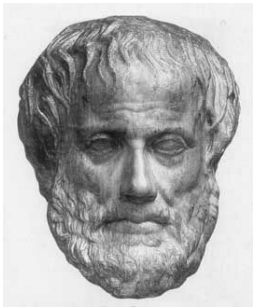
Invited speech. Oxford University (ALFAL-NE III). 21-22 June 2006

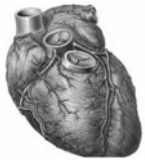
Brain and Language:
The Neural representation of Words and their Meaning

Julio González Ph D
Dpt. Psicología Básica, Clínica y Psicobiología
Universidad Jaume I. Castellón.

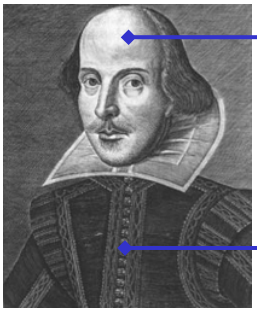
1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions
   - Intact Brain
2. WORDS and NEURAL WEBS
   - Functional webs
   - Word webs
   - Referential meaning and cortex

1. BRAIN and LANGUAGE
   - Brain and cortex: some features





Aristotle



reason

emotion

W. Shakespeare

"cuerdo"

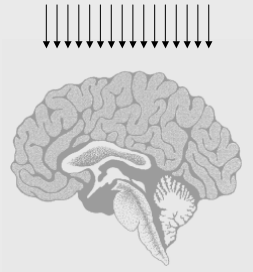
"recordar"

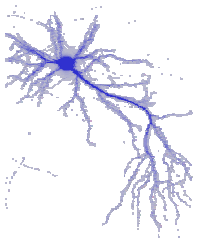
"record"

"recuerdo"

COR
(corazón, heart) (latín)

"de memoria" = "by heart"

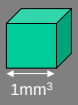




neuron

10^{11} = 100.000 million

each one:
10.000 connections (synapses)



1mm^3

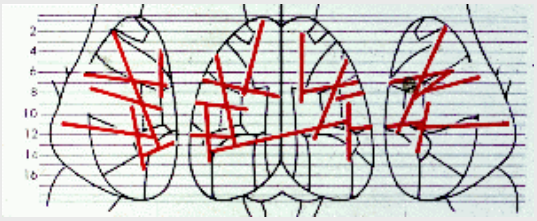
20.000 – 100.000 neurons

through:
4 km. axons
800.000.000 synapses

(Abeles, 1991, 2004; Braitenberg & Shuez, 1998)

- parallel
- distributed

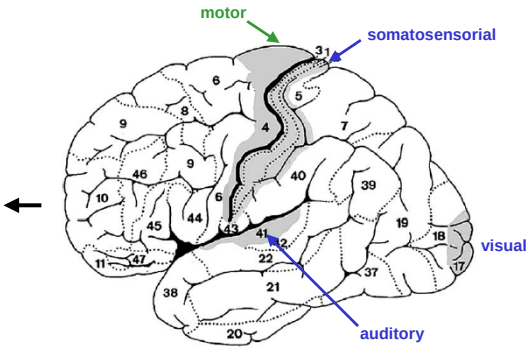
- serial
- local



Karl S. Lashley

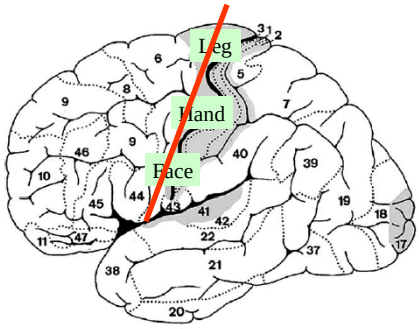
- parallel
- distributed
- massive

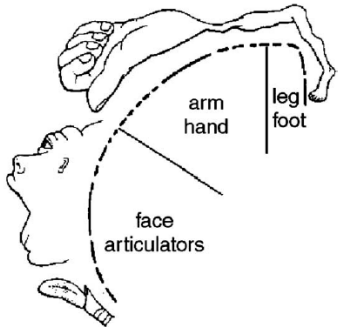
- serial
- local
- nonmassive



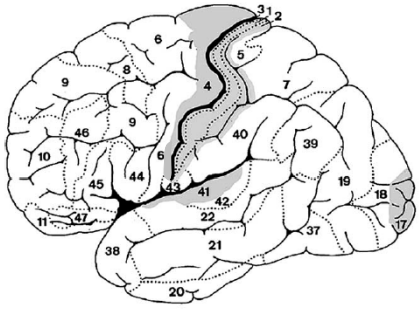
Primary areas: **input**, **output**

(Brodmann, 1909; Pulvermüller, 2002)





