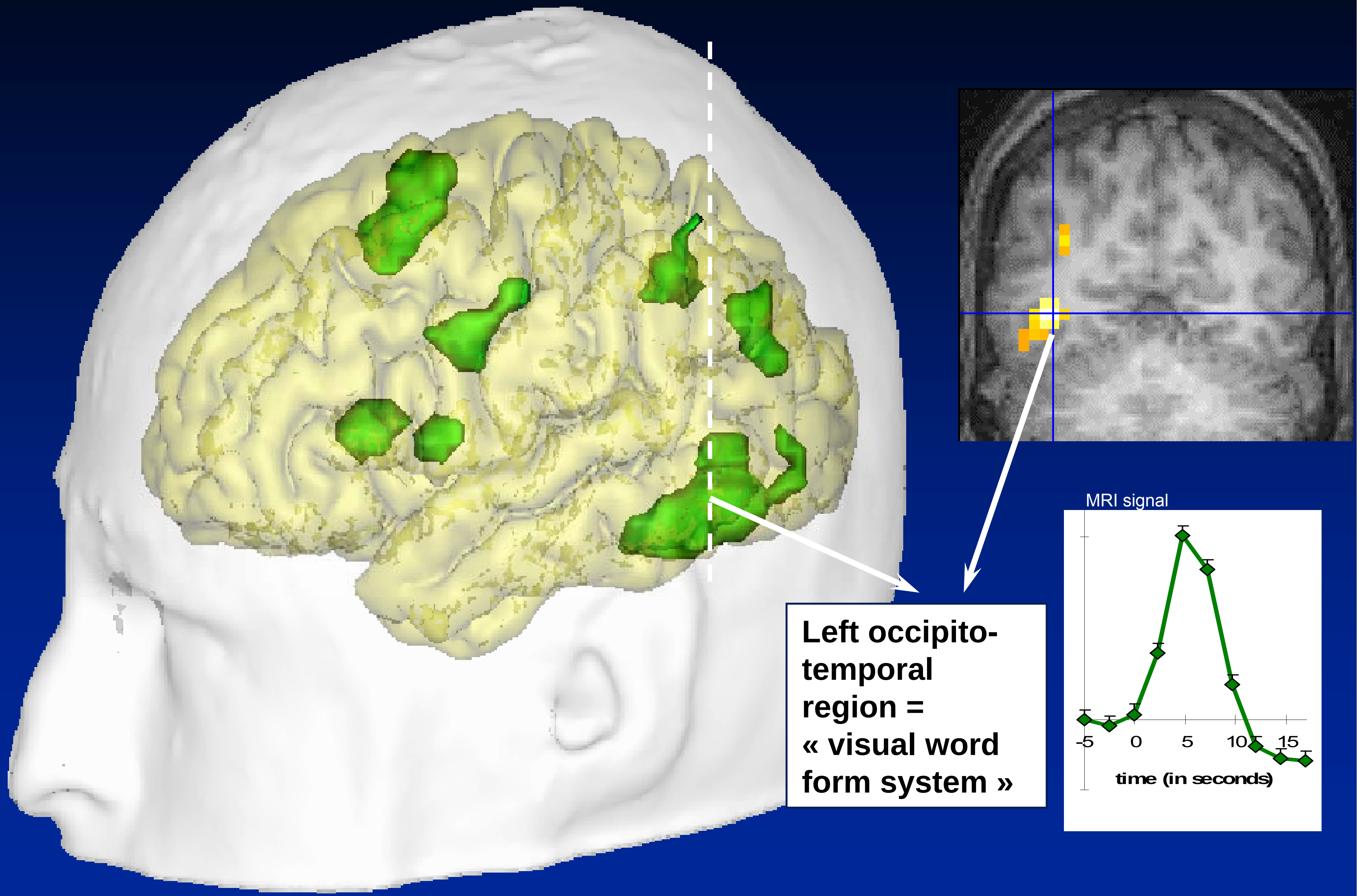
The “neuronal recycling” model:

- The architecture of our primate brain is tightly limited.
- It is laid down under genetic control, though with **a fringe of variability and plasticity** (itself evolved and under genetic control).
- New cultural acquisitions are only possibly inasmuch as they fit within this fringe. Each **cultural object** must find its **neuronal niche**.
- Far from being a blank slate, our brain adapts to a given cultural environment by **minimally reconverting or “recycling”** its existing cerebral predispositions to a different use.

Consequences:

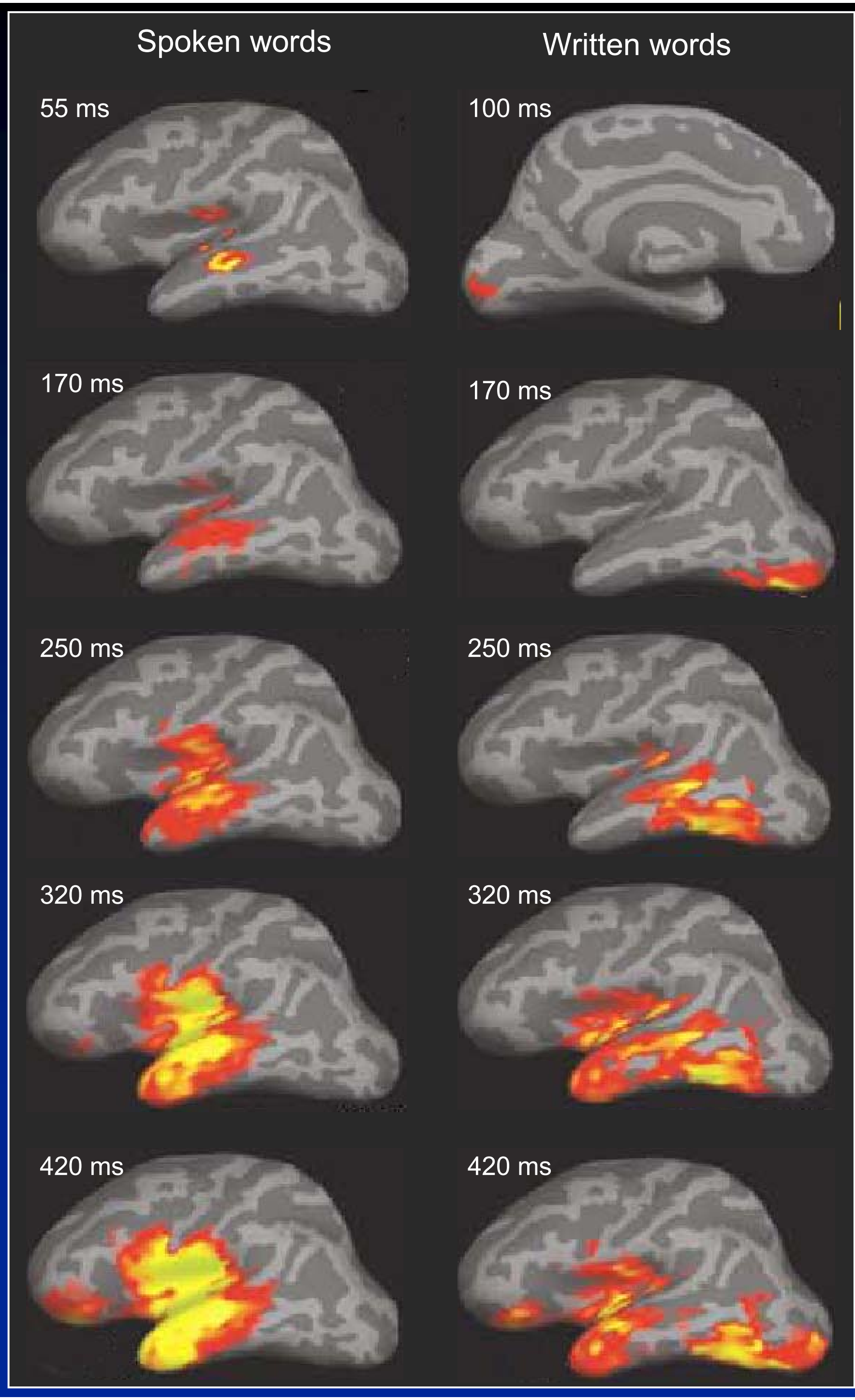
- Numerous **cultural invariants** should be identified and ultimately related to neuronal constraints
- The strengths and weaknesses of our brain architecture should determine the speed and ease of **cultural learning.**

fMRI studies of reading and the visual word form area



Temporal unfolding of activation during reading

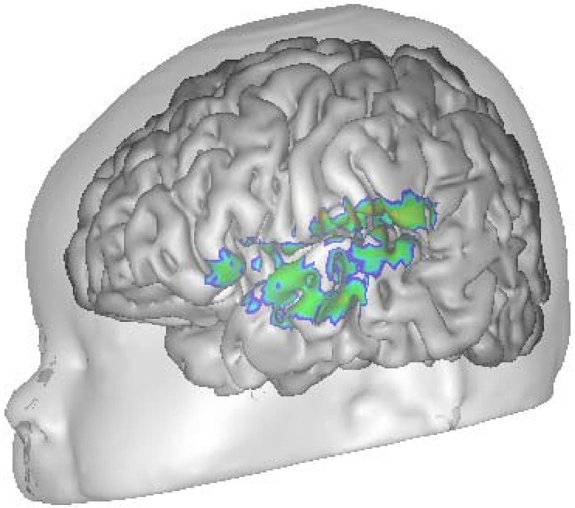
(Marinkovic et al., 2003)



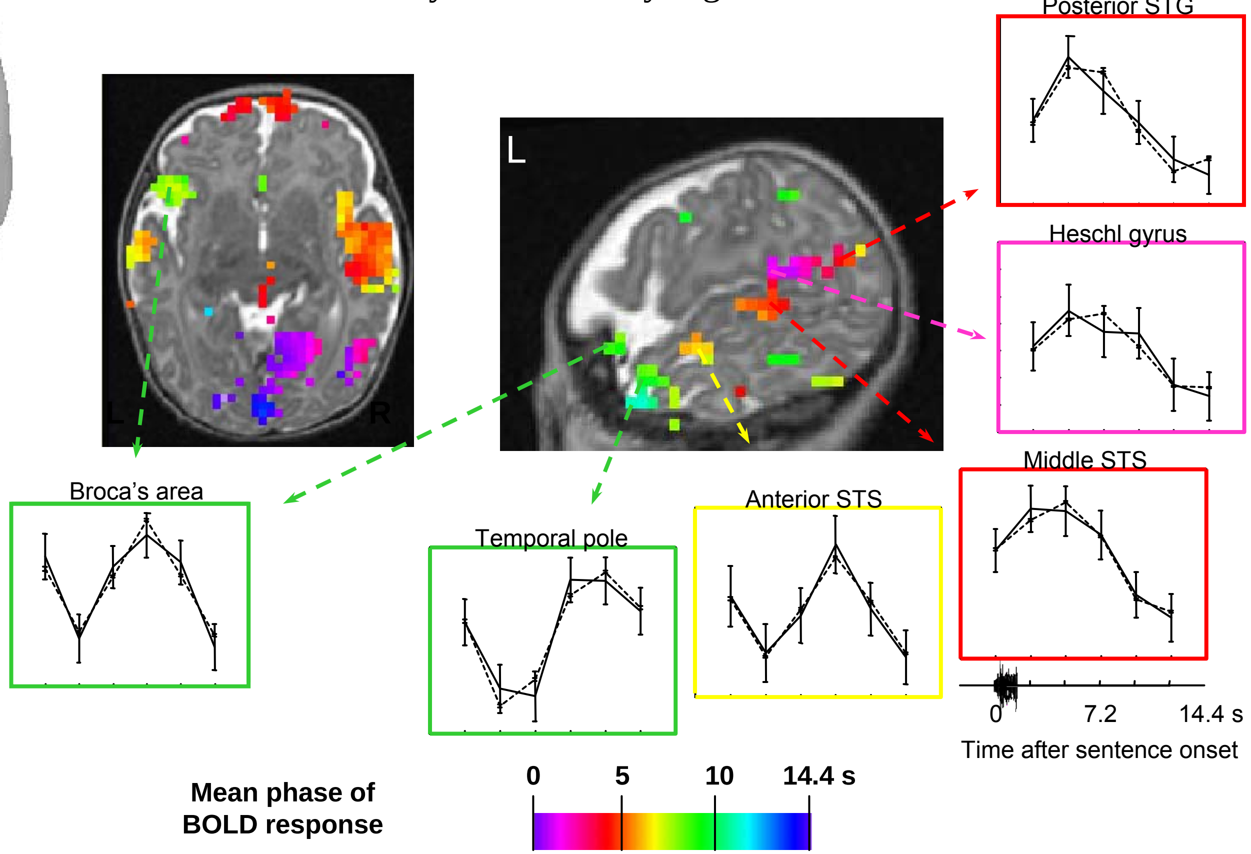
A left temporo-frontal network for language processing in 3 month-old babies

G. Dehaene-Lambertz et al., *Science* 2002, *PNAS* 2006

The **superior temporal gyrus** (STG), **superior temporal sulcus** (STS) and left **inferior frontal area** (Broca) are already activated by short spoken sentences.

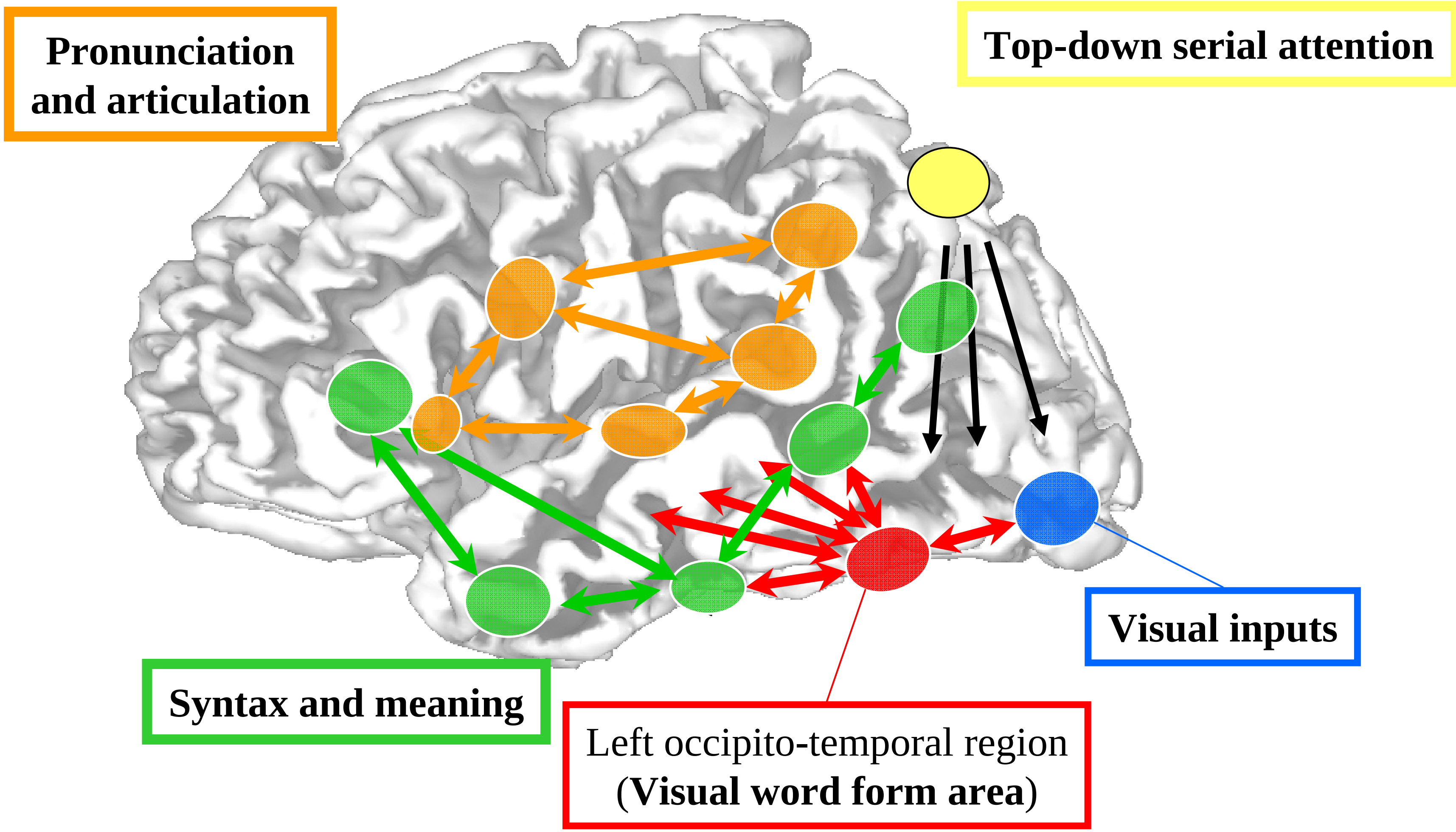


A **systematic arrangement of phases** suggests that the network is already hierarchically organized



A simple view of the brain architecture for reading

Learning to read consists in
- creating an **abstract representation of written strings**
- connecting it to areas coding for **meaning** and **pronunciation**



Is the visual word form area a « myth »?

