Contribution of the Visual Word Form Area to speech processing: When and how?

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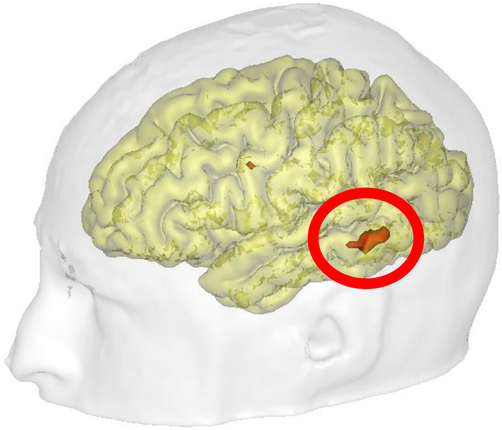
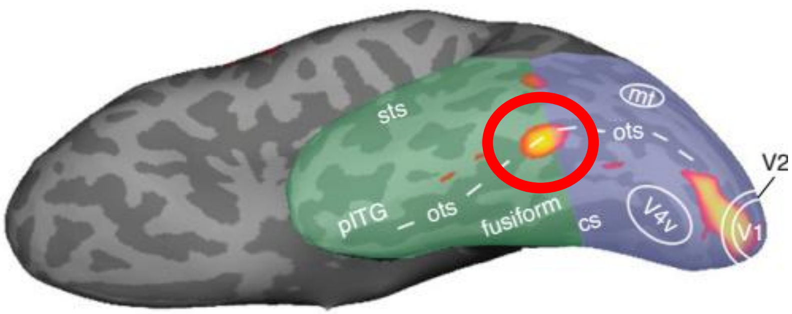
Visual Word Form Area & Reading



Dehaene et al., 2001



Price & Devlin 2011

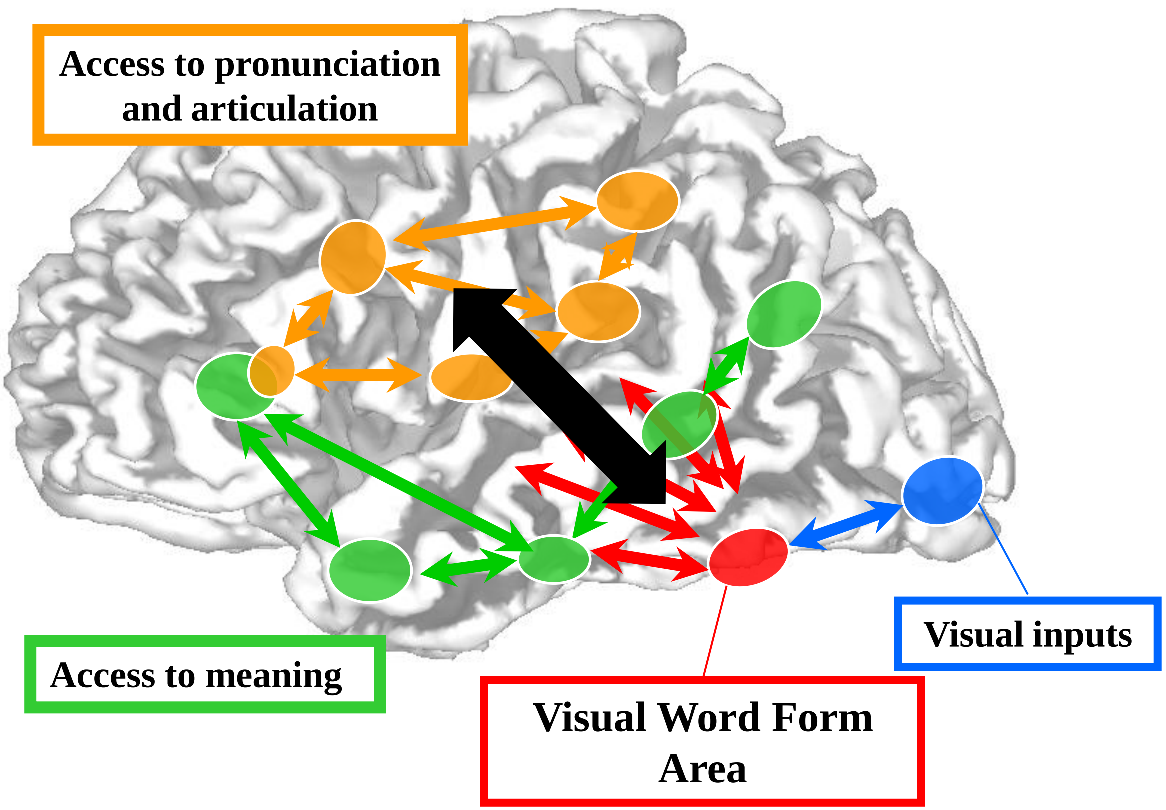
Centred on the occipito-temporal sulcus at the transition from the occipital to the temporal lobe.

Its functional role emerges with reading acquisition. The activation level depends on reading expertise (Brem et al. 2010; Dehaene et al., 2010).

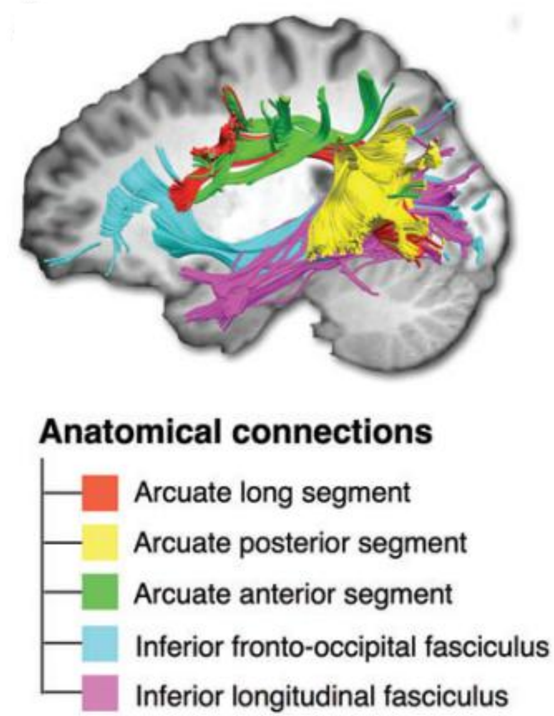
Play a critical role in reading (Duncan et al. 2009; Gaillard et al., 2006)

Reproducible activity across writing systems and individuals (Bolger, Perfetti & Schneider, 2005; Rueckl et al., 2015)