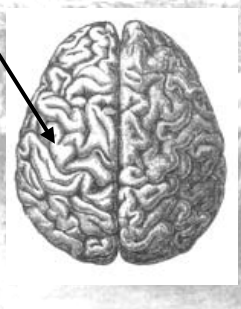
(Penfield & Rasmussen, 1950; Pulvermüller, 2002)



1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions

Language Laterality

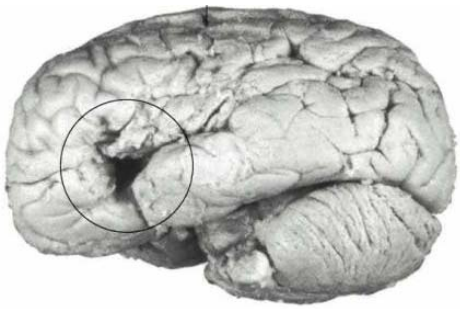
dominant cerebral hemisphere (left)

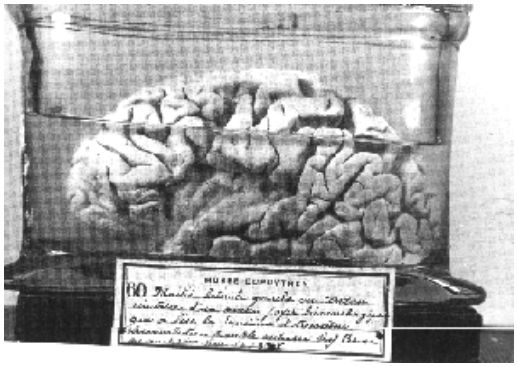


Paul Broca

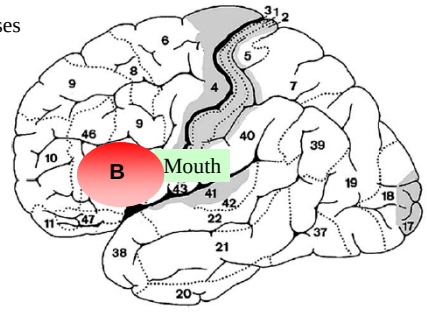
- 1861: monsieur “Tan”

Leborgne’s (*Tan’s*) brain



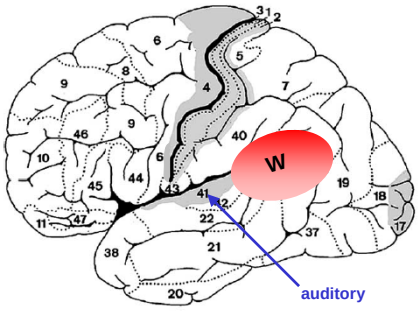


19 cases

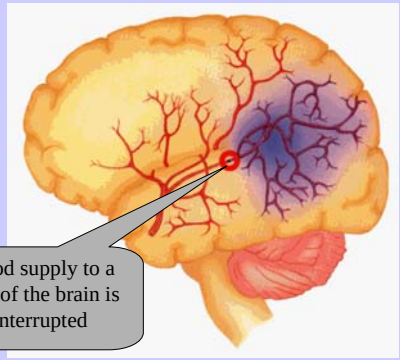


Carl Wernicke

1874: case



Contemporary Examples (Strokes)



Broca's Aphasia

P: ¿Cuántos años tienes? (43)

[Q: How old are you? (43)]

Broca's Aphasia

Difficulty to say:

"cuarenta y tres"

No problem with individual motor gestures (lips, tongue, etc.)

Broca's Aphasia

Q: ¿piso? (7)
Q: ¿puerta? (14)

[Q: floor? door?]