Cathy Price and Joe Devlin « The myth of the visual word form area » (*Neuroimage*, 2003)

« neither neuropsychological nor neuroimaging data are consistent with a cortical region specialized for visual word form representations. »

« this region acts as an interface between visual form information and higher order stimulus properties such as its associated sound and meaning. »

« More importantly, this function is not specific to reading but is also engaged when processing any meaningful visual stimulus. »

Plan of the talk

- What do we mean by « visual word form area »?
- Three concepts of « specialization » :

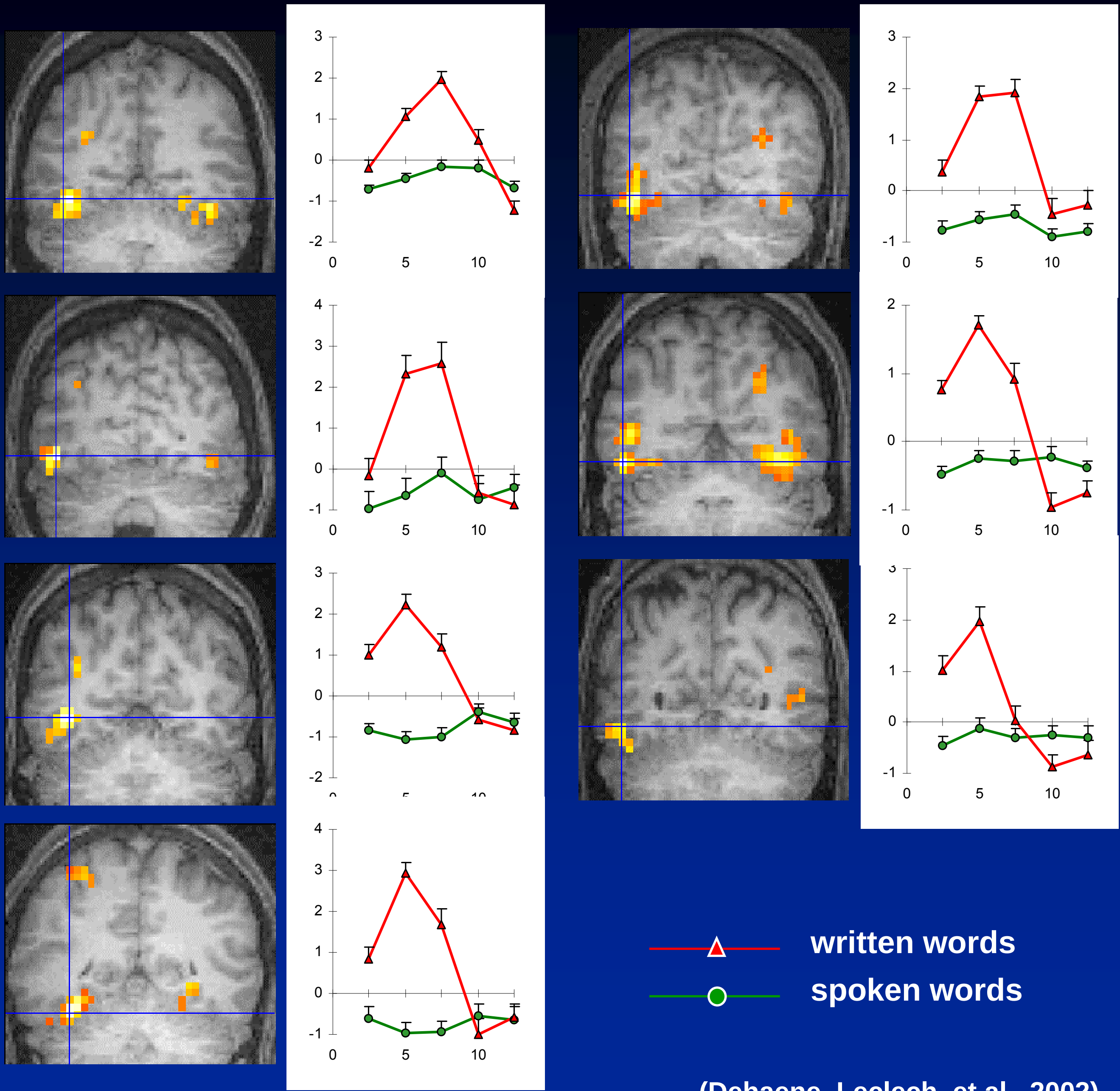
1. Word reading activates a reproducible location
2. This location shows a functional specialization for reading
3. Voxels in this region are uniquely responsive to words (regional selectivity)

- Origins of specialization and hierarchical organization of the VWFA
- Predictions of the neuronal recycling model
  - Evolution of writing
  - Mirror errors in reading

Part I.

Evidence for reproducible localization

Reproducible localization of the VWFA in many different subjects



(Dehaene, Leclech, et al., 2002)

The visual word form area activates at a similar location in all writing systems (English, French, Hebrew, Japanese, Chinese)

e.g. in Japanese

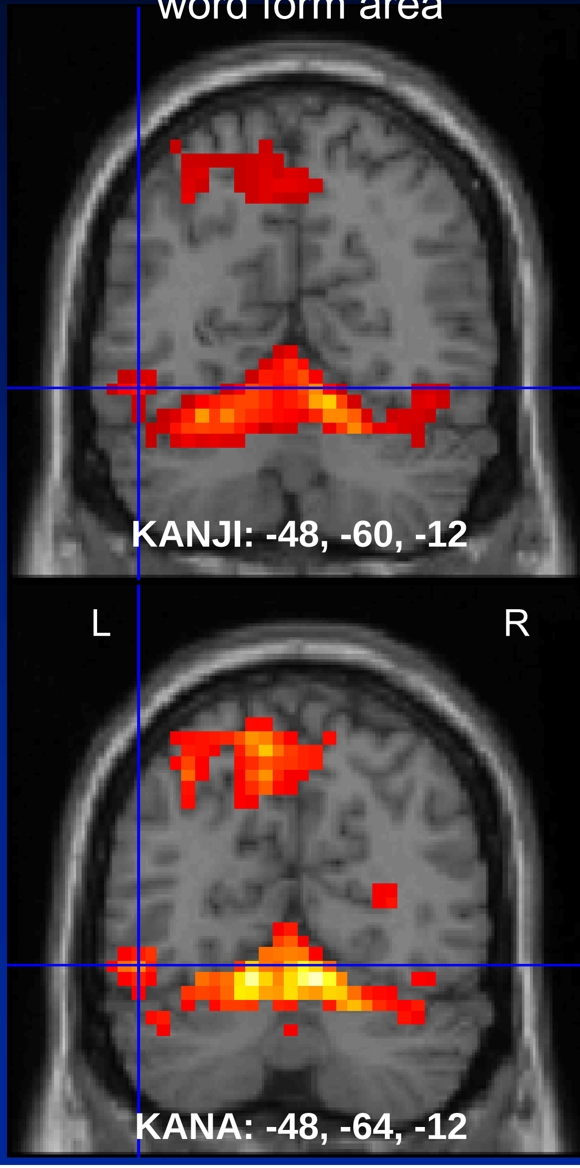
Kanji

神	/kami/
神社	/jiN-ja/
神経	/shiN-kei/
精神	/sei-shiN/
神主	/kaN-nushi/
神戸	/kou-be/

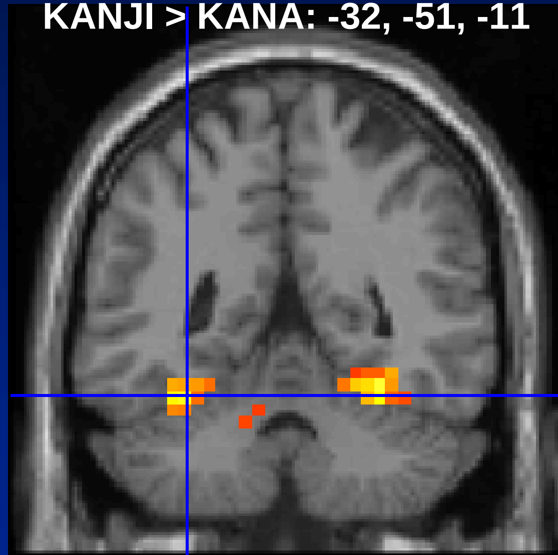
Kana

か	/ka/
かみ	/ka-mi/
かさ	/ka-sa/
あか	/a-ka/
たから	/ta-ka-ra/

Joint activation of the left visual word form area



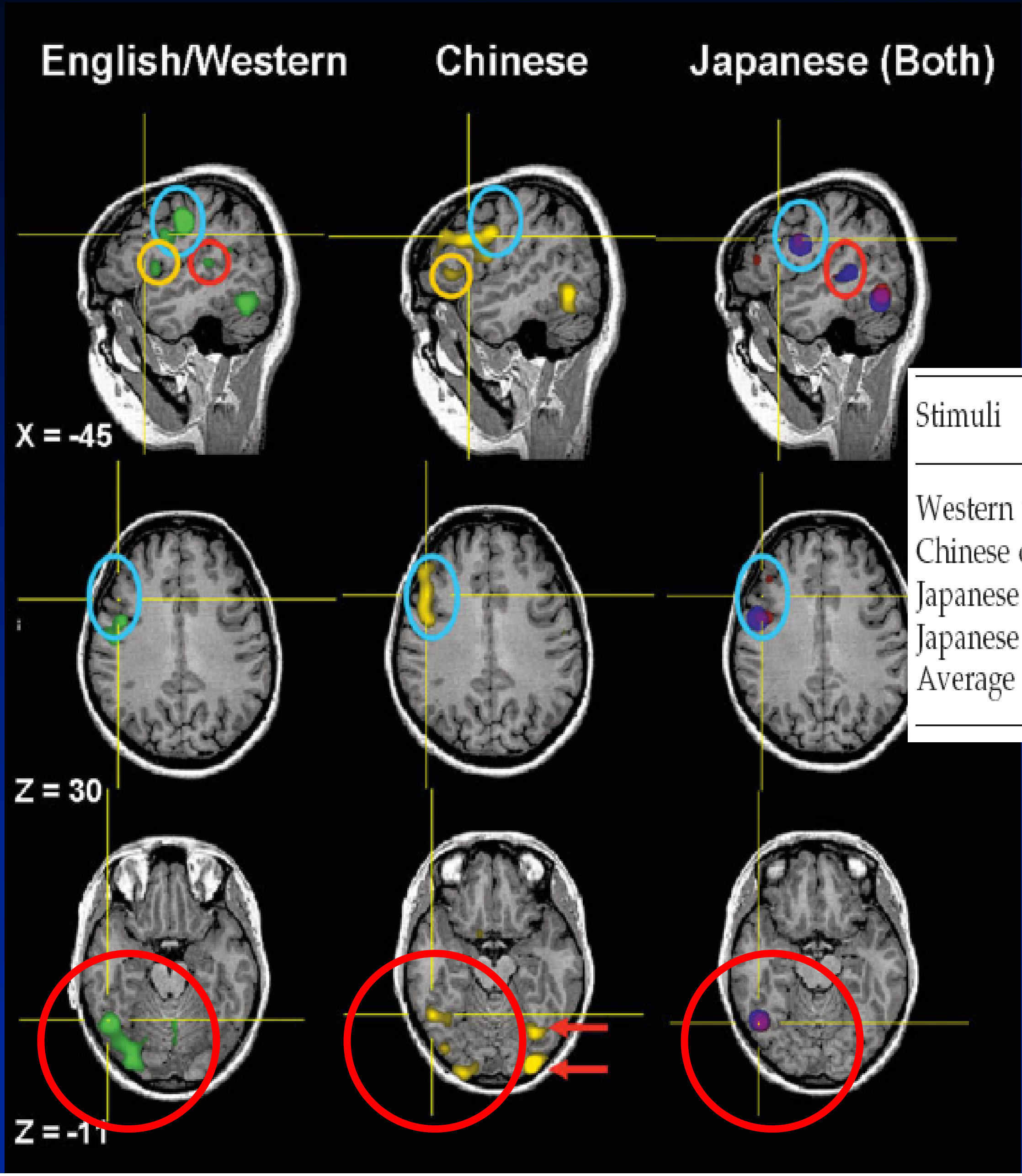
Slight mesial displacement and greater right-hemisphere contribution in Kanji



Nakamura, Dehaene et al., JOCN, 2005

A meta-analysis of reading networks in various cultures

Bolger, Perfetti & Schneider, *Human Brain Mapping*, 2005



Remarkable overlap at the level of the visual word form area

Coordinates proposed by our group: -42, -57, -12

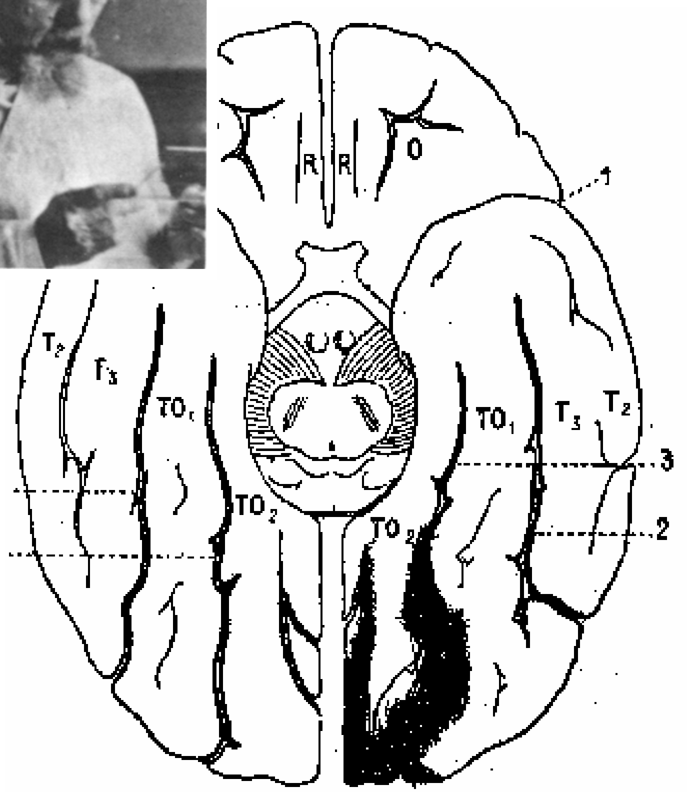
Stimuli	x	y	z
Western words	−46	−56	−15
Chinese characters	−49	−53	−10
Japanese Kana	−46	−55	−8
Japanese Kanji	−47	−58	−9
Average (SD)	−47.2 (1.3)	−55.2 (1.9)	−11.6 (3.6)

Pure Alexia

We are absurdly accustomed to the miracle of a few written signs being able to contain immortal imagery, involutions of thought, new worlds with live people, speaking, weeping, laughing. (…) What if we awake one day, all of us, and find ourselves utterly unable to read?