Neural model of reading



Dehaene 2009

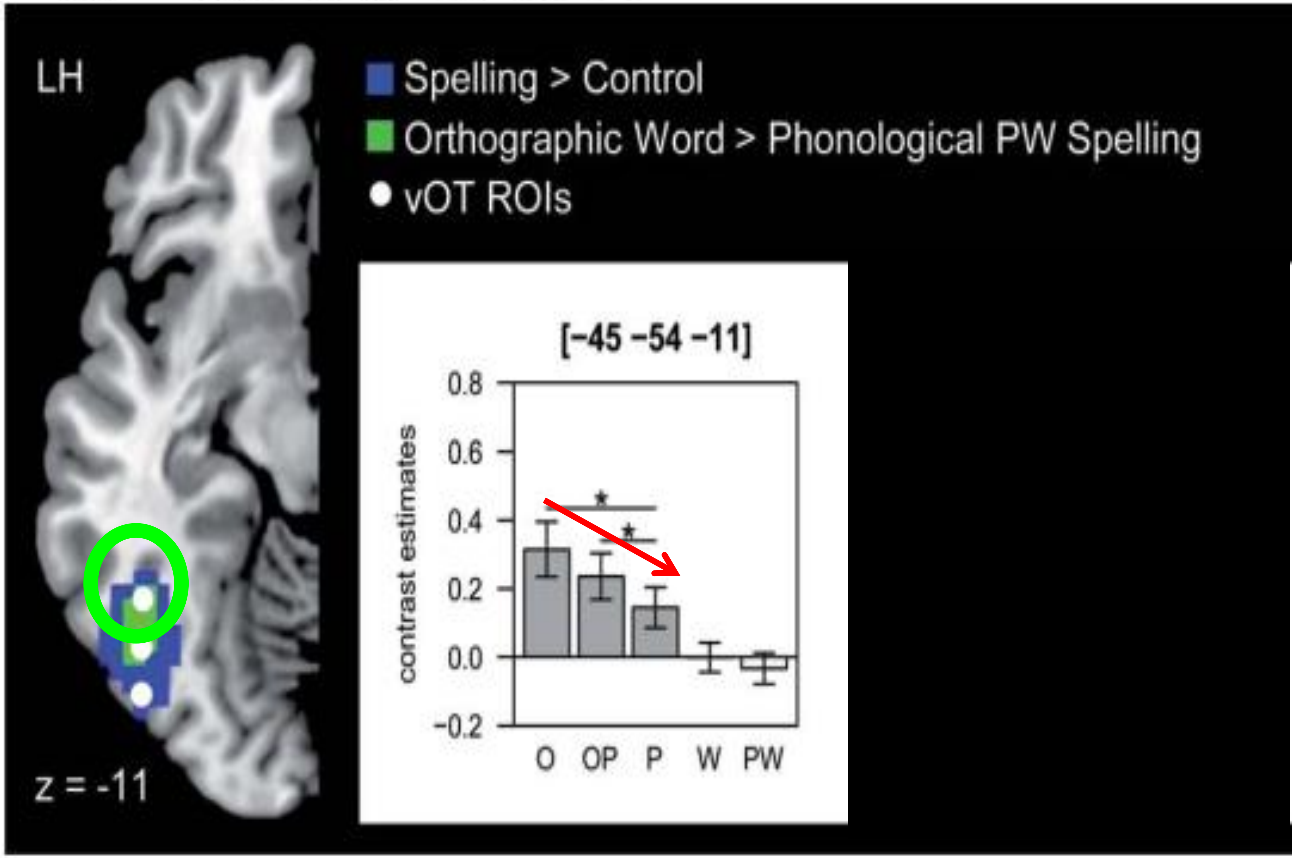


Thiebaut de Schotten et al., 2014

VWFA responses during speech processing

• Speech processing tasks that **require an activation of orthographic knowledge**. E.g., do spoken words share the same spelling (Booth et al, 2002) or contain a specific letter (Ludersdorfer et al., 2015)

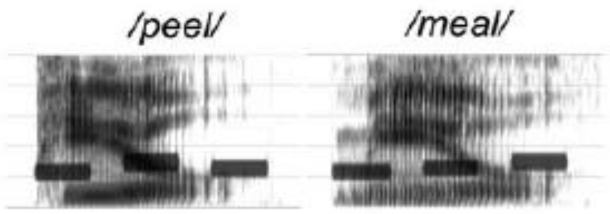
Spoken input	Target letter
/fa:zə/ (PHASE)	« p »
/fa:zə/ (PHASE)	« a »
/tiska/ (TISKA)	« i »



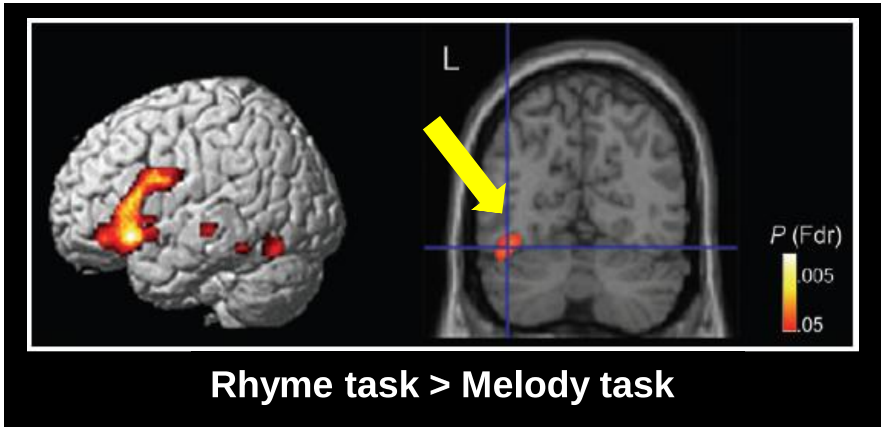
Ludersdorfer et al., 2015

• Speech processing tasks that **do not** require an activation of orthographic knowledge

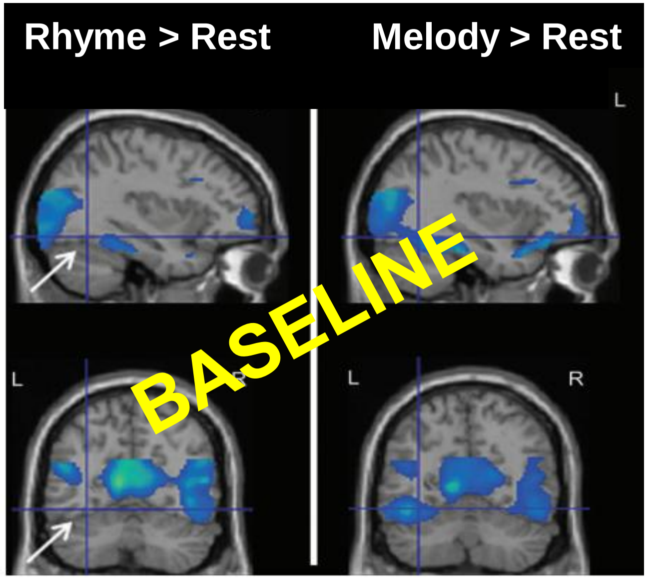
Rhyme judgment vs. melody judgment (Yoncheva et al., 2009)



Selectively attending to speech, relative to selectively attending to melody, leads to increased activity in the VWFA



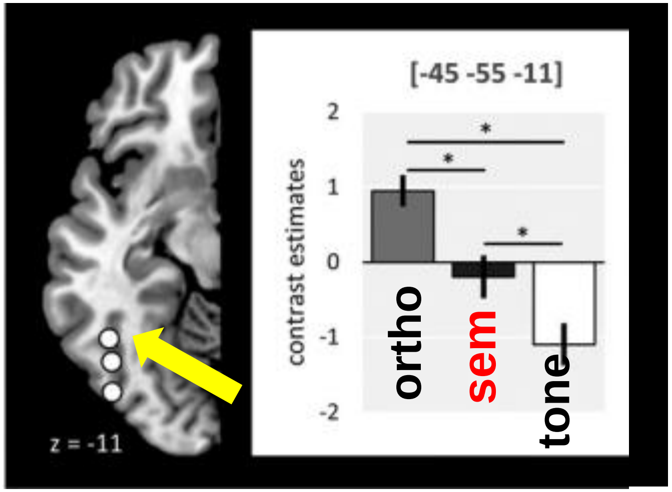
Yoncheva et al., 2009



"cross-modal sensory suppression" phenomenon

• Speech processing tasks that **do not** require an activation of orthographic knowledge

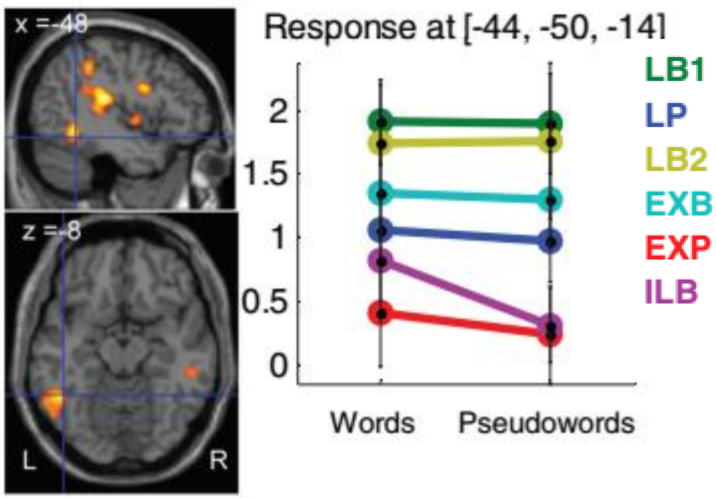
Comparisons between orthographic, semantic and tone processing tasks.