Broca's Aphasia

Difficulty to say:

"siete" "catorce"

Compensatory strategies:

" 1, 2, 3, 4, 5, 6, 7 "

Broca's Aphasia

Naming task:

(codo , muñeca)

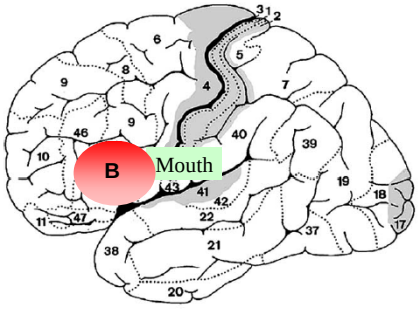
[elbow , wrist]

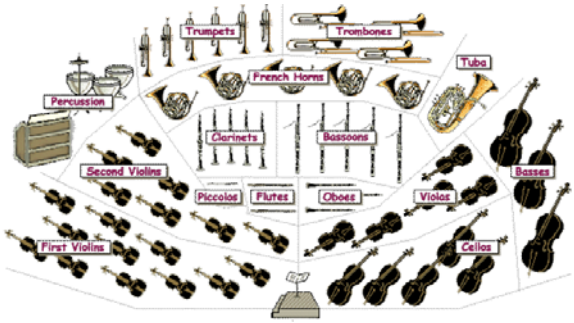
Broca's Aphasia

Comprehension?: Fairly good, but...

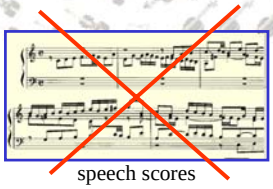
difficulty with grammatically complex sentences:

"¿cuanto hace que no vienes por aquí?"





individual muscular groups: Ok.



speech scores

Wernicke's Aphasia

a more central damage

This patient:

L1: Valencian (Catalan)

L2: Spanish

Wernicke's Aphasia

Very poor Comprehension:

Toque un círcul

[Touch a circle]

Wernicke's Aphasia

Very poor Comprehension:

Toque una fitxa groga

[Touch a yellow token]

Wernicke's Aphasia

Very poor Comprehension:

P: On viu vosté?

[Q: Where do you live?]

Wernicke's Aphasia

Diffficulty understanding:

- language of <u>others</u>
- <u>own</u> language (thought organization)

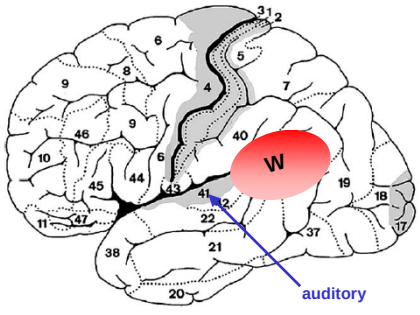
Wernicke's Aphasia

Fluent speech but meaningless:

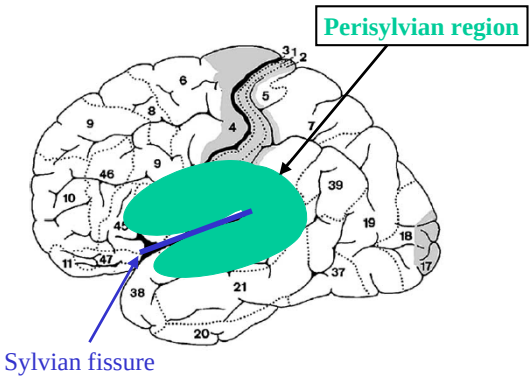
- Paraphasias and Neologisms
- Intrusive material:

"Jo soc Valencià"

[I am Valencian]



CLASSICAL LANGUAGE AREAS



Brain lesions:

- Valuable source of evidence
- Shortcomings:
  - uncontrolled and unique (N=1)
  - several subsystems and connections between remote areas can be damaged

1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions
   - Intact Brain

Intact Brain:

- Modern neurophysiological and Neuroimagen techniques

good temporal resolution (ms):