Vladimir Nabokov, *Pale Fire*

Déjerine, 1892



In October 1888, Mister C., a retired salesman, suddenly realises that he can no longer read a single word

Pure alexia

-Word reading is severely impaired

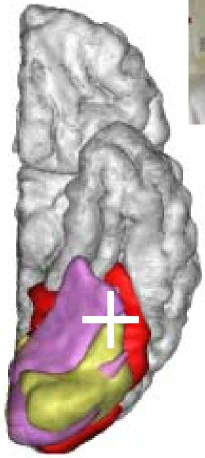
-Object naming and face recognition are preserved

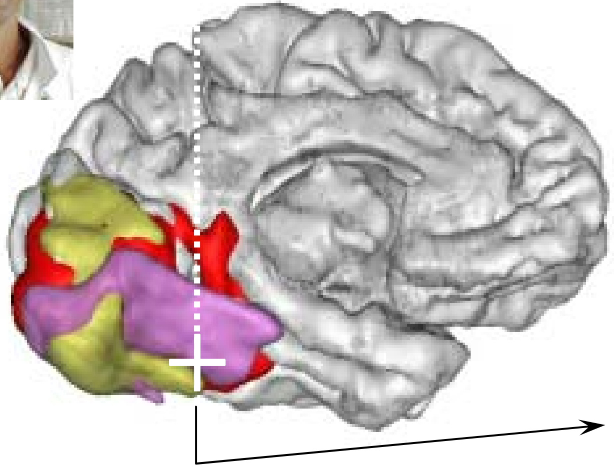
-Speech perception, production, and even writing are preserved

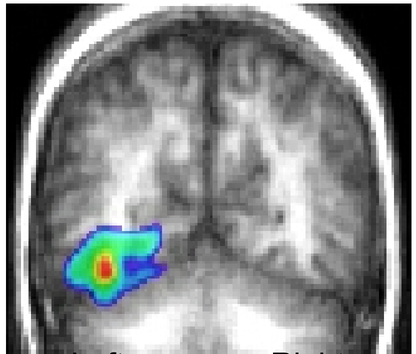
Pinpointing the lesion site associated with pure alexia

Laurent Cohen and collaborators, 2003

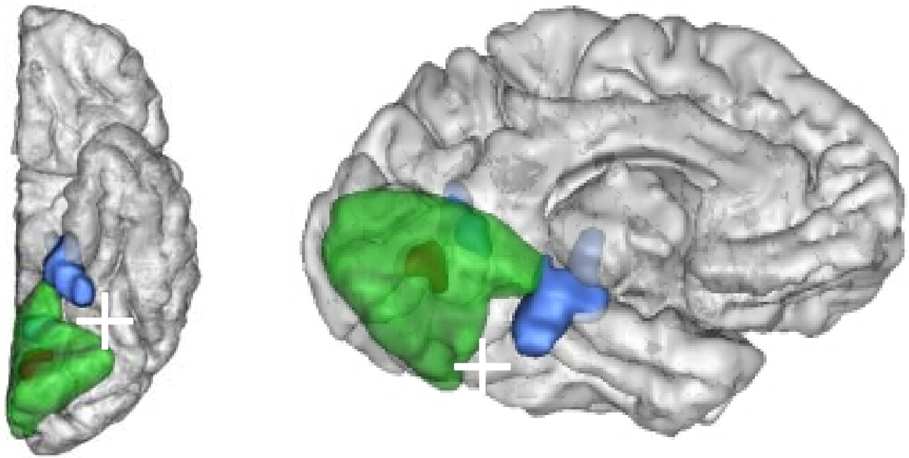
3 patients
***with* alexia**





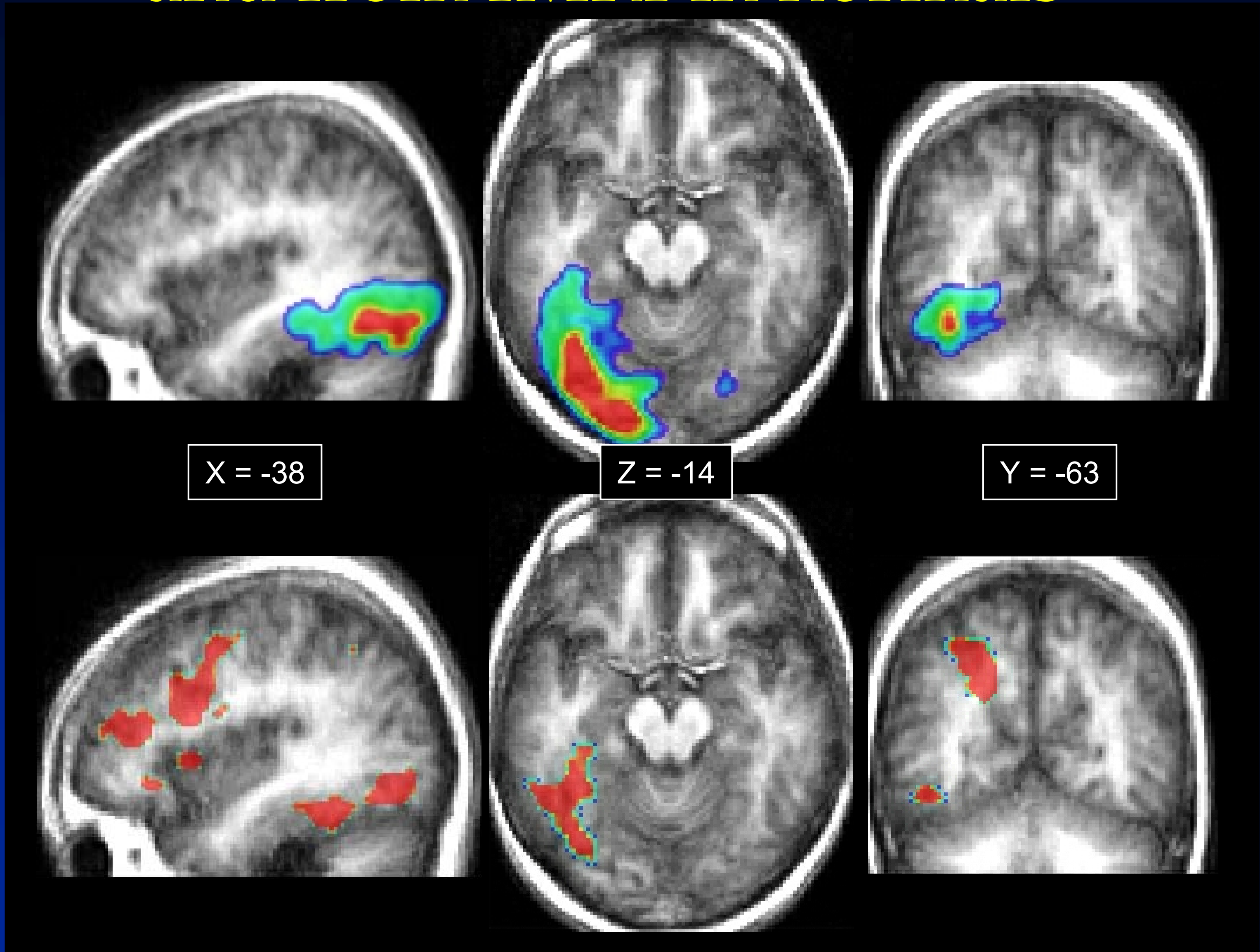


2 patients
without
alexia



See also Damasio & Damasio (1983); Binder & Mohr (1992); Leff et al. (2001)

Convergence of evidence from lesion data and from fMRI in normals

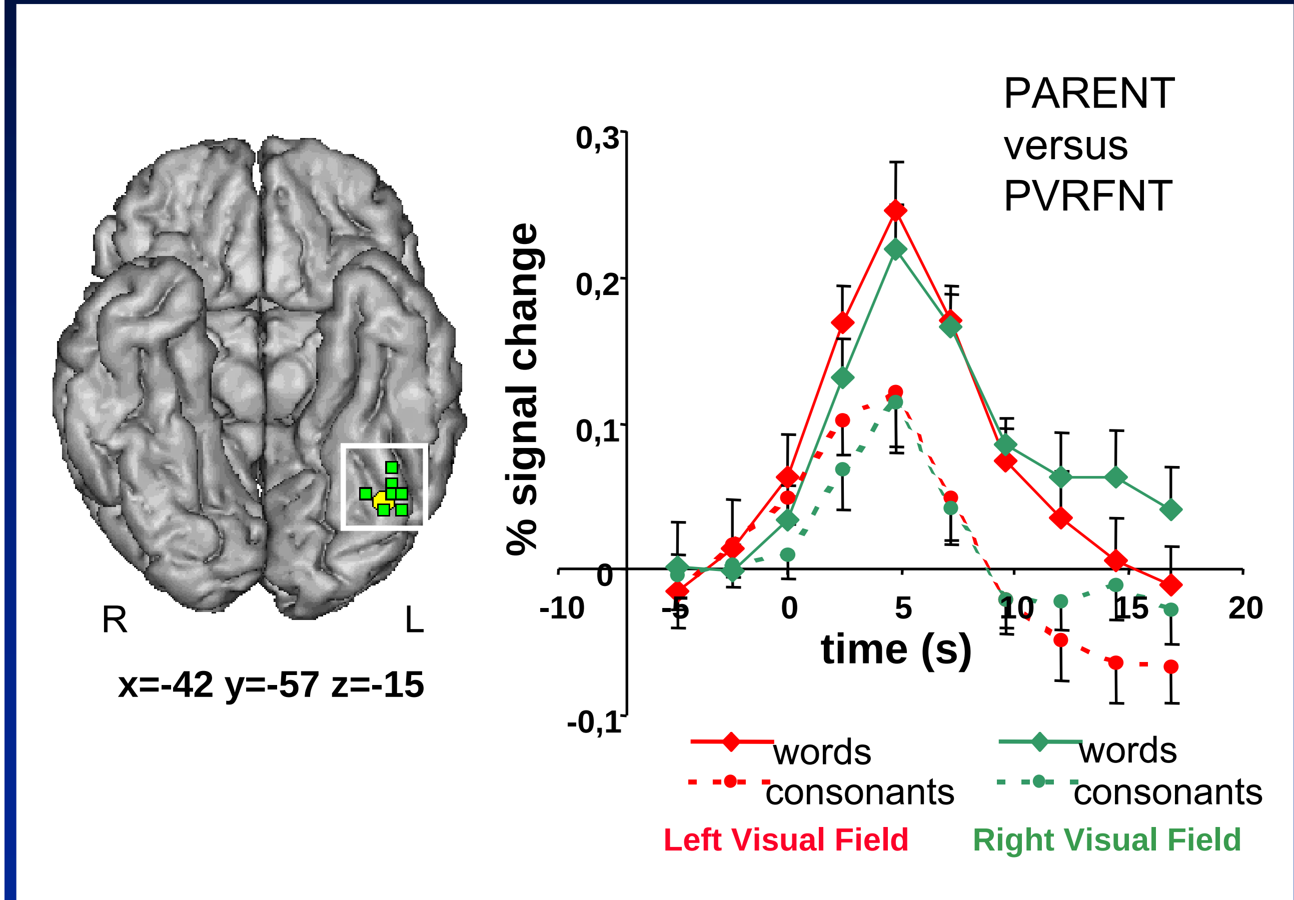


Part II.

Evidence for functional specialization

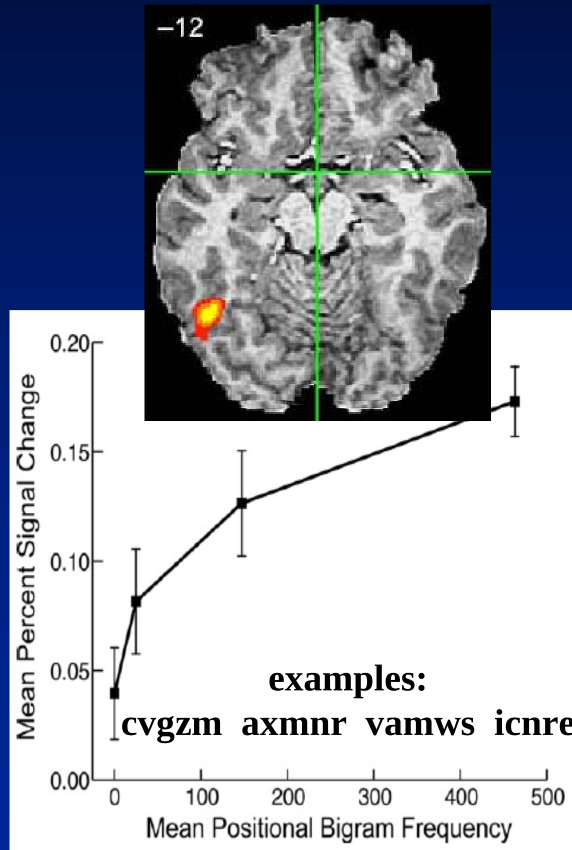
The visual word form area adapts to recurrent orthographic patterns in a given culture

It responds more to words than to consonant strings



Cohen, L., Lehericy, S., Chochon, F., Lemer, C., Rivaud, S., & Dehaene, S. (2002). *Brain, 125*, 1054-1069.