Ludersdorfer, 2016

Auditory lexical decision

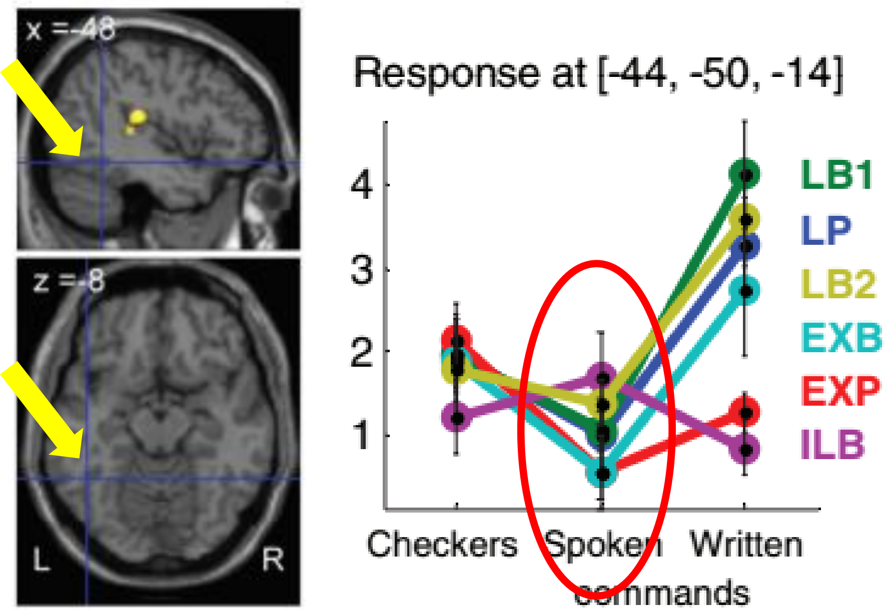
The activation level depends on reading expertise



Dehaene et al. 2010

What happens in more natural speech processing situations?

- **Passive sentence listening**



Dehaene et al., 2010

-No significant VWFA activity

- The level of VWFA activity did not vary with reading expertise

Sentences instead of single words which make sound to spelling conversion less likely?

Passive situation?

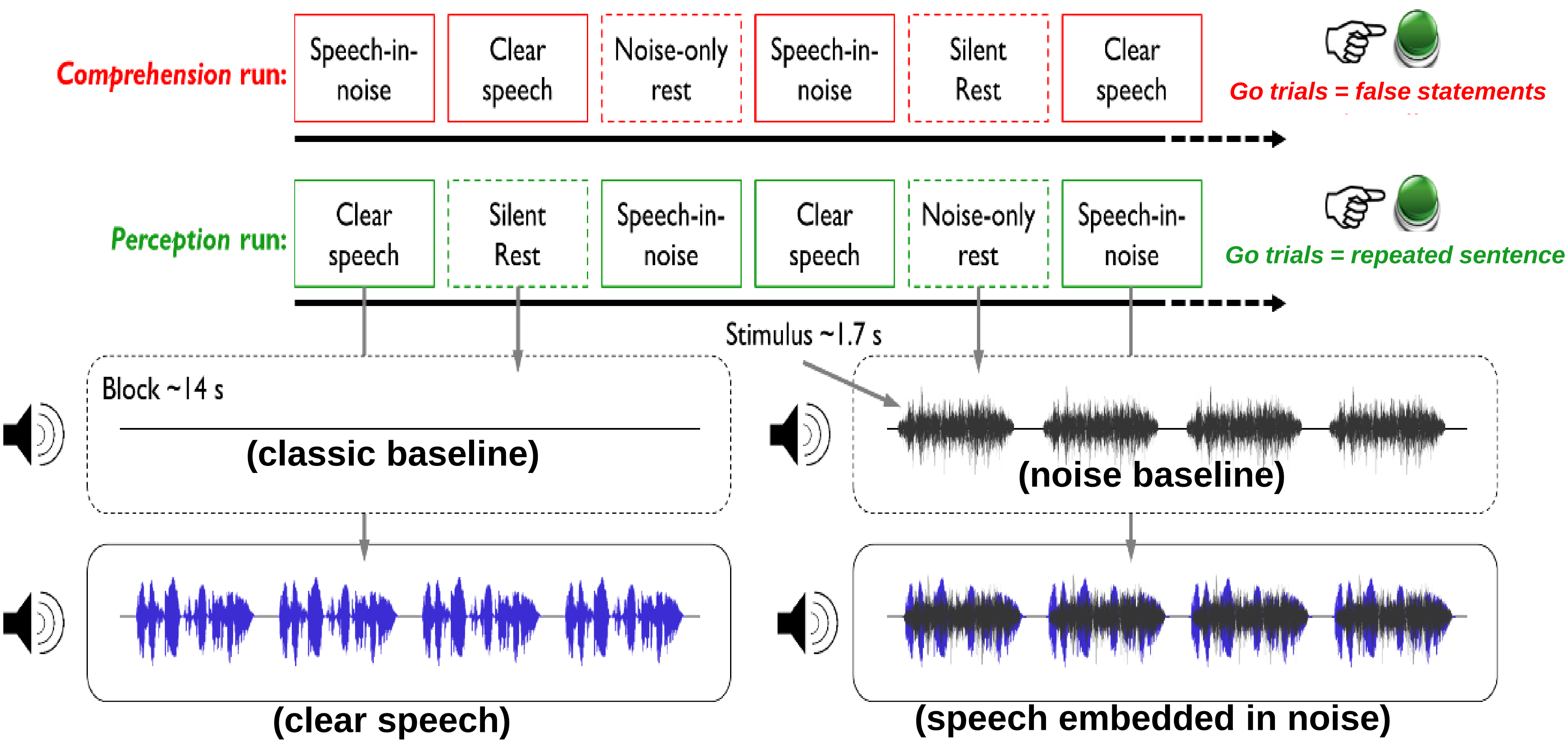
“Rest” rather than non-language auditory baseline?

Other reasons?

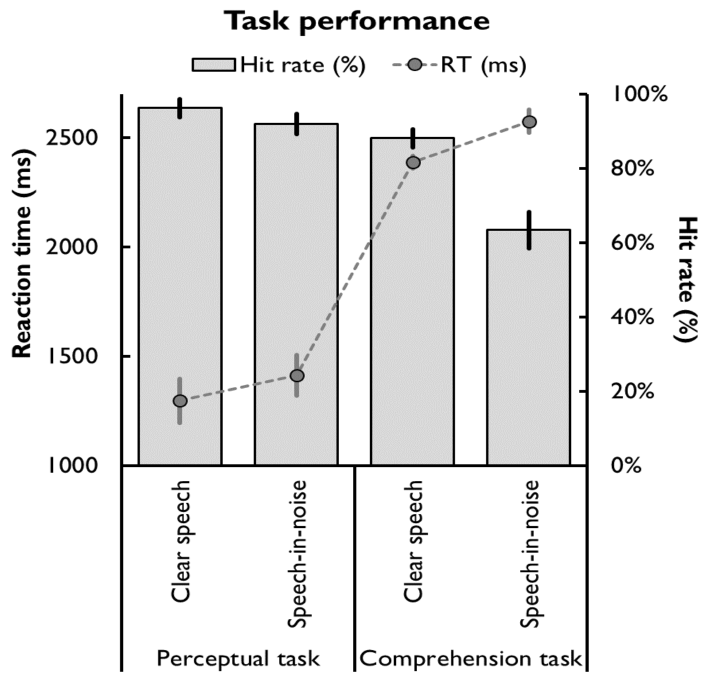
VWFA involvement in spoken sentence processing

Planton, S., Chanoine, V., Sein, J., Anton. J-L, Nazarian, B., Pallier, C., Pattamadilok, C. (in prep.)