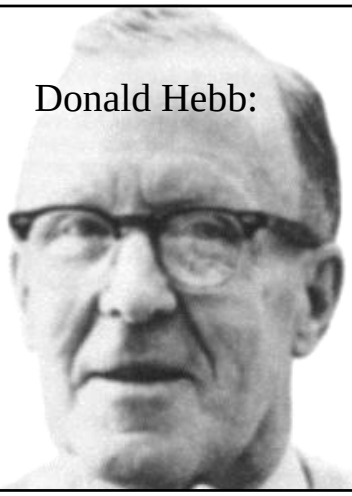
- **EEG / ERP** (event-related potentials)
- **MEG** (magnetoencephalography)

good spatial resolution (mm^3):

- **PET** (positron emission tomography)
- **fMRI** (functional magnetic resonance imaging)

1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions
   - Intact Brain
2. WORDS and NEURAL WEBS
   - Functional webs

Donald Hebb:



Donald Hebb:

"Any two cells or systems of cells that are repeatedly active at the same time will tend to become 'associated', so that activity in one facilitates activity in the other"

(Hebb, 1949, p.70)

correlation learning principle

localizationists

"cell assemblies"

synchronously activated neurons should link into cell assemblies underlying cognitive processes

holistic approach

The question whether cell assemblies exist in cortex has long been believed to be impossible to test by empirical research.

However, more recent experimental work provided strong evidence for the Hebbian ideas.

(Pulvermüller, 1999)

functional Web:

a set of neurons that:

(1) are *strongly connected* to each other

(2) are *distributed* over a specific set of cortical areas

(3) work together as a *functional unit*

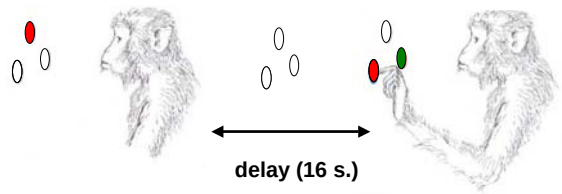
(4) whose major parts are *dependent* of each other

Pulvermüller (2003)

functional Web

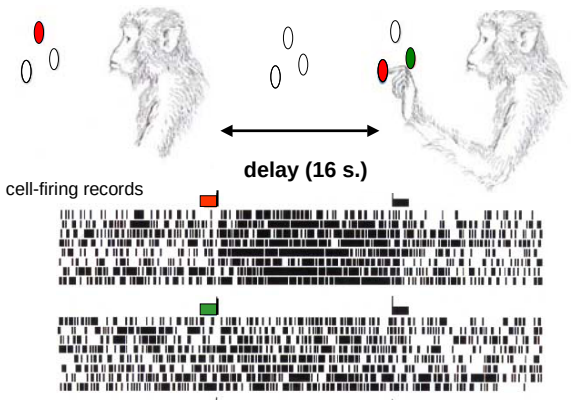
two activity states:

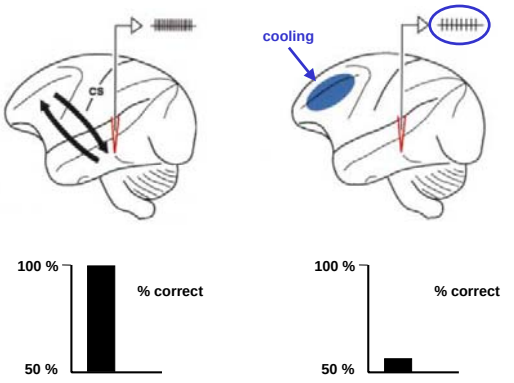
- ignition (full activation) (Braitemberg, 1978)
- reverberation (Abeles et al., 1991, 1992)



delayed match-to-sample (DMS) task

Fuster (1997); Fuster & Jervey (1982)





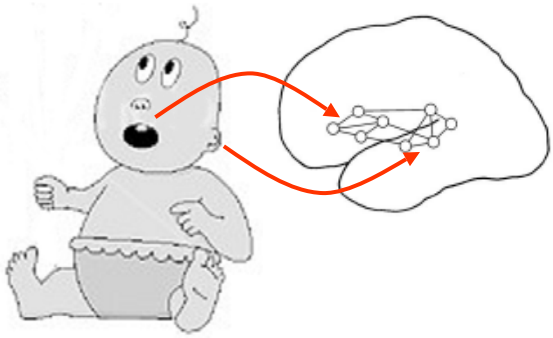
1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions
   - Intact Brain
2. WORDS and NEURAL WEBS
   - Functional webs
   - Word webs