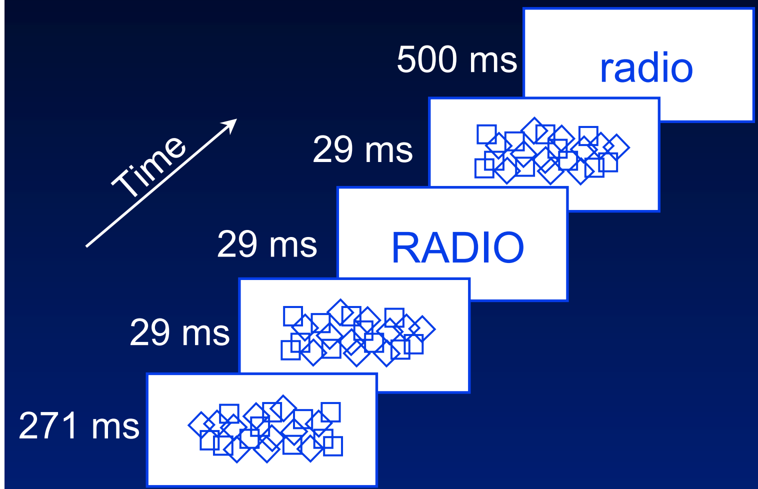
It prefers non-words made of frequent bigrams



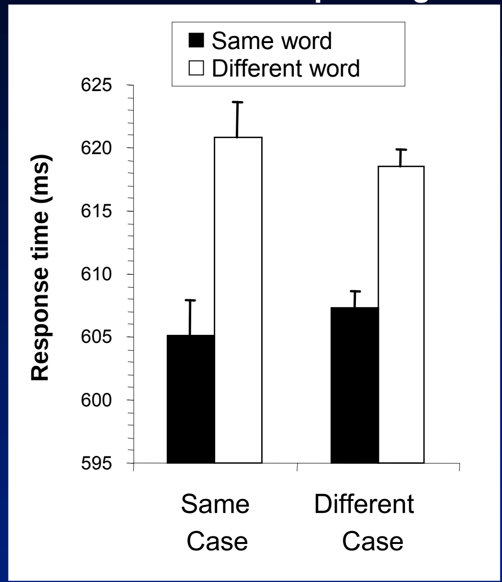
Binder et al. (2006)
Neuroimage

Invariance for case in the visual word form area

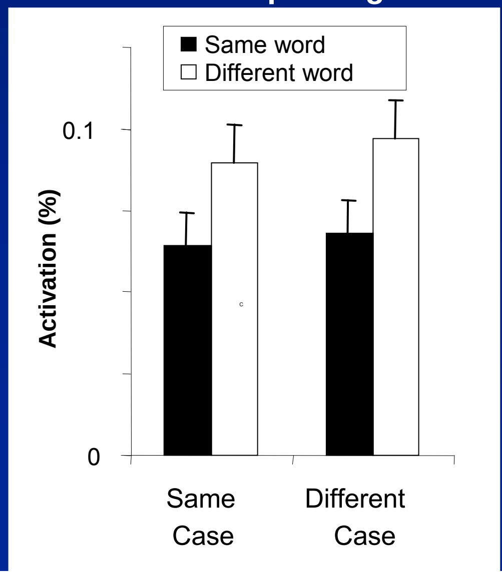
Dehaene et al, *Nature Neuroscience*, 2001; *Psychological Science*, 2004

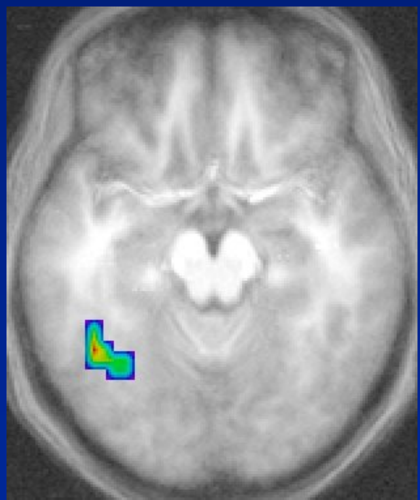


Behavioral priming



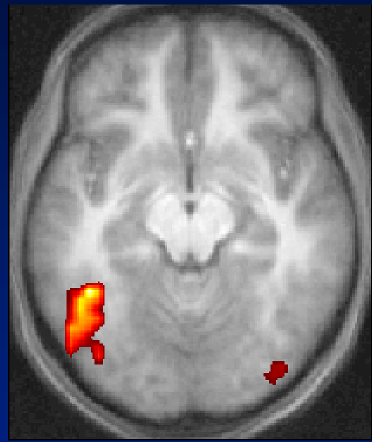
fMRI priming



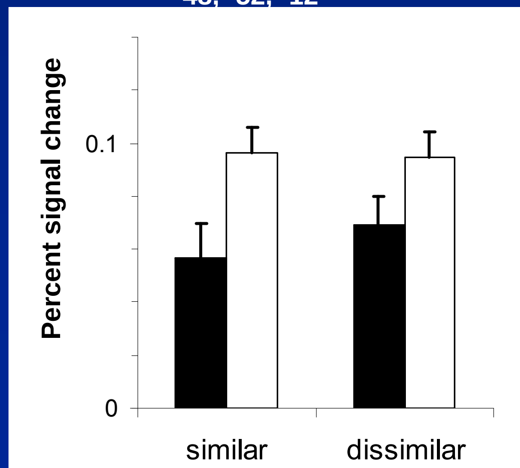


Left fusiform
(-44, -52, -20)

Case-invariant priming independent of letter similarity



Left fusiform
-48, -52, -12



e.g. COUP-coup vs RAGE-rage

Part III.

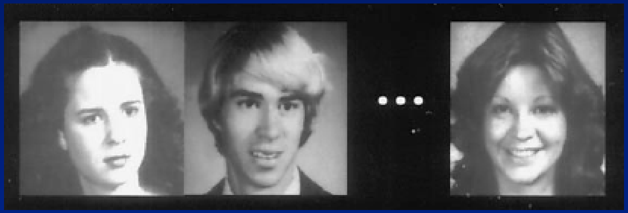
Evidence for anatomical specificity:

is the visual form area uniquely responsive to written words?

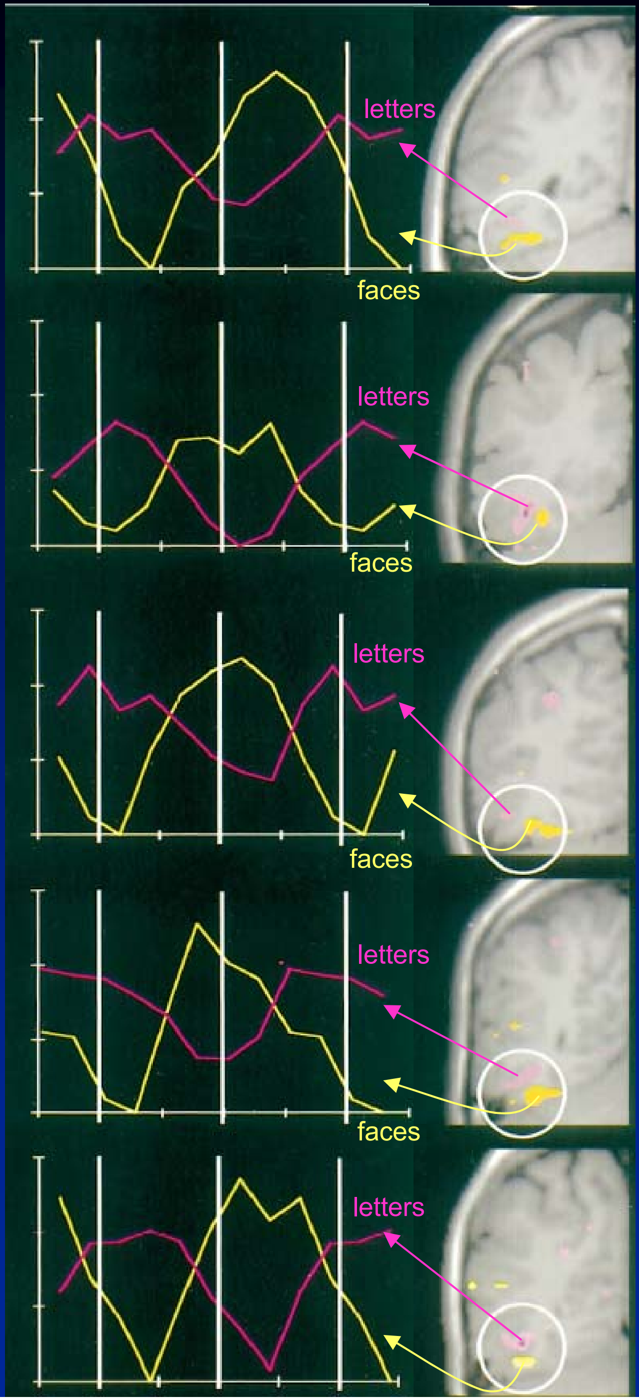
Regional selectivity for faces versus letter strings

Strings of letters

faces



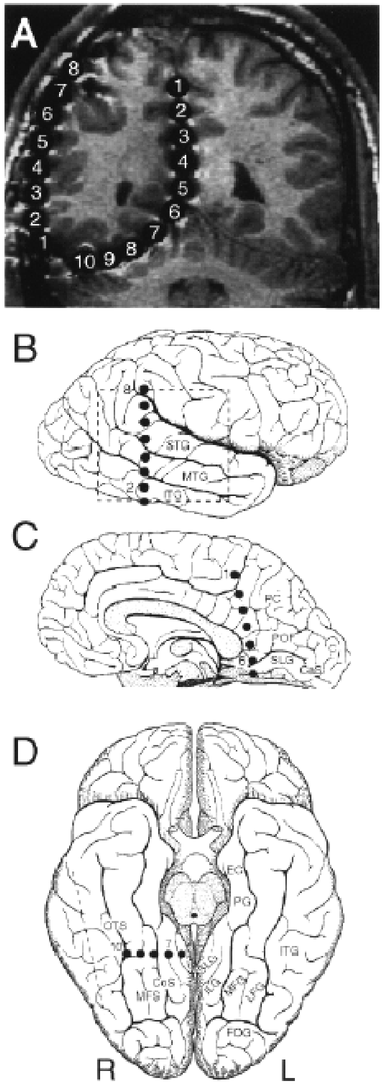
Coronal slice through left hemisphere



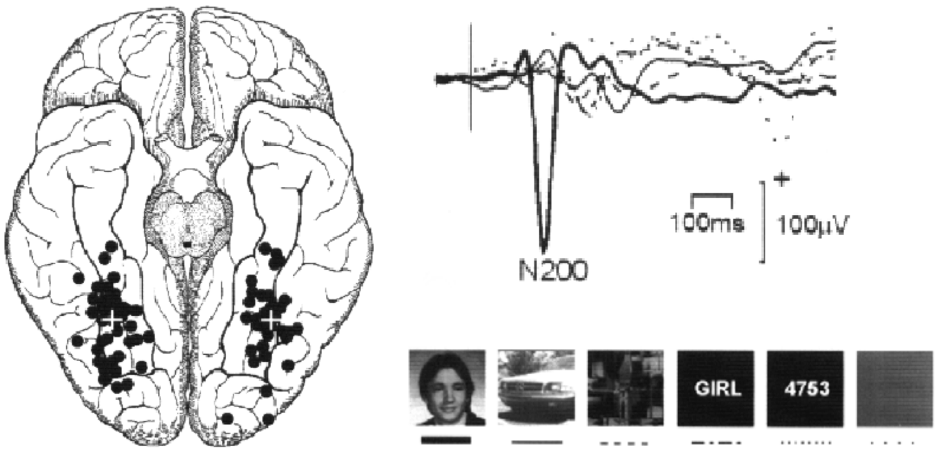
Puce, A., Allison, T., Asgari, M., Gore, J. C., & McCarthy, G. (1996). Differential sensitivity of human visual cortex to faces, letterstrings, and textures: a functional magnetic resonance imaging study. *Journal of Neuroscience, 16*, 5205-5215.

Intracranial Recordings

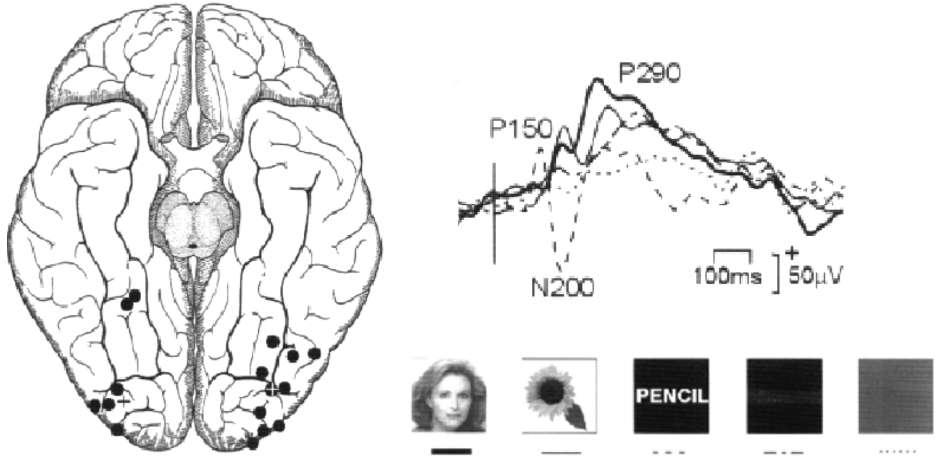
Allison, T., Puce, A., Spencer, D. D., & McCarthy, G. (1999). Electrophysiological studies of human face perception. I: Potentials generated in occipitotemporal cortex by face and non-face stimuli. *Cereb Cortex, 9*(5), 415-430.