Aim: Identify the circumstances leading to VWFA responses to spoken sentences
Participants: 24 adults, right handed, skilled readers.
Stimuli: Spoken sentences
Task demands: Comprehension (false statement detection) vs. Perceptual task (one-back)
Signal quality: Clear vs. degraded listening condition (multi-speaker babble)

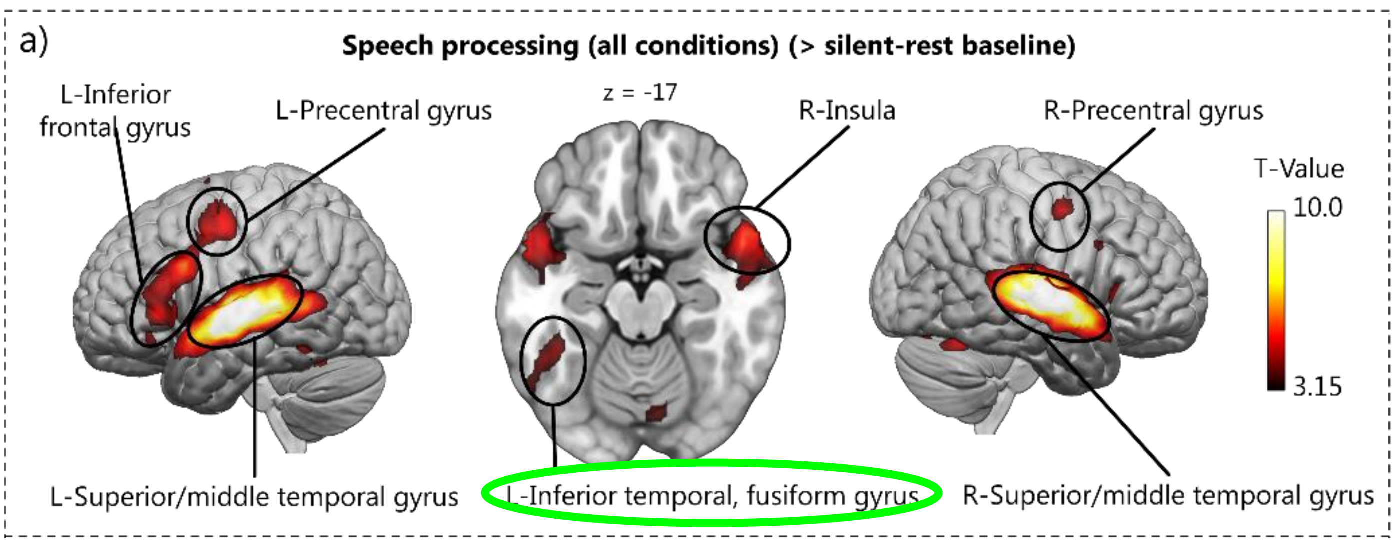


Behavioral data on Go trials

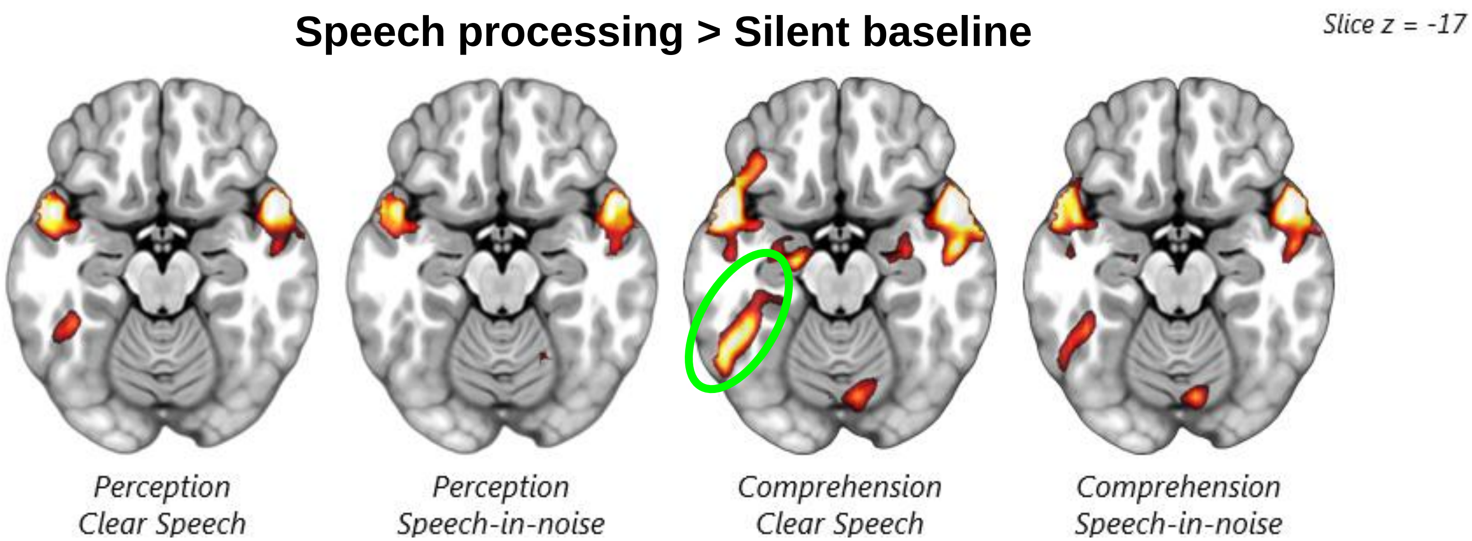


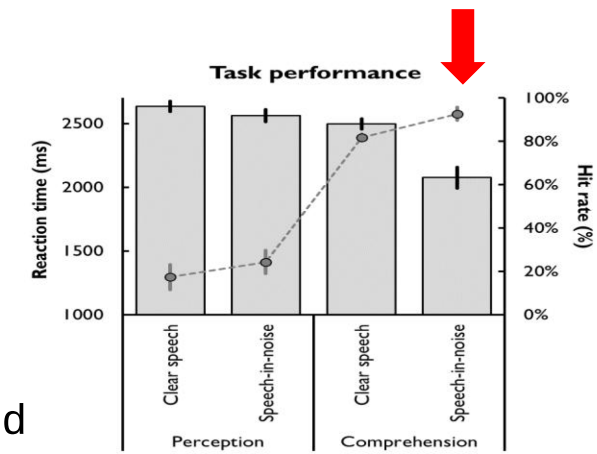
Brain-imaging data on Nogo trials

Global network



Speech processing > Silent baseline



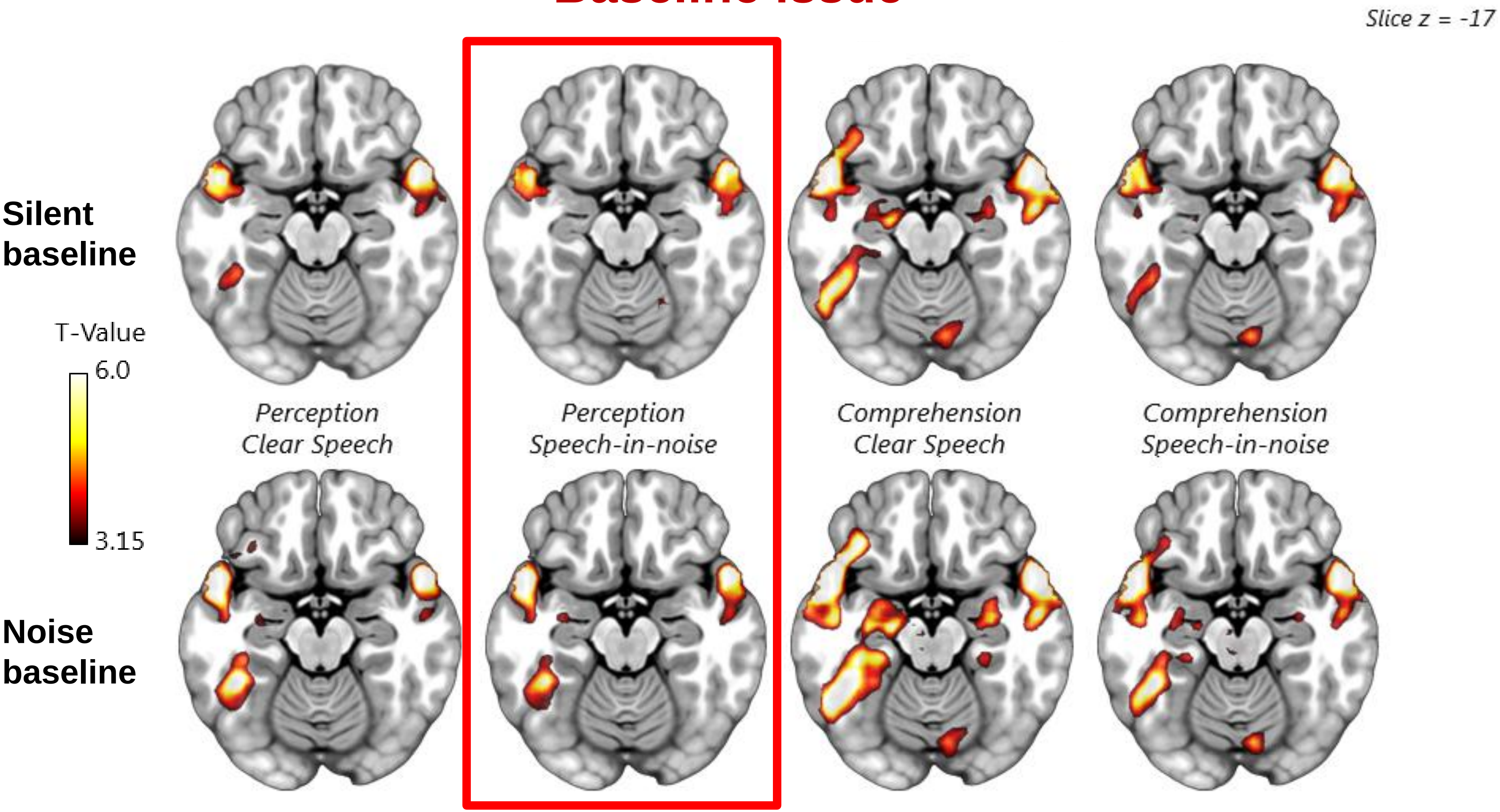


- **Task effect**
  - Increased VWFA activation in comprehension compared to perception task
  - Small but significant VWFA activation in the perceptual task