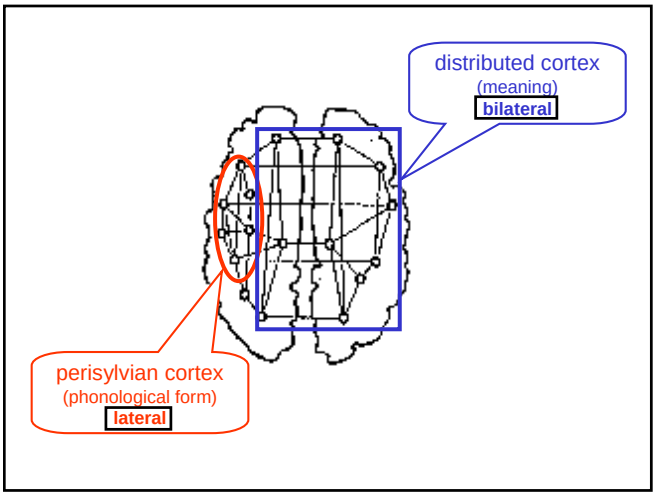
Word Webs:

Words are processed by distributed neuronal webs with cortical topographies that reflect their meanings

This rules out a unified "meaning center"

Friedemann Pulvermüller
Medical Research Council (MRC). Cambridge, UK





Evidences of word webs

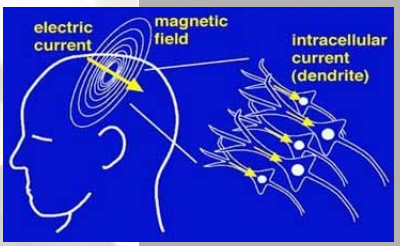
ERP (Event-related Potentials)

Words

Pseudowords

MEG (Magnetoencephalography)

MEG (magnetoencephalography)



Words: activity in the *gamma* band (>25 Hz)

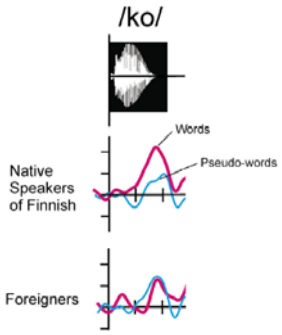
(Eulitz et al., 2000; Krause et al., 1998; Pulvermüller, et al., 1996)

Finnish:

"lakko" (strike)

"vakko" (.....)

acoustic waveform



Mismatch negativities (MMNs) elicited by /ko/. Pulvermüller, Kujala, et al. (2001).

Mismatch negativities (MMNs) elicited by /ko/. Pulvermüller, Kujala, et al. (2001).

brain response to a word:
(full activation of a word web)

- early (200 ms)
- automatic (attention is not necessary)

1. BRAIN and LANGUAGE
   - Brain and cortex: some features
   - Lesions
   - Intact Brain
2. WORDS and NEURAL WEBS
   - Functional webs
   - Word webs
   - Referential meaning and cortex

Referential meaning and cortex:

Word use in the context of objects and actions leads to associations between neurons in the language areas and additional neurons in areas processing information about the word's referents

Pulvermüller (2003)

Referential meaning and cortex:

additional neurons in areas processing information about the word's referents

their cortical distribution is determined by the referent

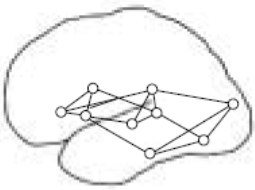
Visually related words

other animals

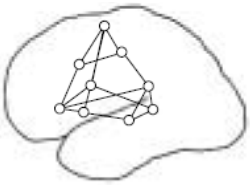
Action related words

tool names / verbs

Visually related words



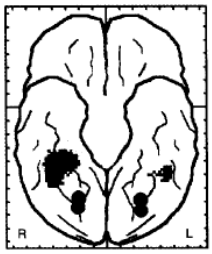
Action related words



Martin, Wiggs, et al., (1996); Pulvermüller, Lutzenberger, et al., (1999).