FACES



WORDS

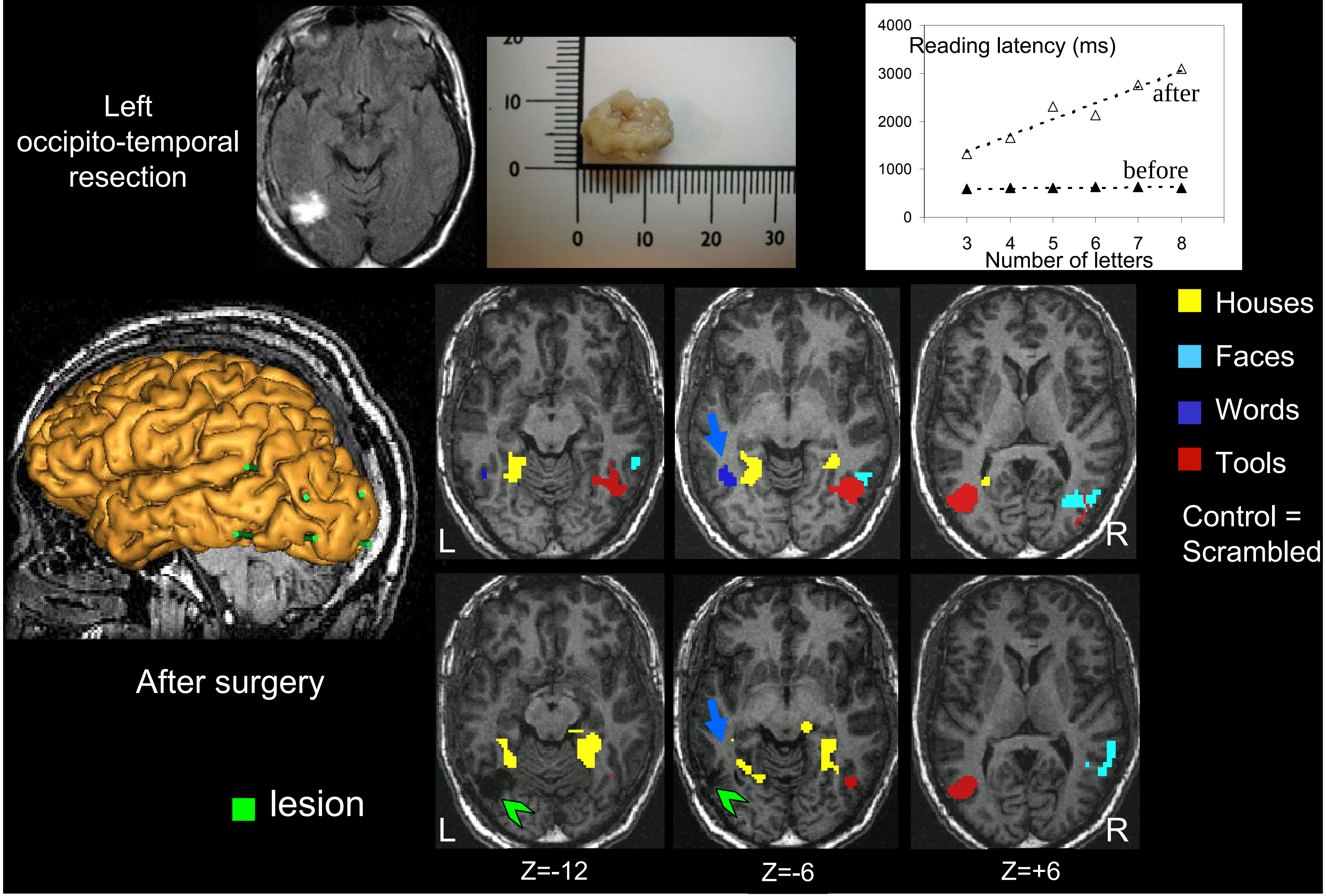


Right Hemisphere

Left Hemisphere

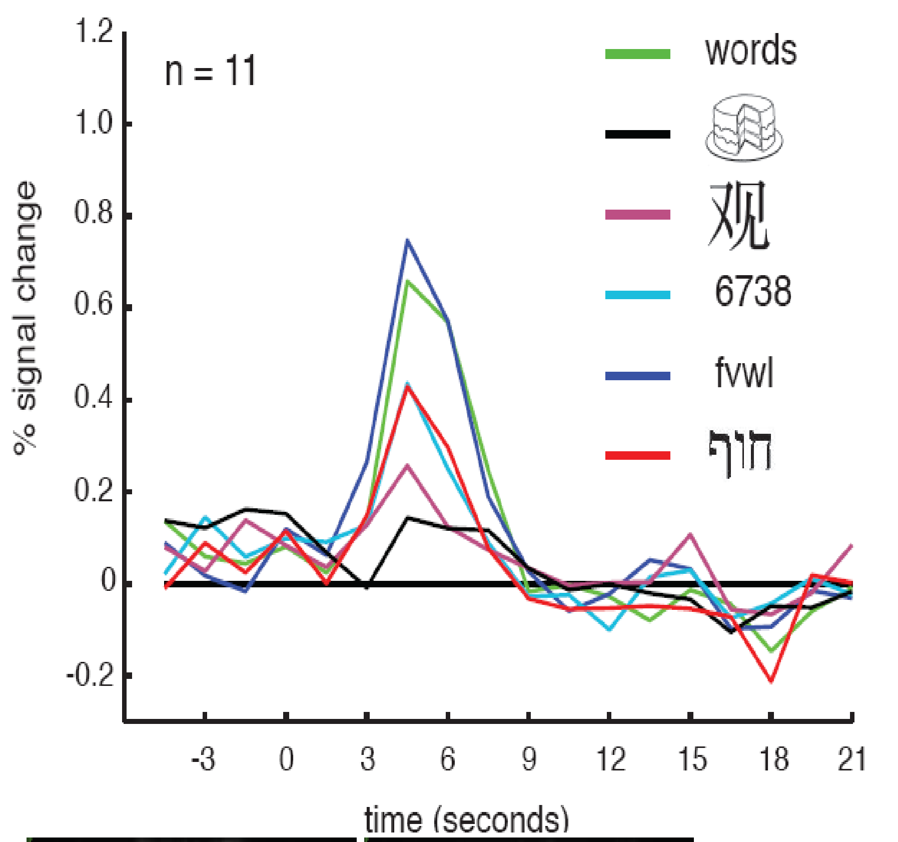
Specialization for reading in left infero-temporal cortex: A single-case study

with R. Gaillard, L. Cohen, L. Naccache, C. Adam, M. Baulac (*Neuron*, 2006)

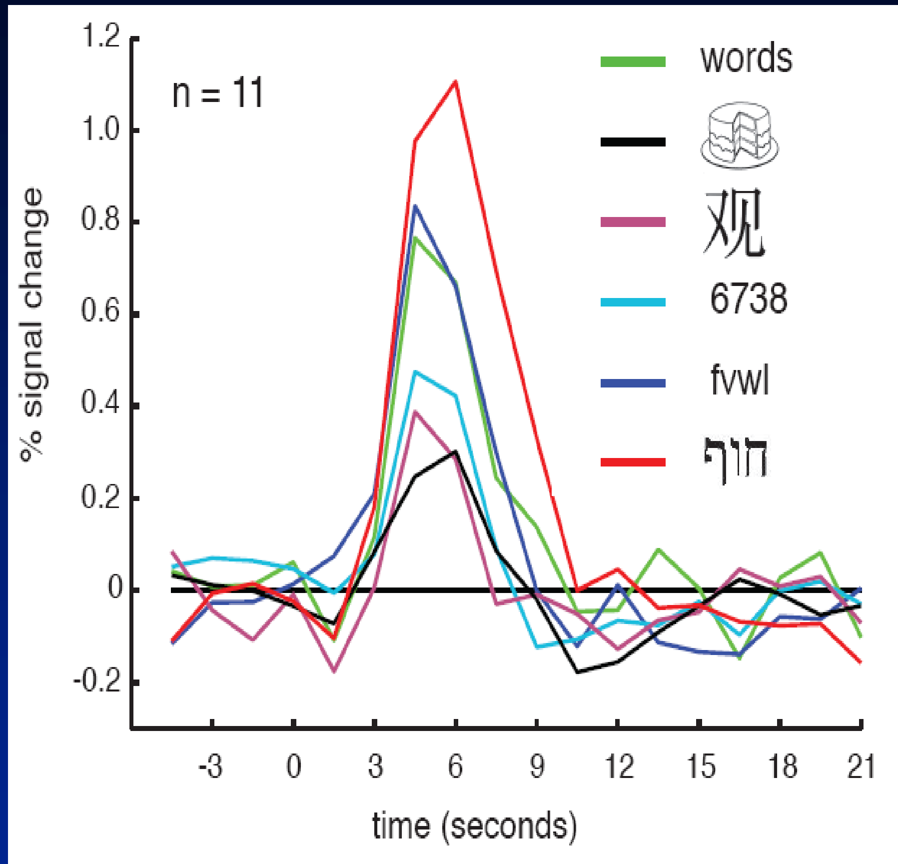


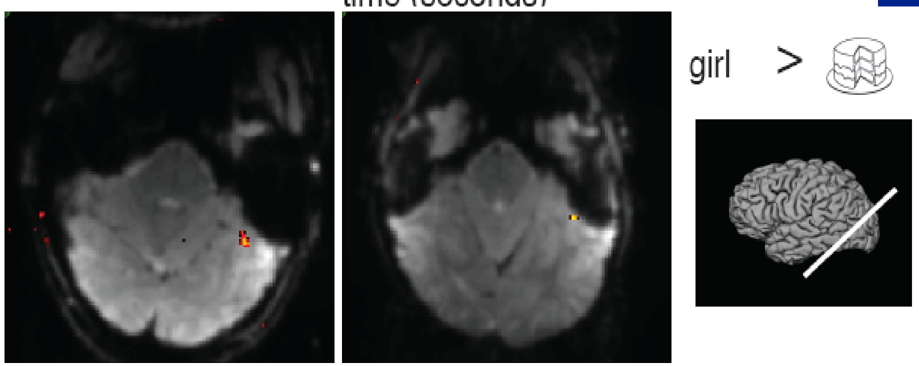
The visual word form area adapts to a given writing system

English readers



Readers of English and Hebrew

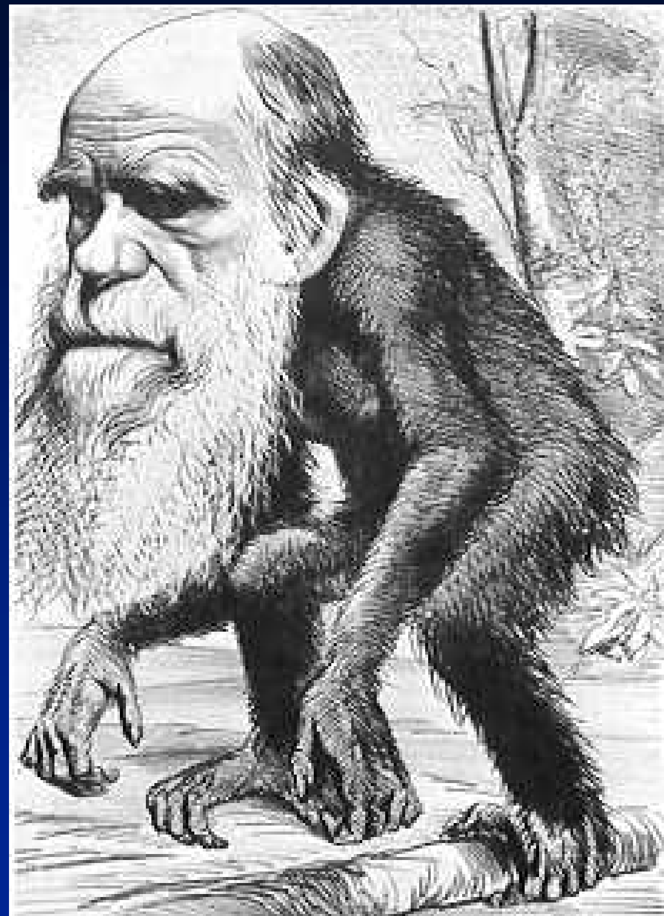




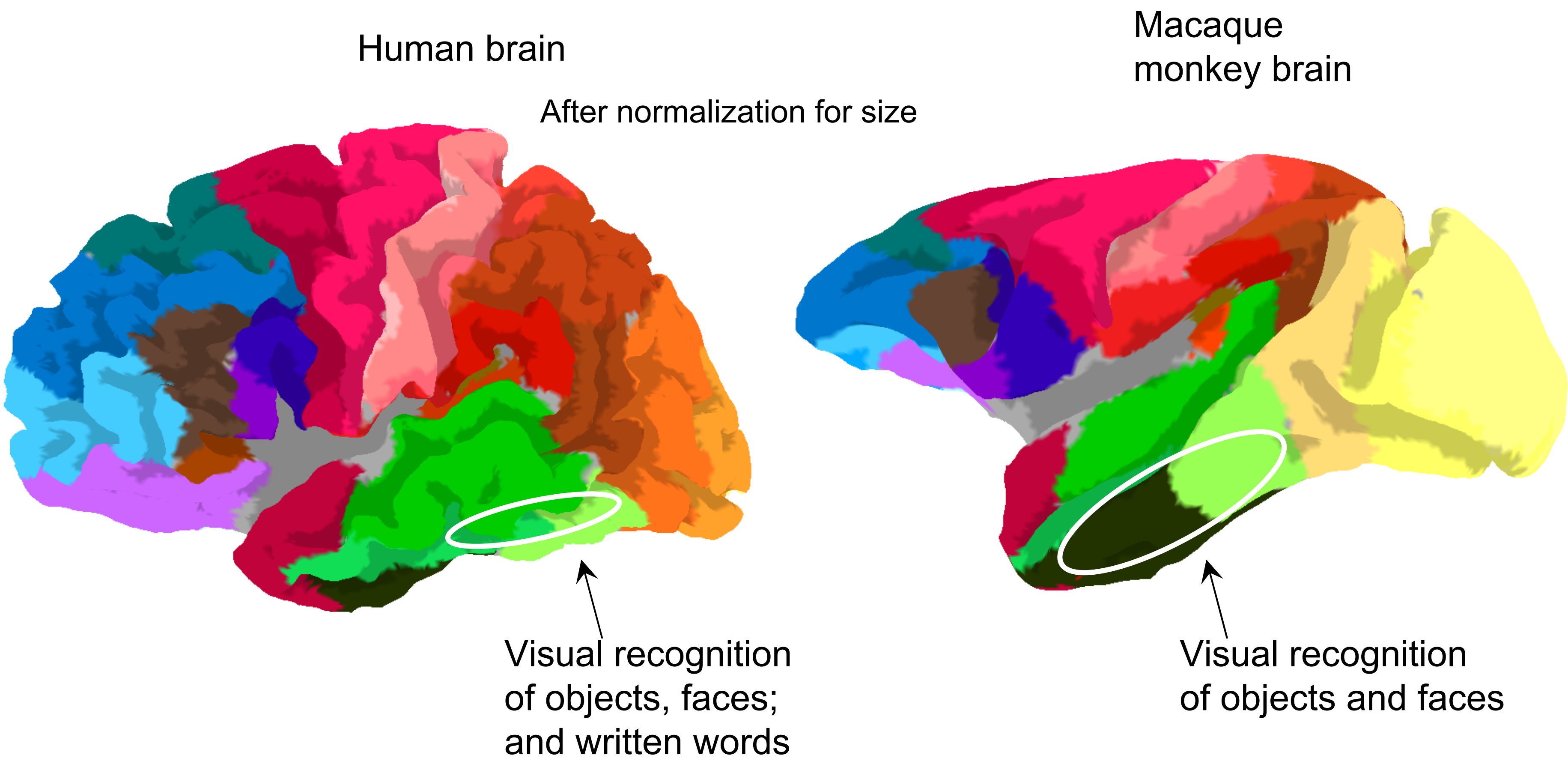
Baker, C. I., Liu, J., Wald, L. L., Kwong, K. K., Benner, T., & Kanwisher, N. (2007). Visual word processing and experiential origins of functional selectivity in human extrastriate cortex. *Proc Natl Acad Sci U S A, 104*(21), 9087-9092.

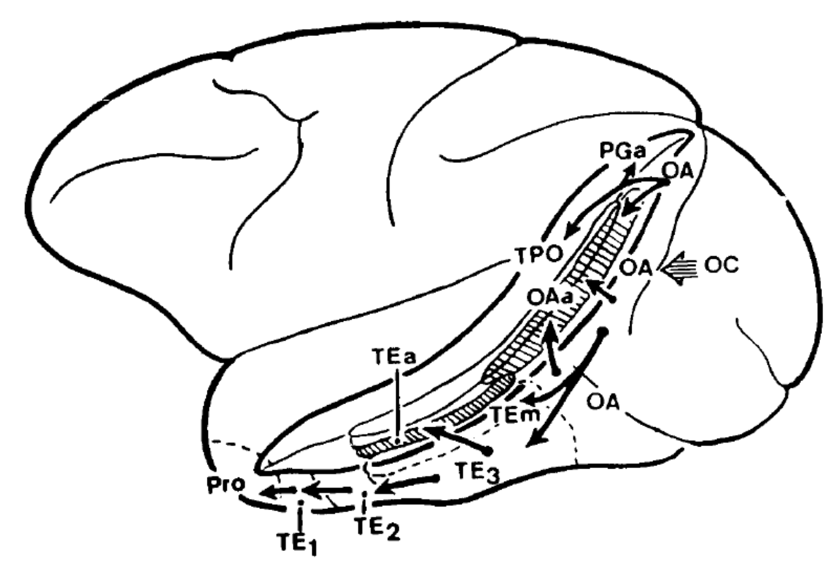
The « paradox of reading »

- All good readers activate a reproducible and restricted brain area, part of which is highly attuned to invariant visual word recognition.
- The localization of this area is reproducible across individuals and cultures (within 1 cm)
- How is this possible?
- This part of the visual system has an evolutionarily older role in object recognition. We « recycle » it for reading
- The prior properties of this region can account for some of the properties of the reading system, including
  - Hierarchical organization
  - Position and size invariance
  - Letter shapes and reading universals
  - Mirror errors



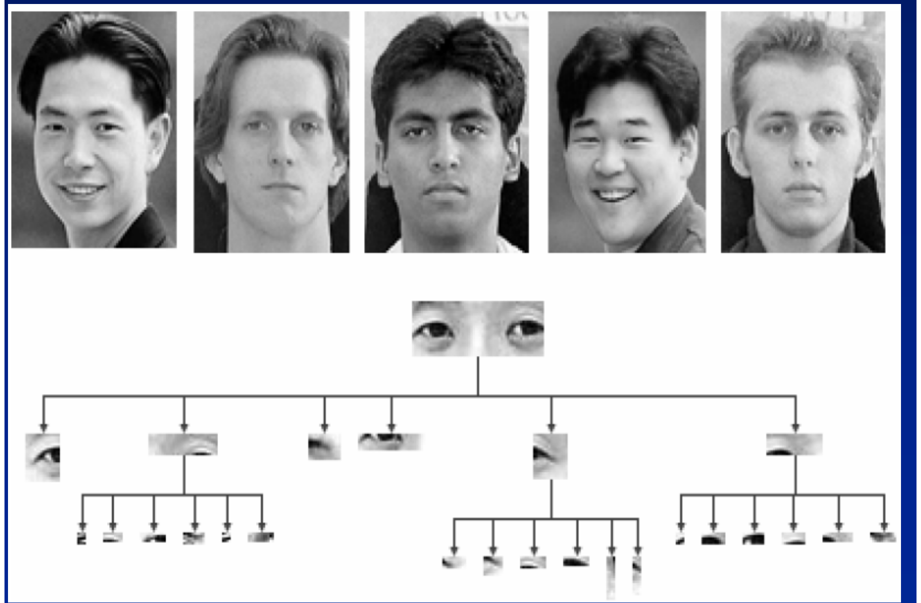
What is the prior function of the visual word form area in the monkey brain?