- **Noise effect**
  - Adding noise into the signal made the task more difficult but did not lead to an increase of VWFA activity. The opposite tendency was found. Processing difficulty plays a role but not in the expected way → Disengagement of VWFA activity when speech is degraded?

    → Stronger propagation of brain activity to “non-phonological” systems when speech is clearly perceived?

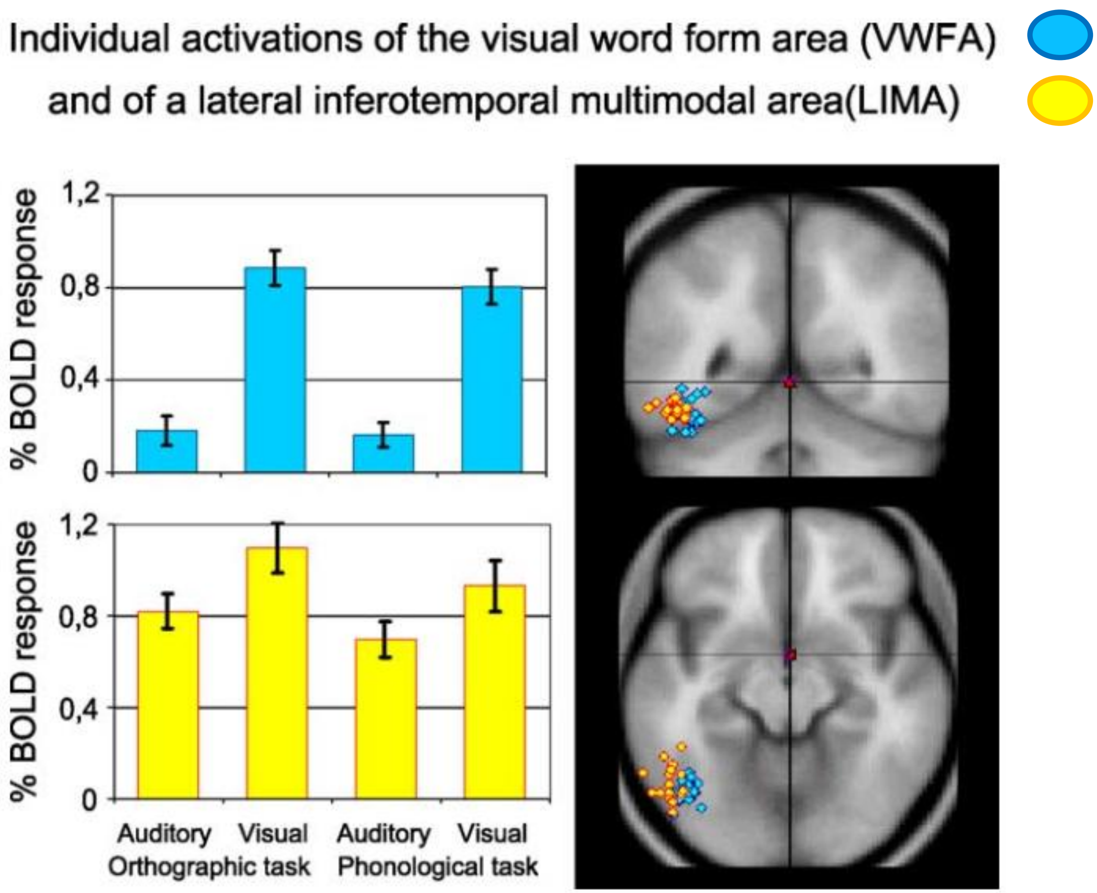
Baseline issue

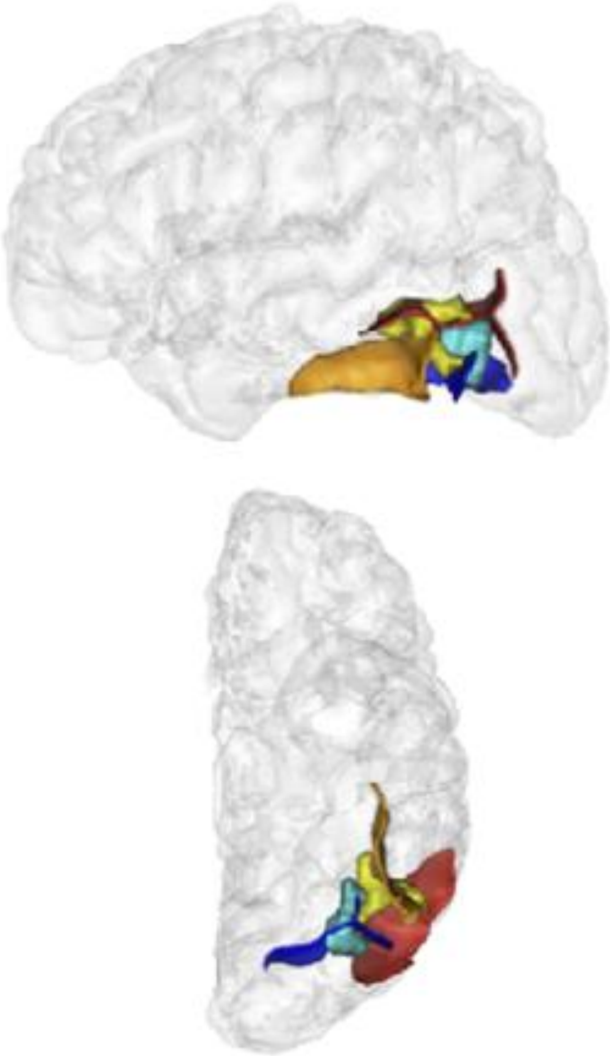


- •Non language auditory input induces “cross-model sensory suppression” within the visual system
- • Using noise baseline artificially increases the effect size ➔ can change the conclusion of the study (e.g., perception in noise)!