COLOR NAMES

“green”
“red”
“blue”
.....



PET

Martin, Haxby, et al., *Science* (1995).

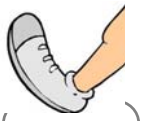
Neuropsychological patient studies:

Nouns and verbs, animal and tool names are differentially affected by brain damage.

(Damasio & Tranel, 1993; Daniele et al., 1994; Humphreys & Borde, 2001; Miceli et al., 1984, 1988; Warrington & McCarthy, 1983; Warrington & Shallice, 1984; etc.)

more fine-grained predictions:

- Action verbs (body parts)



to walk
to kick
to run
to jump
to wander
.....

to pick
to applaud
to comb
to grab
to draw
.....

to kiss
to bite
to blow
to chew
to yawn
.....

Hauk, Johnsrude, & Pulvermüller, 2004

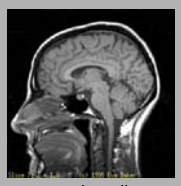
to pick

passive reading task

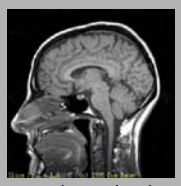
Hauk, Johnsrude, & Pulvermüller, 2004

functional Magnetic Resonance Imaging (fMRI)

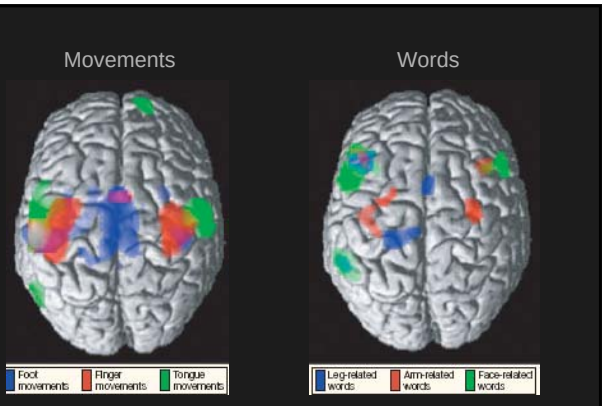
functional Magnetic Resonance Imaging (fMRI)



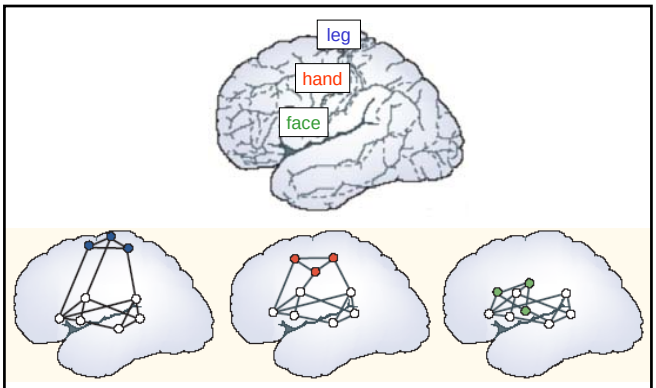
rest or baseline



experimental task



Pulvermüller, *Nature Reviews Neuroscience* (2005).

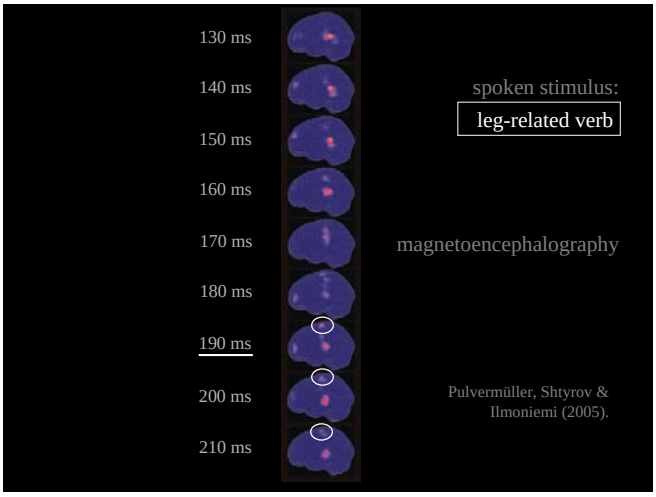


to kick = chutar

to pick = coger

to kiss = besar

Pulvermüller, *Nature Reviews Neuroscience* (2005).