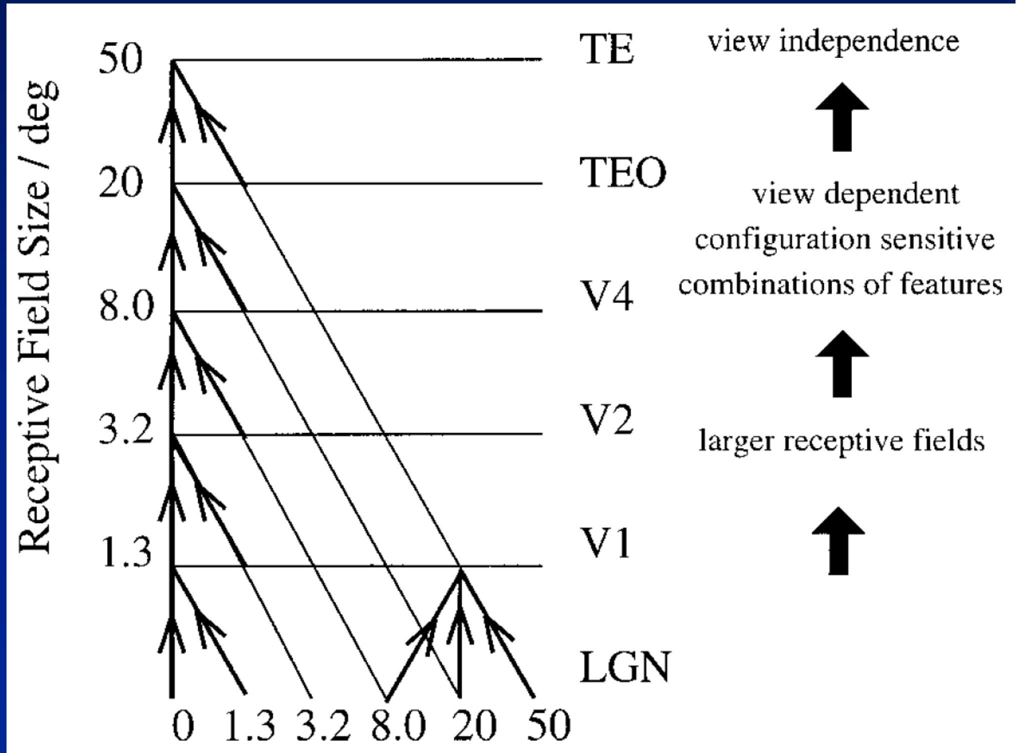


A visual hierarchy achieves invariant recognition in the primate visual system

- Rolls, *Neuron* 2000
- see also Tanaka, Logothetis, Poggio, Perrett, etc.



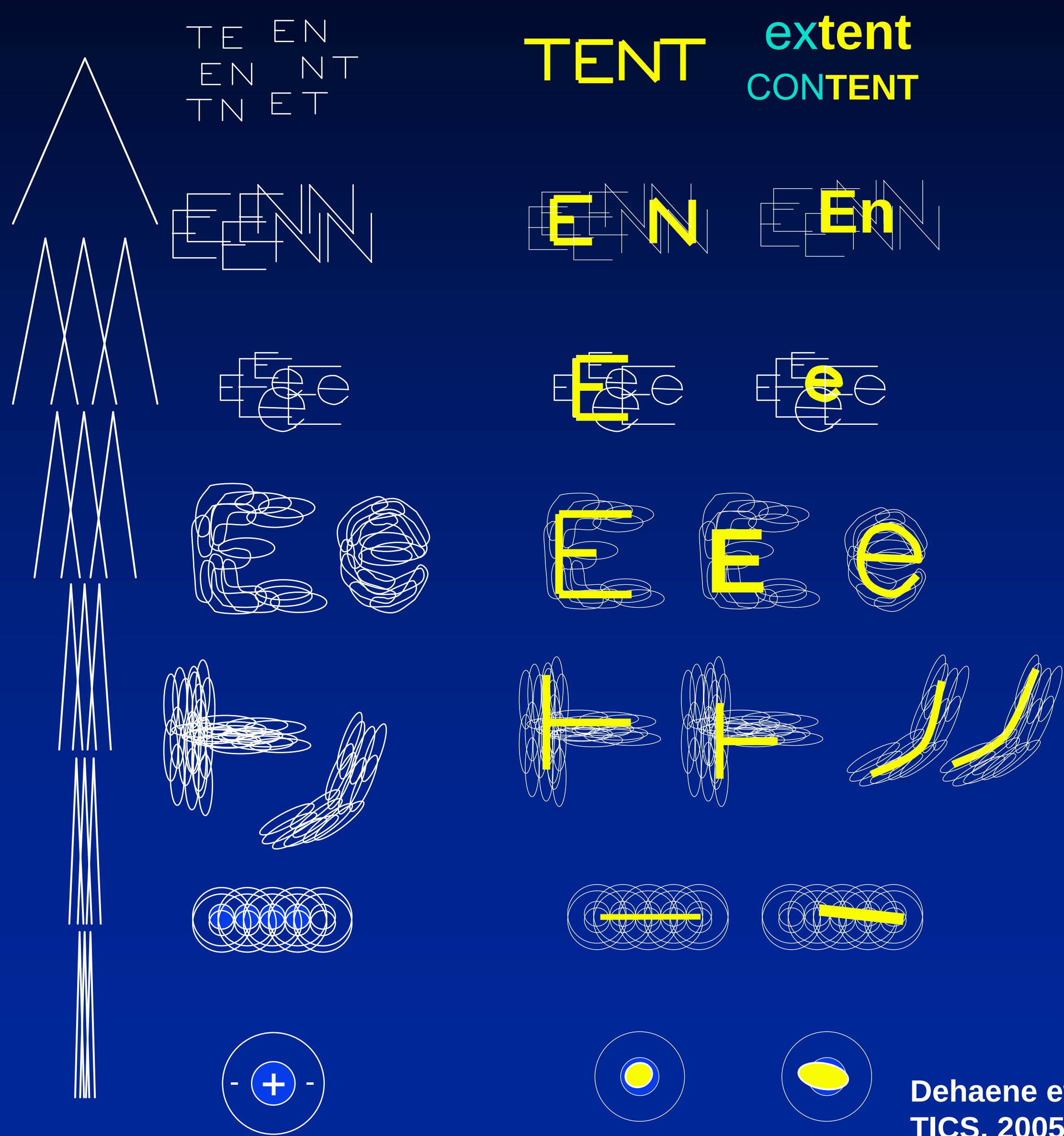
Shimon Ullman



Local Combination Detectors: A model of invariant visual word recognition

Putative area	Coded units
Left occipito-temporal sulcus? (y ≈ -48)	Small words and recurring substrings (e.g. morphemes)
Left occipito-temporal sulcus? (y ≈ -56)	Local bigrams
Bilateral V8? (y ≈ -64)	Bank of abstract letter detectors
Bilateral V4?	Letter shapes (case-specific)
Bilateral V2	Local contours (letter fragments)
Bilateral V1	Oriented bars
Bilateral LGN	Local contrasts

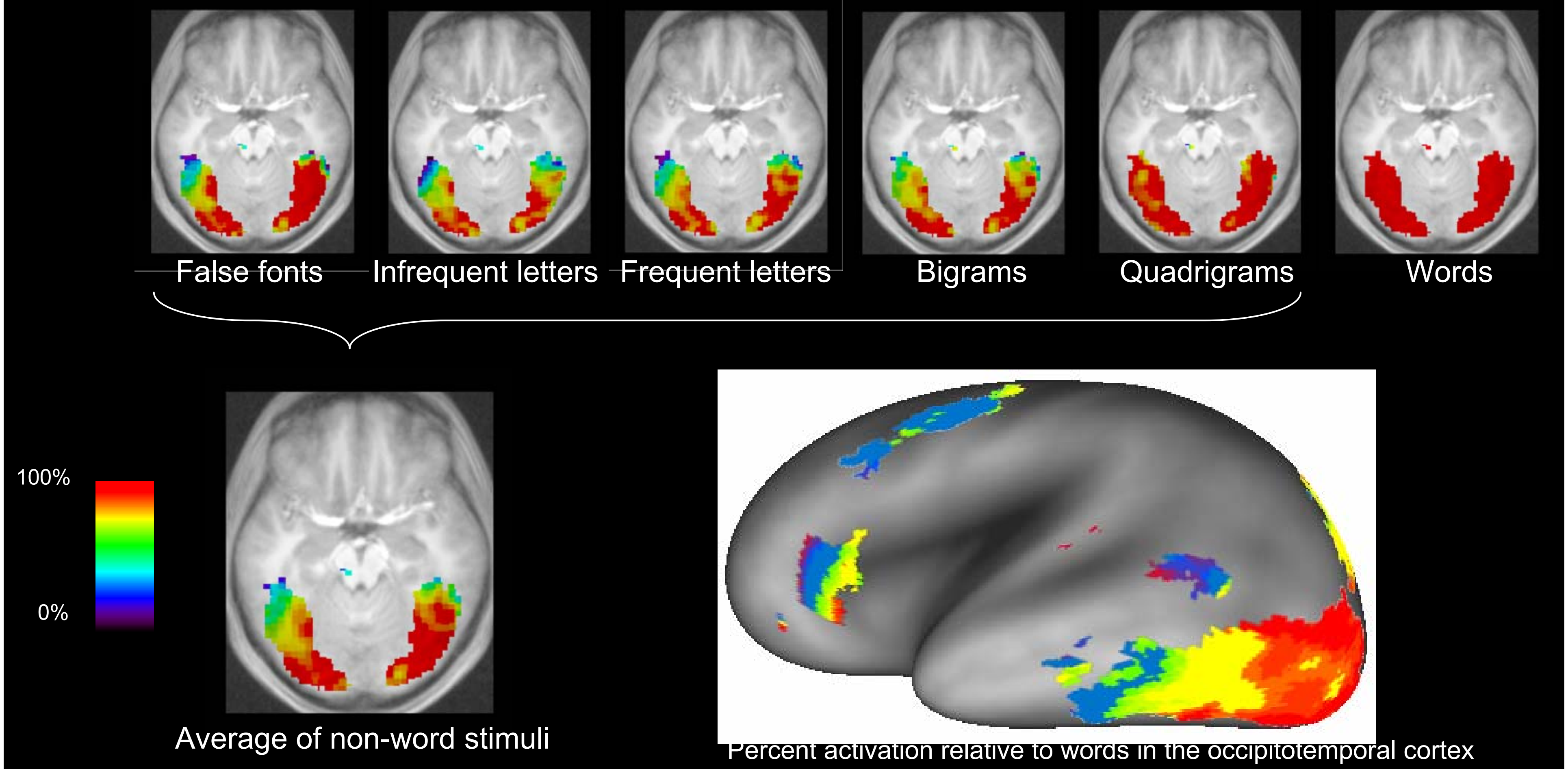
Receptive field size and structure / **Examples of preferred stimuli**



Dehaene et al. TICS, 2005

Testing the predicted hierarchical organization of the visual word form area

False Font	Infrequent Letters	Frequent Letters	Frequent Bigrams	Frequent Quadrigrams	Words
[illegible]	JZWYWK	QOADTQ	QUMBSS	AVONIL	MOUTON

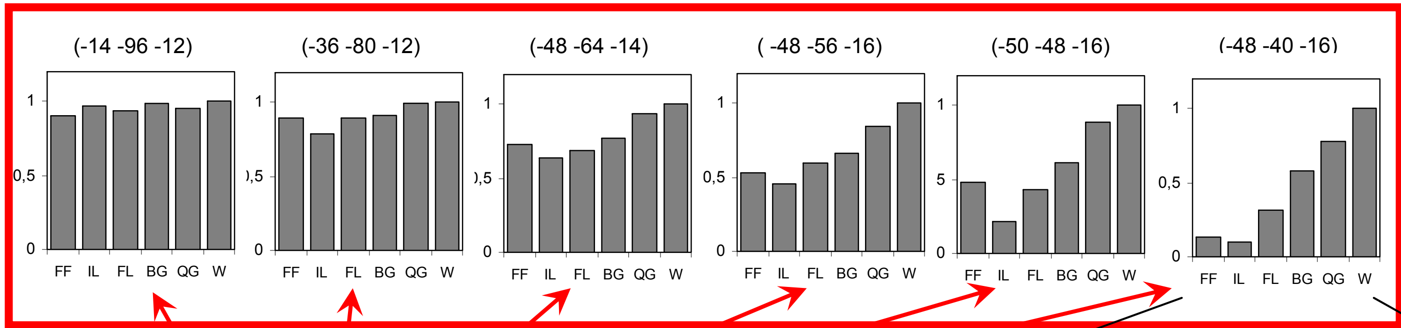


Percent activation relative to words in the occipitotemporal cortex

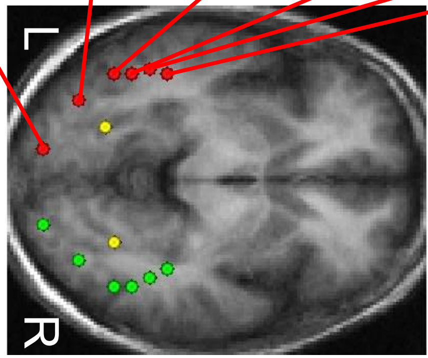
Cohen , Dehaene et al, Neuron 2007

A hierarchical organization in left occipito-temporal cortex

posterior ← **Left** occipito-temporal region → anterior

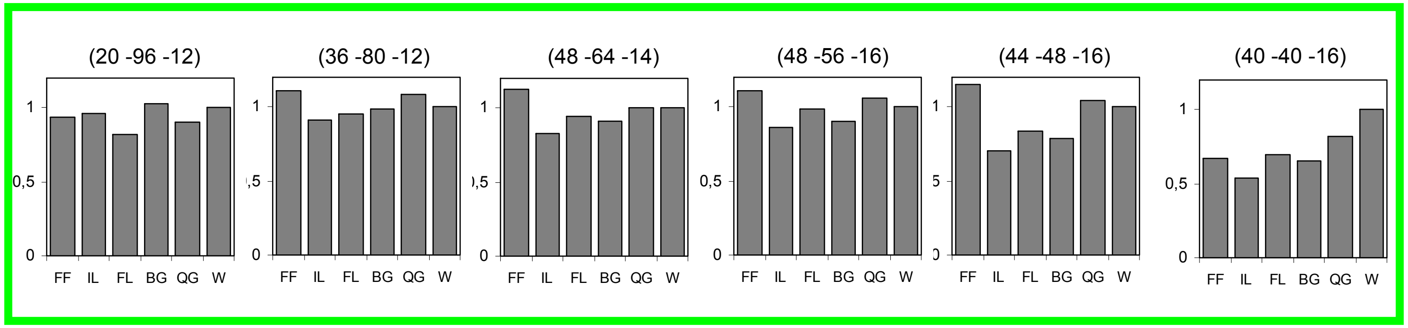


Activation level
relative to
real words
in occipito-temporal
regions of interest



False Font	Infrequent Letters	Frequent Letters	Frequent Bigrams	Frequent Quadrigrams	Words
[illegible]	JZWYWK	QOADTQ	QUMBSS	AVONIL	MOUTON