Anatomical correspondence between the voxels activated by spoken sentences and those activated by written words

Same or adjacent voxels?



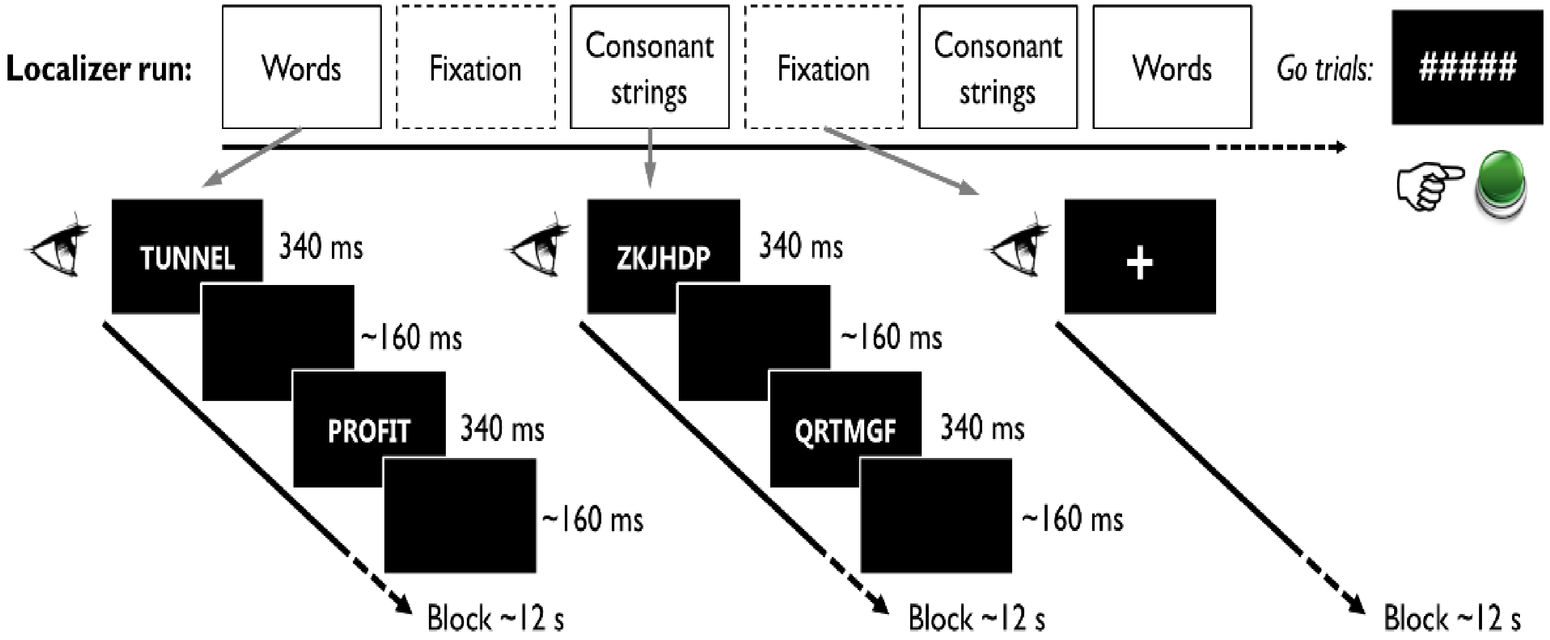


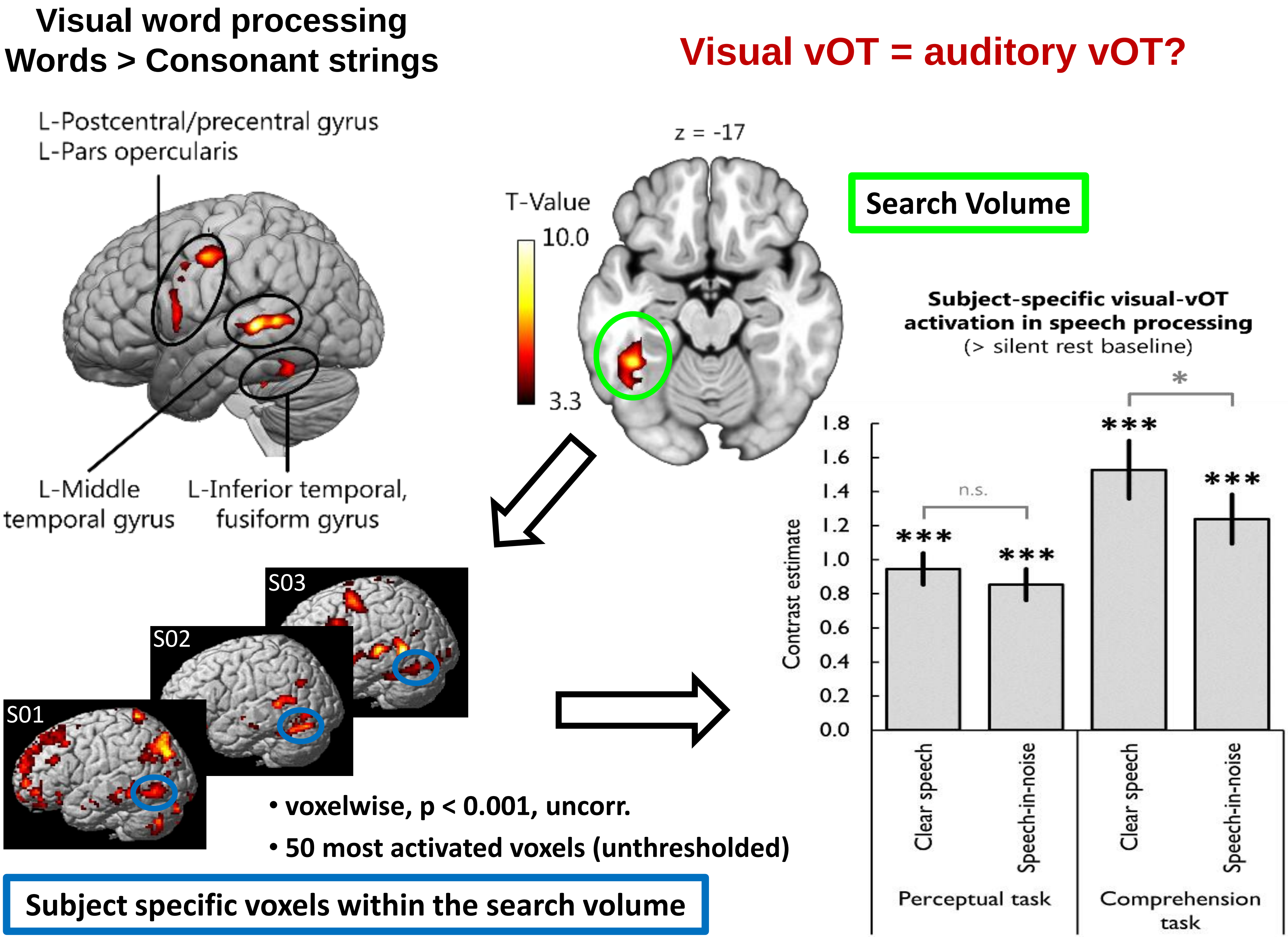
Cohen et al., 2004

Anatomical correspondence between the voxels activated by spoken sentences and those activated by written words