Information about the body parts with which actions are being carried out may be woven into the word-related cortical networks.

Words are represented and processed by functional webs in which information about a word's form and that about its semantics are interwoven.

- "Olfactory" words
  odour-related words

Universidad Jaume I. Castellón (Spain)

rating words according to their olfactory associations

18 people

1 2 3 4 5 6 7

no or very weak associations

very strong associations

60 *olfactory* words	60 control words
• ajo (garlic)	• nube (cloud)
• canela (cinnamon)	• gafas (glasses)
• cloaca (sewer)	• pinza (hairgrip)
• flor (flower)	• aguja (needle)
• colonia (cologne)	• tambor (drum)
• sobaco (armpit)	• letra (letter)
• ……..	• ……..
mean rate (1-7) = **6.0**	mean rate (1-7) = **1.2**

60 *olfactory* words	60 control words
• ajo (garlic)	• nube (cloud)
• canela (cinnamon)	• gafas (glasses)
• cloaca (sewer)	• pinza (hairgrip)
• flor (flower)	• aguja (needle)
• colonia (cologne)	• tambor (drum)
• sobaco (armpit)	• letra (letter)
•	• .....
mean rate (1-7) = **6.0**	mean rate (1-7) = **1.2**

ajo

passive reading task

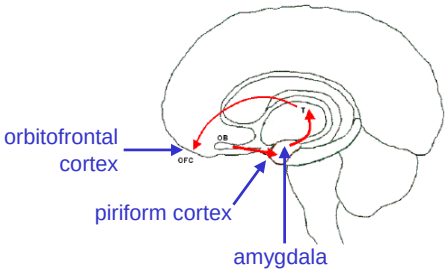
750 milliseconds

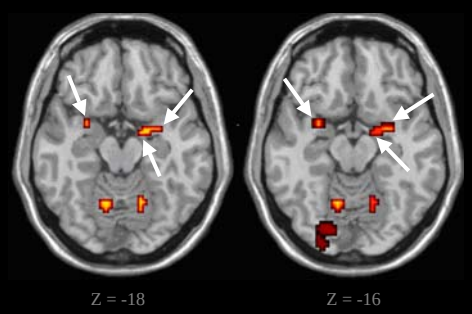
Siemens Avanto 1.5 tesla

Hospital General Castellón (ERESA)

23 participants

Odour processing:
main pathways





Z = -18 Z = -16

Brain activation reading *olfactory* words (minus control words)

González, Barros, PulverMüller, et al., (2006).

Our results suggest that reading odour-related words elicits activation of olfactory brain regions

This fact is compatible with a theoretical framework according to which words are processed by distributed cortical systems involving information about the referential meaning.

NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 32 (2006) 906 – 912

Reading *cinnamon* activates olfactory brain regions

Julio González,[a,*] Alfonso Barros-Loscertales,[a] Friedemann Pulvermüller,[b] Vanessa Meseguer,[a] Ana Sanjuán,[a] Vicente Belloch,[c] and César Ávila[a]

[a]*Department Psicología Básica, Clínica y Psicobiología, Universitat Jaume I. 12071-Castellón de la Plana, Spain*
[b]*MRC Cognition and Brain Sciences Unit, Cambridge, UK*
[c]*Servicio Radiología, ERESA, Castelló, Spain*

Further Research:

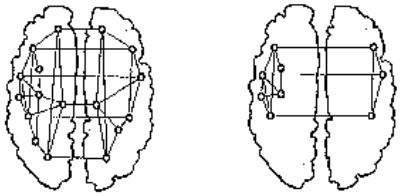
- to determine the point in time when olfactory activation arises, and whether this activation occurs automatically and immediately as part of the semantic processing.
- role of the hedonic valence (pleasant vs unpleasant odour).

CONCLUSION:

Data suggest that word meaning is not confined to just meaning-specific brain regions; rather, it seems likely that semantic representations are distributed in a systematic way throughout the entire brain.

E N D

content word **function word**



Pulvermüller (1999)