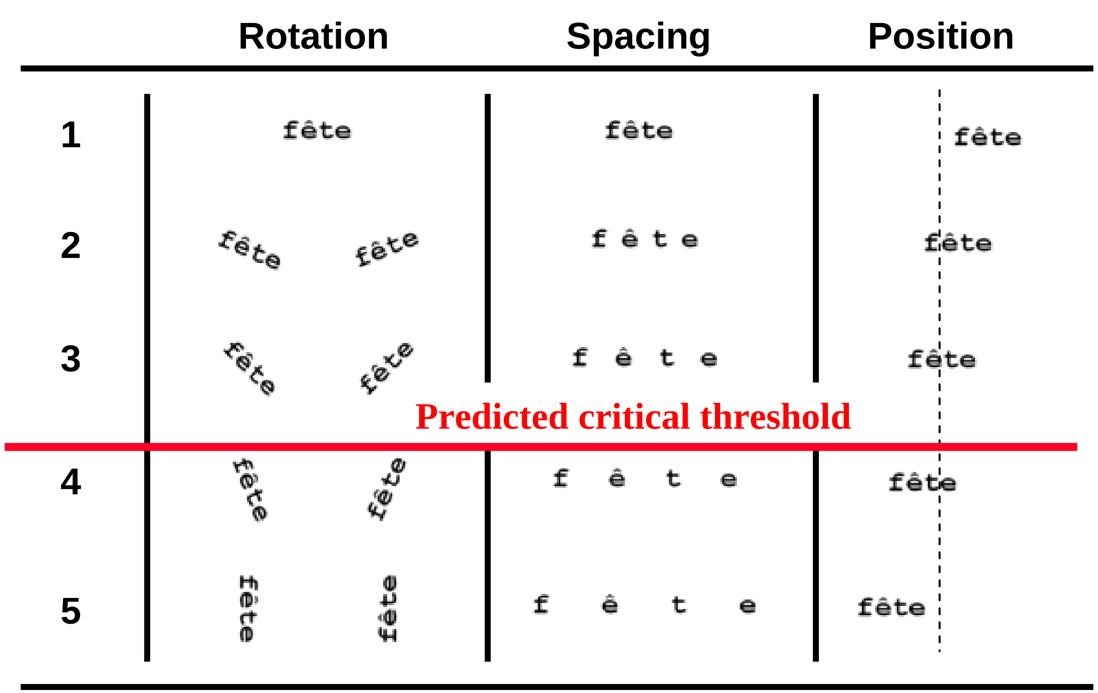
posterior ← **Right** occipito-temporal region → anterior

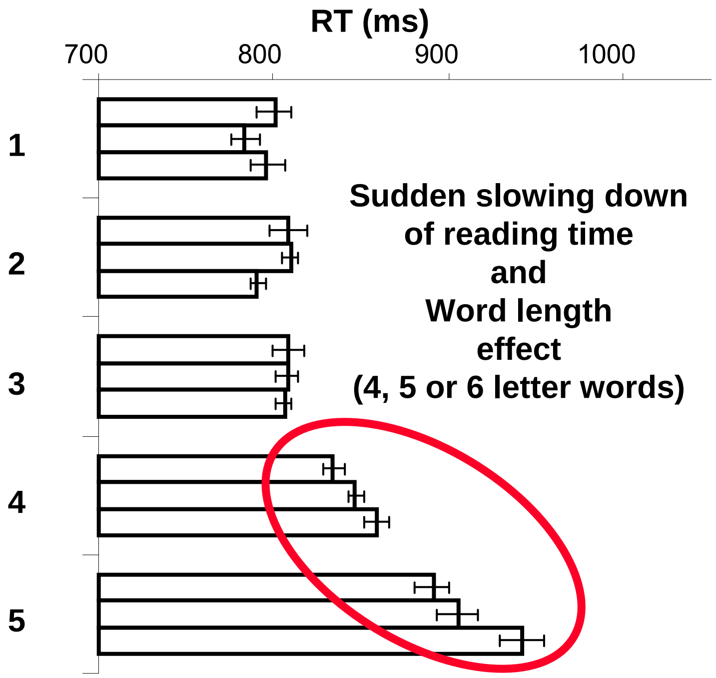


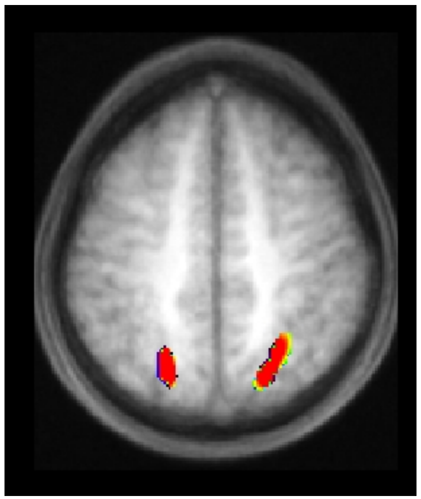
Cohen , Dehaene et al, Neuron 2007

Testing the LCD model by word degradation

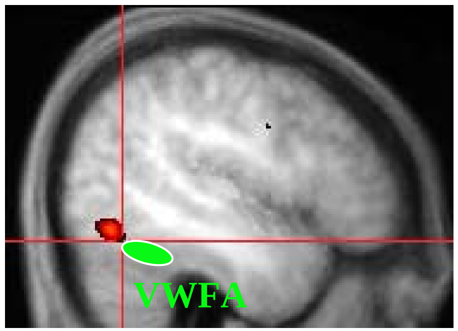
Three modes of word degradation







Sudden onset of parietal activation common to all three degradation modes



Amplification of activation in the posterior VWFA (peaking at the putative location of letter detectors)

Cohen, Dehaene, Vinckier et al, *Neuroimage 2007*

Testing the LCD model in a parietal patient

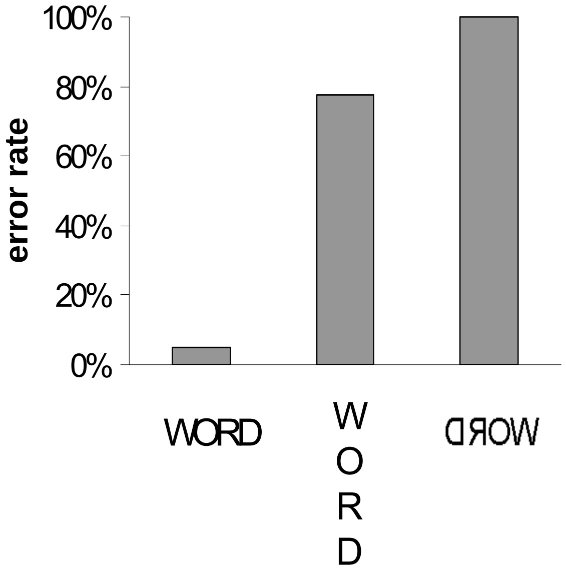
Normal ventral pathway

Impaired dorsal pathway

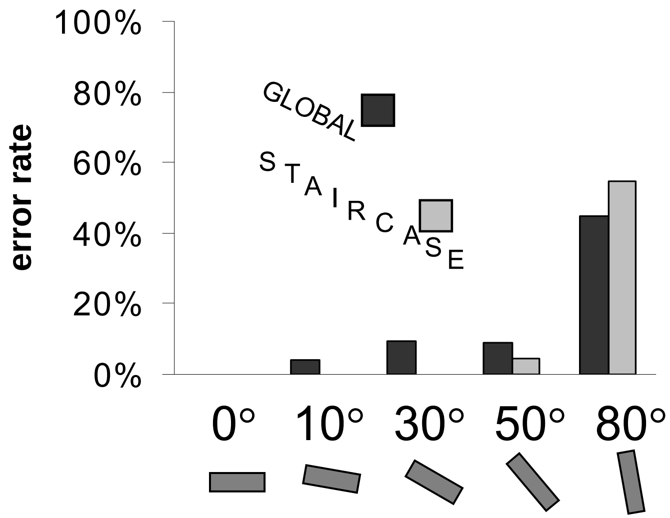
•Following a bilateral parietal degeneration, the patient became unable to deploy attention serially in space (simultanagnosia), and therefore to read letter-by-letter

•We used this case to exploit the limits of the isolated ventral visual word form system

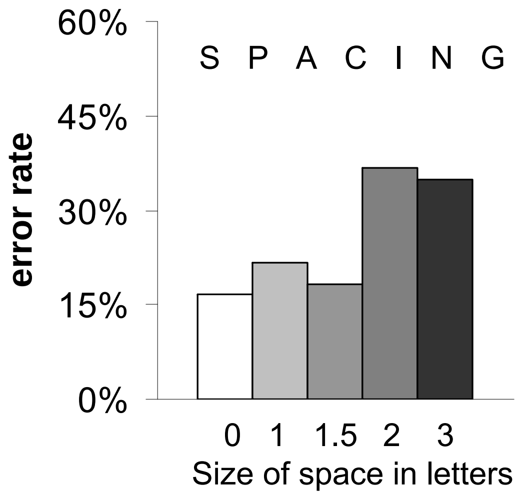
Orientation



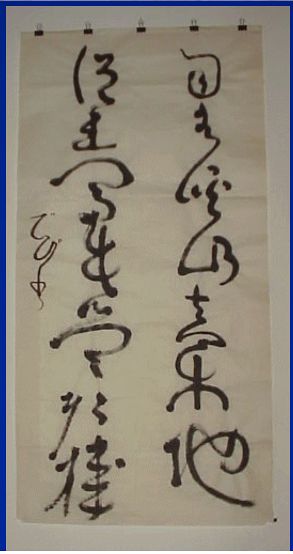
Rotation angle



Letter spacing



Vinckier, Cohen, Dehaene et al., *Journal of Cognitive Neuroscience*, 2006



Two consequences of neuronal recycling

- Prediction 1:

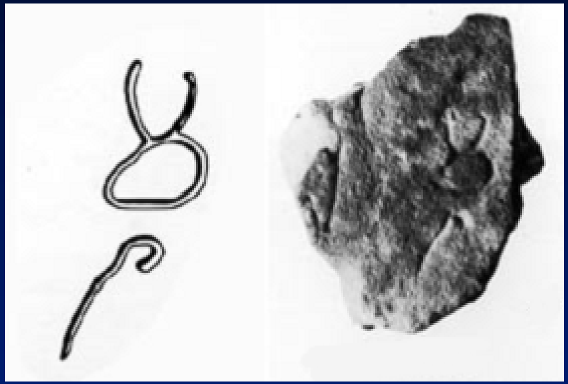
The brain did not evolve for reading – Rather, writing systems evolved to be easily learnable by the brain.

Strong cross-cultural universals should be present in writing systems, and they should be ultimately related to constraints of our brain circuitry.

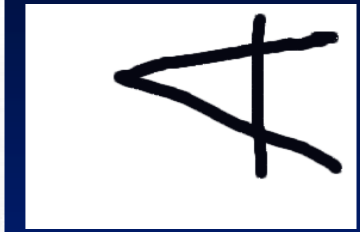
Are symbol shapes just accidents of history?

Lascaux

Proto-sinaitic

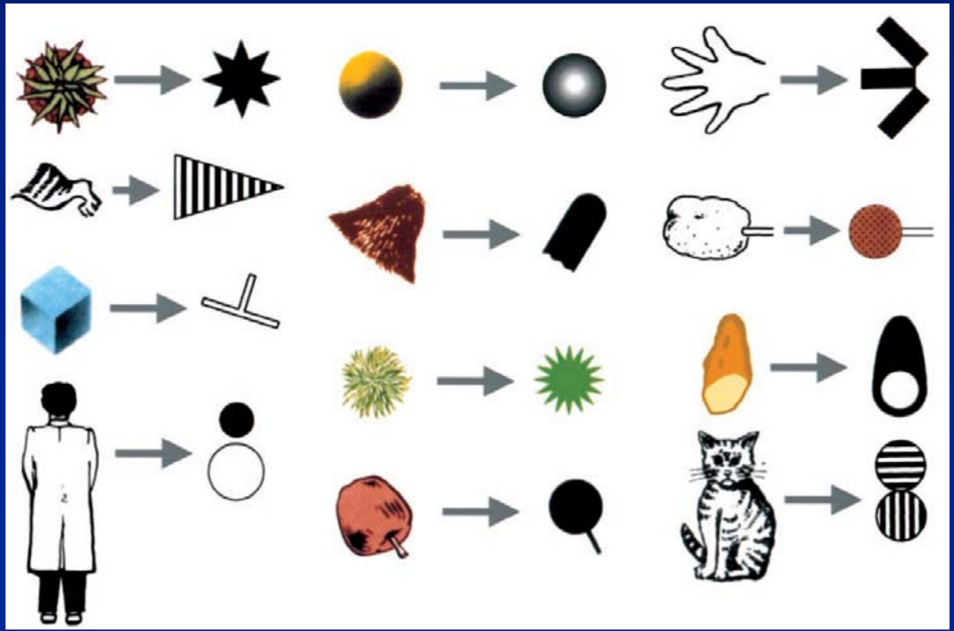


Phoenician



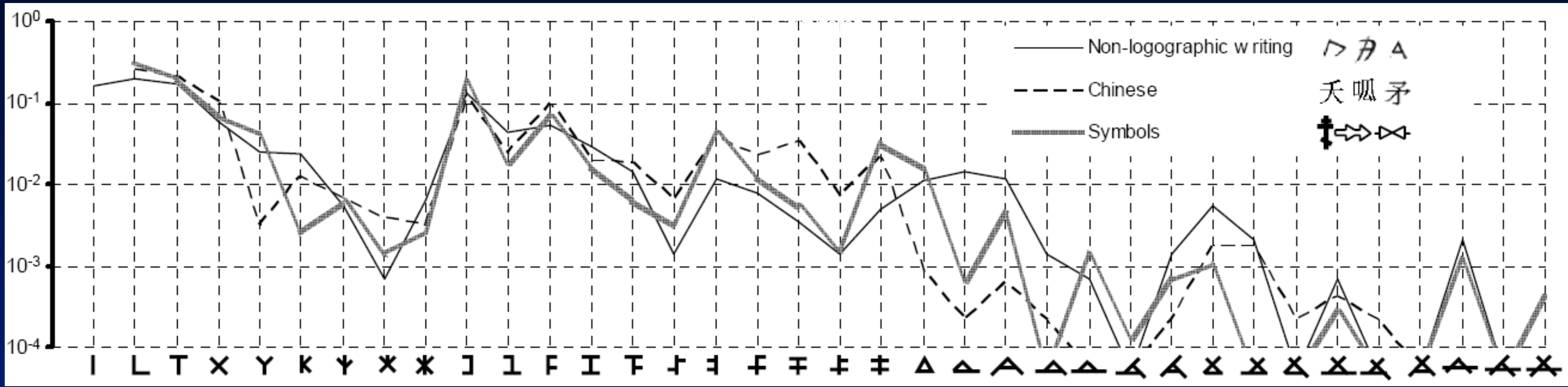
Greek / Latin

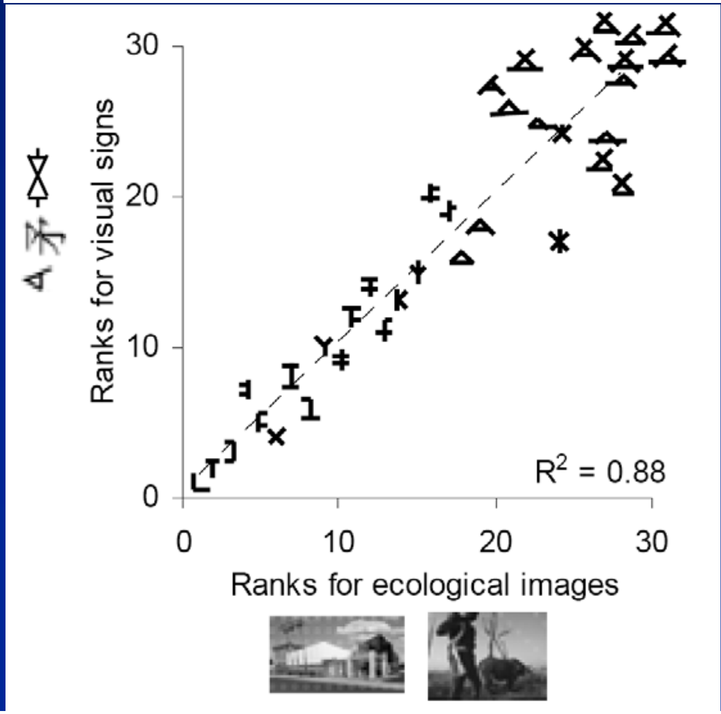
A



The topology of strokes in written symbols obeys a universal statistical distribution