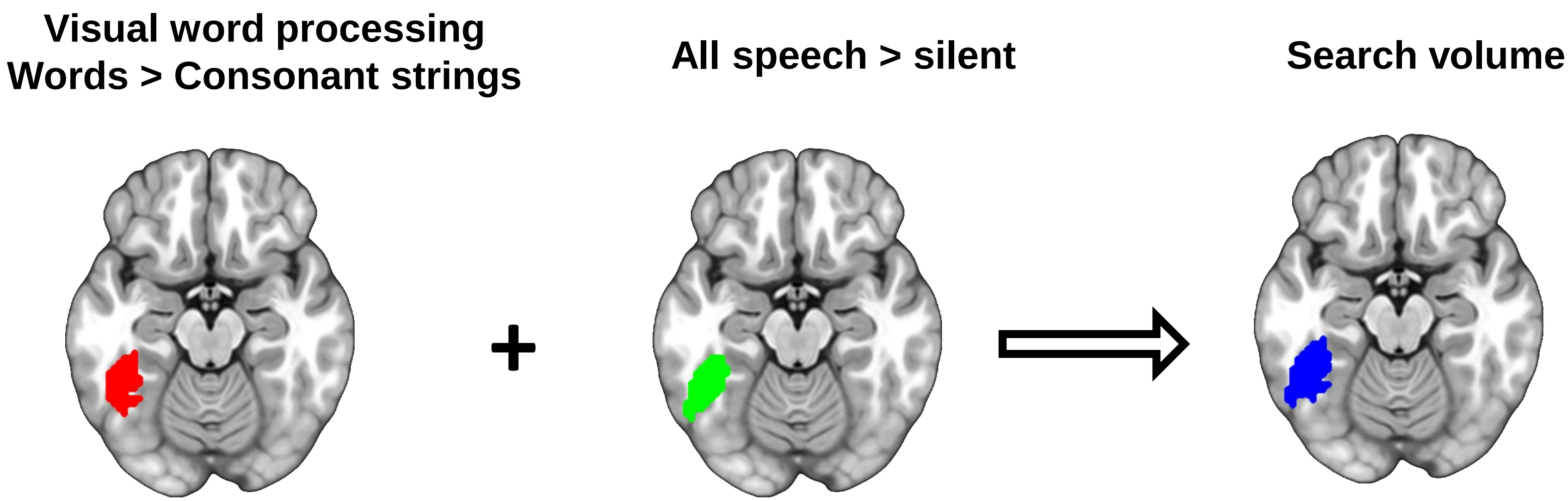
Localizer experiment

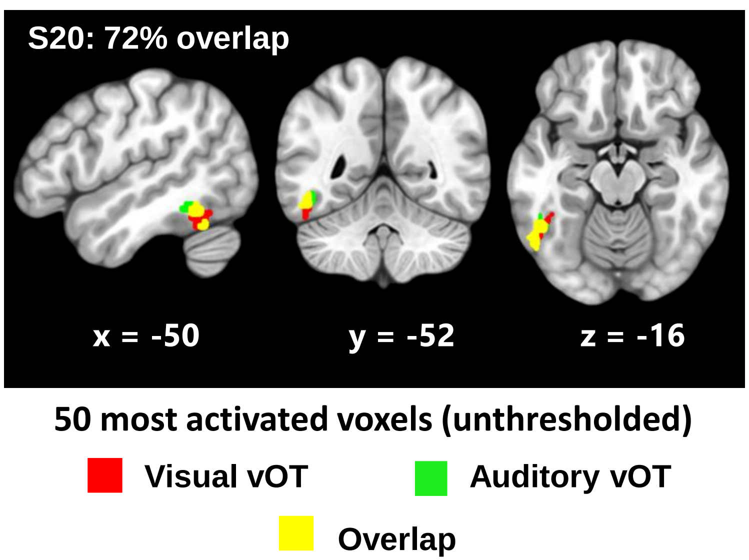
- Aim: Localize the voxels that **respond to written words** in each individual subject
- Additional fMRI run: Visual presentation of **Words** or **Consonant strings**.
- Task: detection of a target stimulus "#####" that appeared randomly

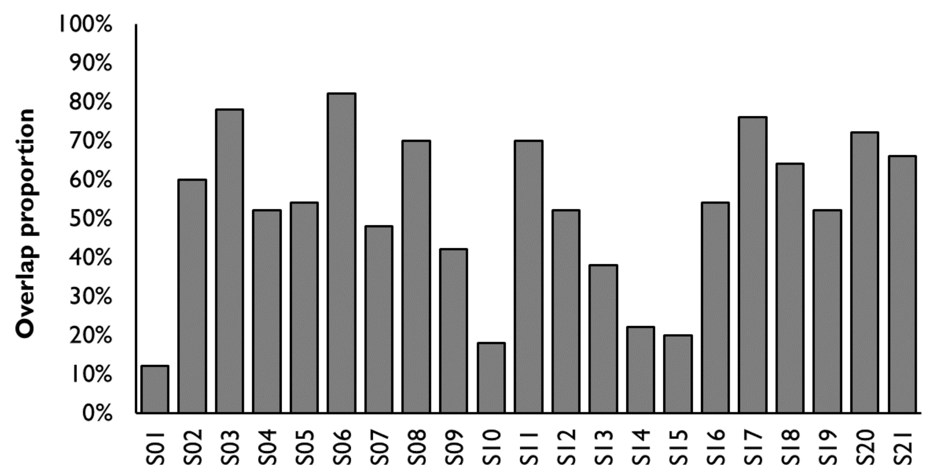



Visual word processing
Words > Consonant strings
Visual vOT = auditory vOT?
L-Postcentral/precentral gyrus
L-Pars opercularis
L-Middle temporal gyrus
L-Inferior temporal, fusiform gyrus
z = -17
T-Value
10.0
3.3
Search Volume
Subject-specific visual-vOT activation in speech processing
(> silent rest baseline)
Contrast estimate
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
n.s.
***
*
Clear speech
Speech-in-noise
Perceptual task
Comprehension task
S03
S02
S01
• voxelwise, p < 0.001, uncorr.
• 50 most activated voxels (unthresholded)
Subject specific voxels within the search volume

The degree of overlap between “visual vOT” and “auditory vOT”





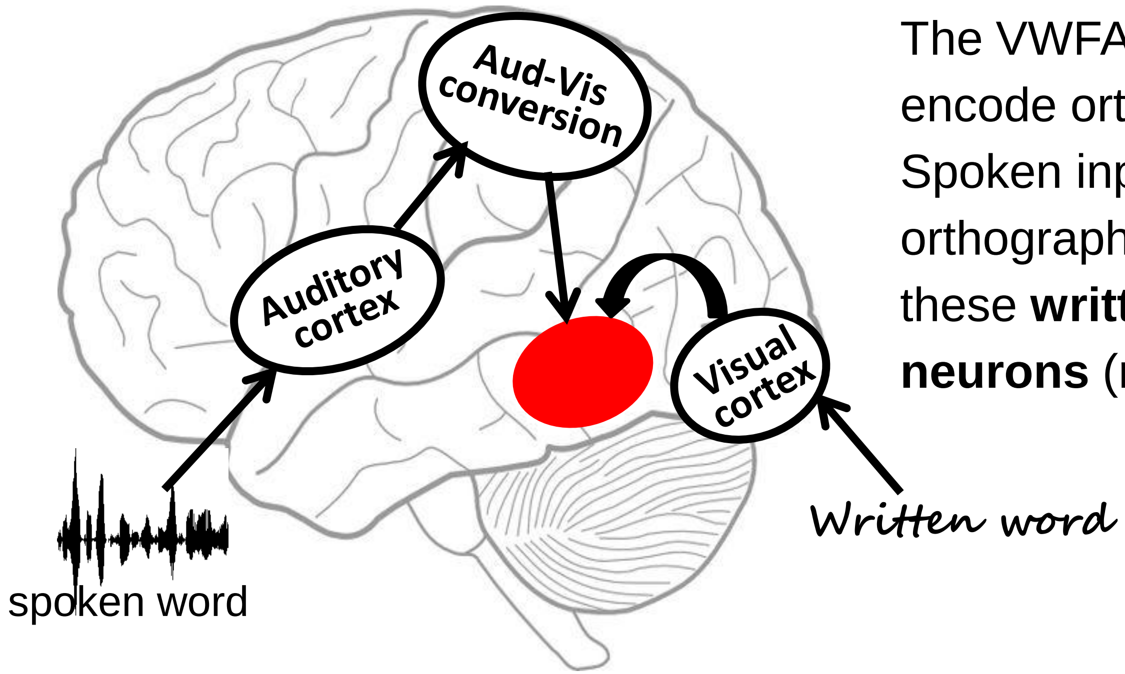


Group average = 52% overlap

Underlying mechanisms of VWFA involvement in speech processing

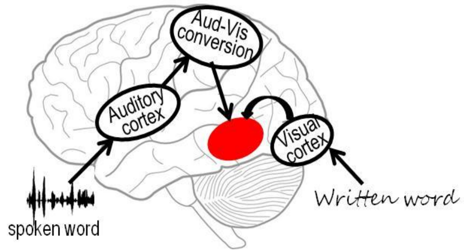
Pattamadilok, C., Planton, S., & Bonnard, M., *NeuroImage, 2019*