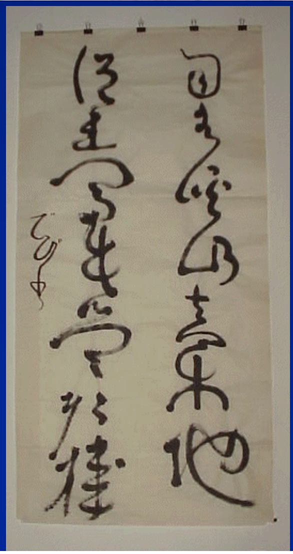
Changizi's universal distribution





Changizi's 9 most frequent configurations

Changizi & Shimojo (2005)
Changizi et al (2006)



Two consequences of neuronal recycling

- Prediction 1:

The brain did not evolve for reading – Rather, writing systems evolved to be easily learnable by the brain.

Strong cross-cultural universals should be present in writing systems, and they should be ultimately related to constraints of our brain circuitry.

- Prediction 2:

The difficulty of learning certain concepts or techniques should depend on the distance between the initial function and the new one.

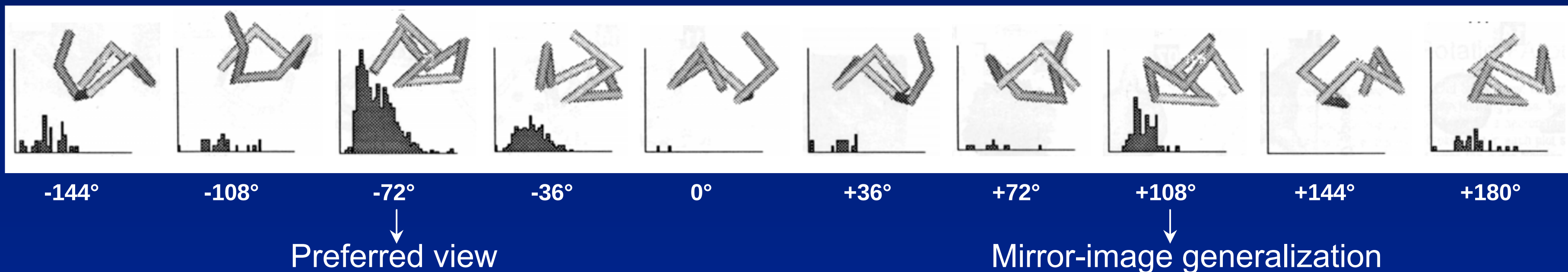
- Plasticity, invariance are all advantageous to reading acquisition

- Other features of brain organization may be detrimental to cultural learning

Symmetry generalization:
The « Panda's thumb » of cultural recycling?

• We have evolved a symmetry mechanism that helps to recognize faces and objects regardless of their orientation

• Infero-temporal neurons spontaneously generalize to mirror images

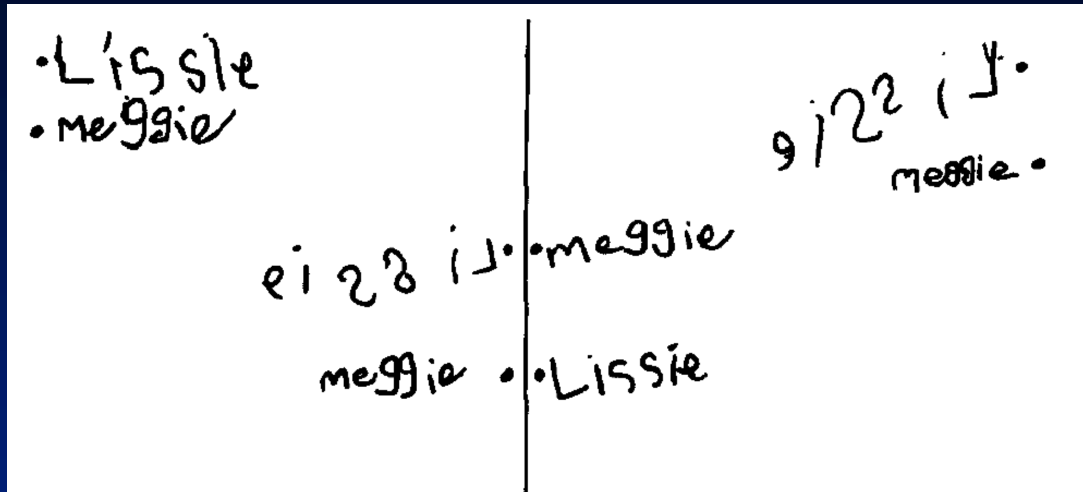


Logothetis, 1995

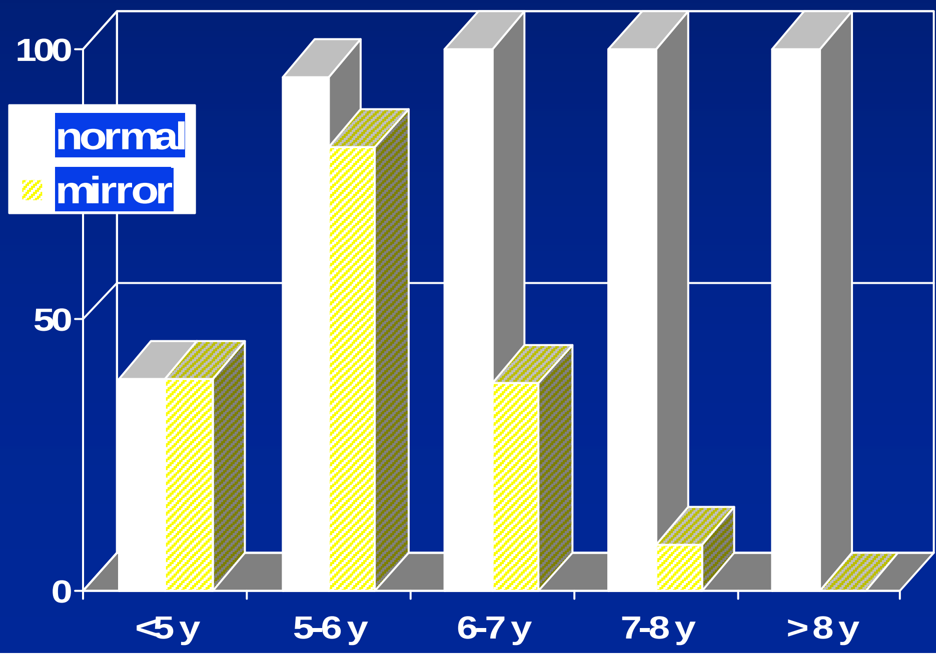
•This « symmetry generalization » may have to be **un-learned** when we learn to read

odil   libo

A trace of neuronal recycling?
A « mirror stage » in learning to read



% children able to write their name

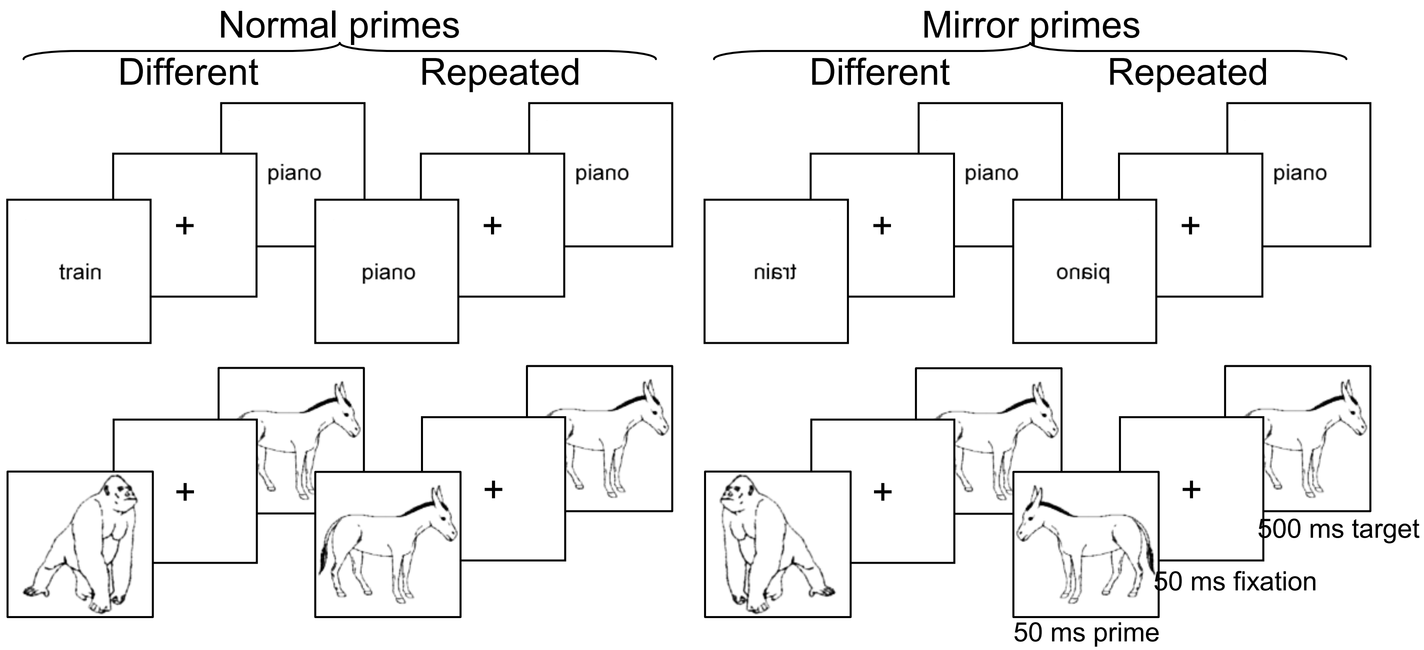


Children's age

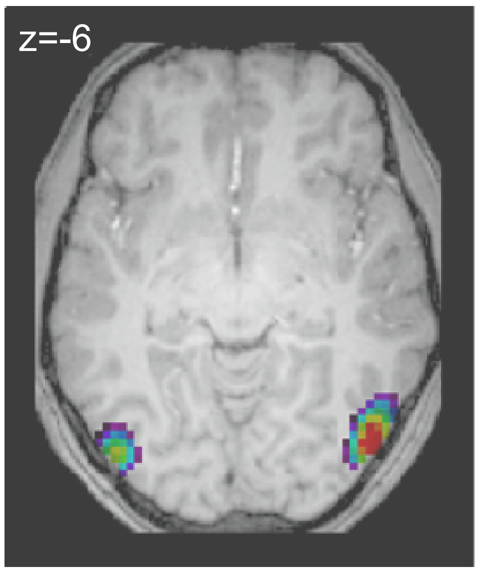
(Data from Cornell, 1985)

« Unlearning » of symmetry in the visual word form area

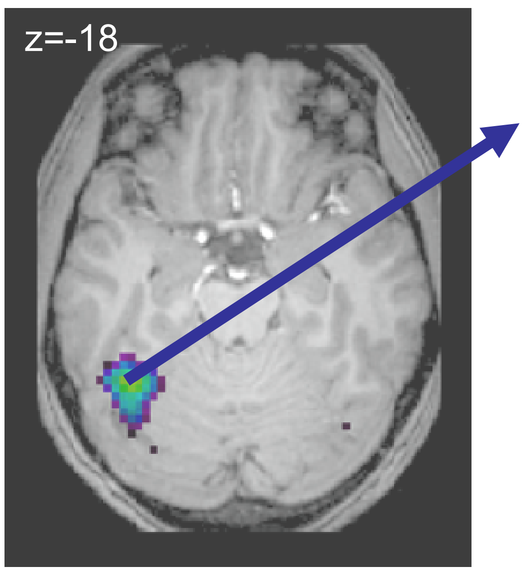
Dehaene et al., in preparation

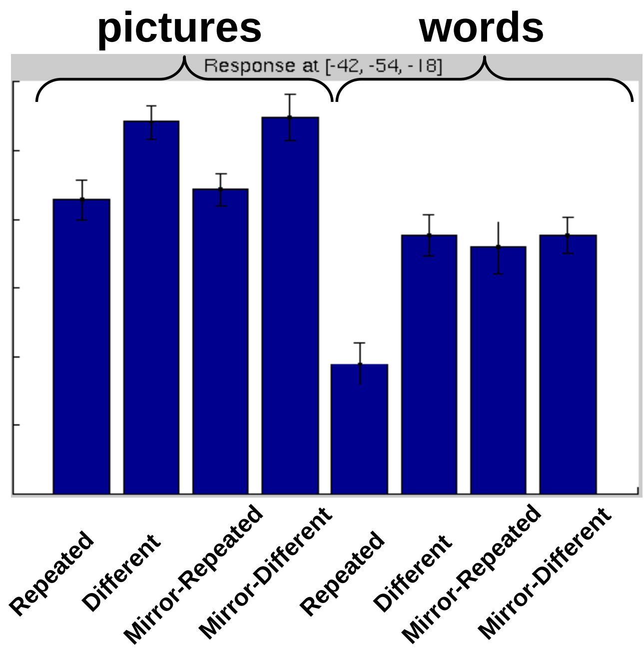


Picture repetition priming



Word repetition priming





Conclusions

- Although writing is a recent cultural invention and shows a large degree of cultural variation, reading acquisition is not « the furnishing of the mind's white paper » (Locke)
- We are able to learn to read because we inherit from evolution an efficient object recognition system with enough plasticity to learn new shapes, and with the relevant connections to link these shapes to existing language areas.
- Cultural evolution can be viewed as a slow discovery of the optimal stimulus for our occipito-temporal system (yet the system remains sub-optimal, as attested by the example of mirror symmetry)
- The acquisition of reading slowly specializes many neurons of this region to create an efficient hierarchical « visual word form system »
- We all learn to read with a similar brain architecture. Cognitive neuroscience data are therefore relevant for the teaching of reading.