Three hypotheses

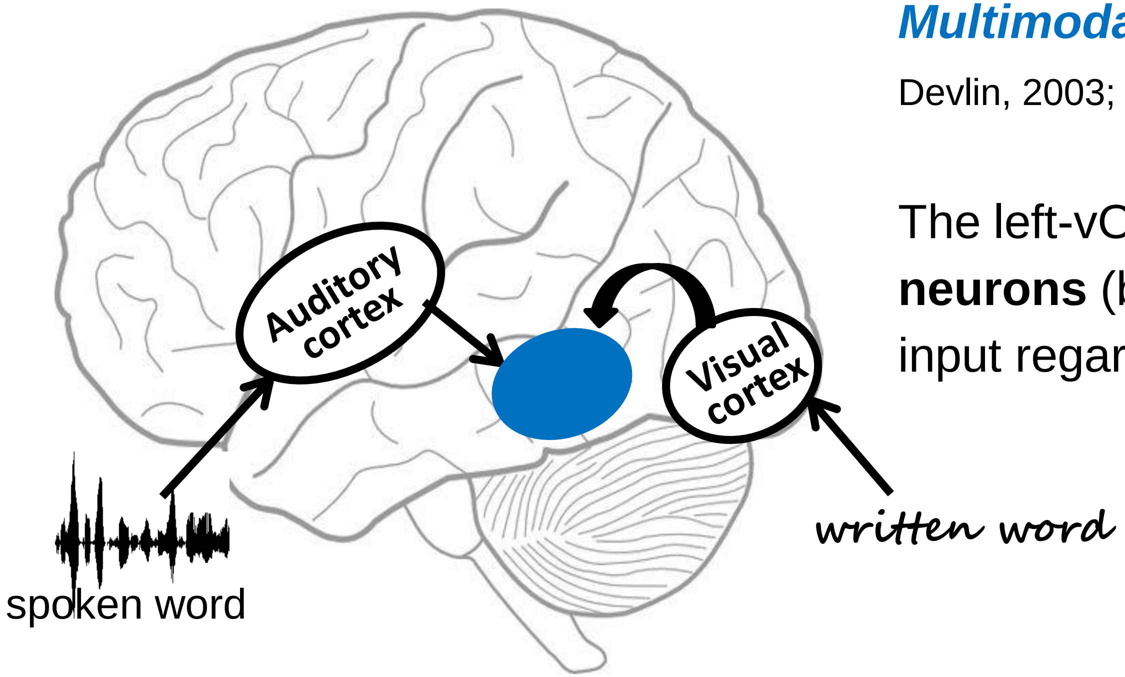


Orthographic tuning hypothesis (Cohen & Dehaene 2005; Dehaene & Cohen, 2011).

The VWFA only contains neurons that encode orthographic inputs.
Spoken input is first converted to an orthographic representation that activates these **written language-encoding neurons** (red dot) in a top-down fashion.

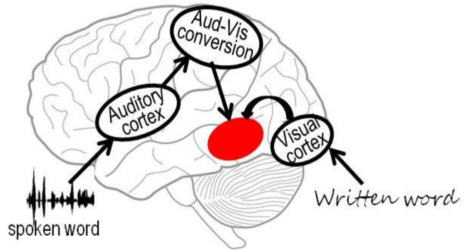


Orthographic tuning hypothesis

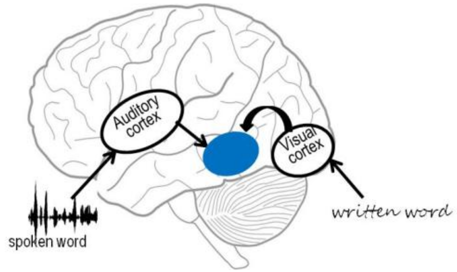


Multimodal neurons hypothesis (Price & Devlin, 2003; 2011)

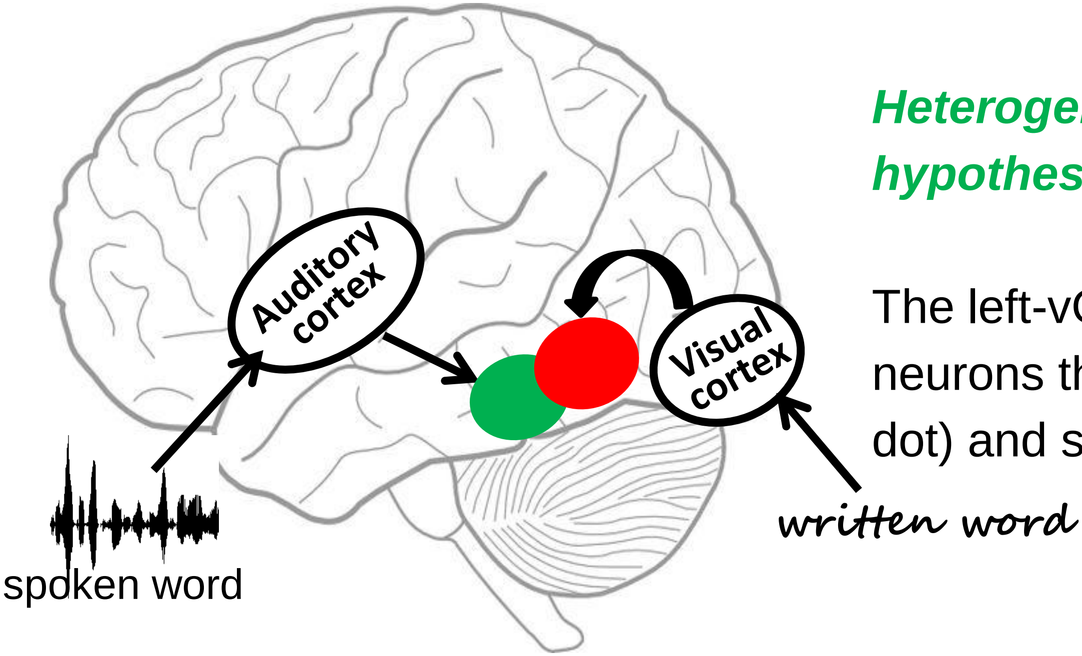
The left-vOT contains **multimodal neurons** (blue dot) that encode language input regardless of its modality



Orthographic tuning hypothesis



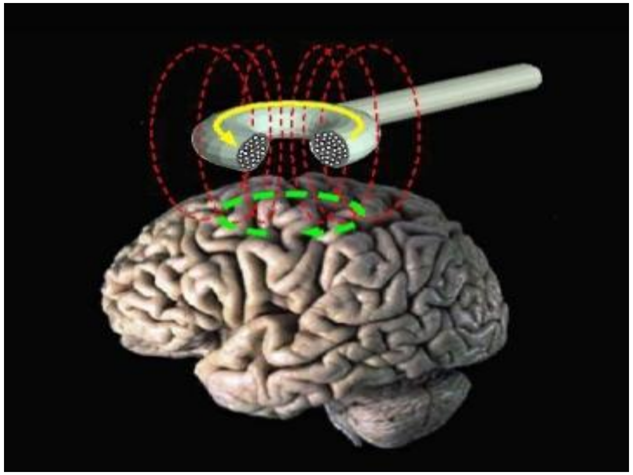
Multimodal neurons hypothesis



Heterogeneous neuronal populations hypothesis (Price & Devlin, 2003)

The left-vOT contains different populations of neurons that *selectively* encode written (red dot) and spoken (green dot) language inputs.

Properties of the neurons within the VWFA revealed by TMS-adaptation protocol

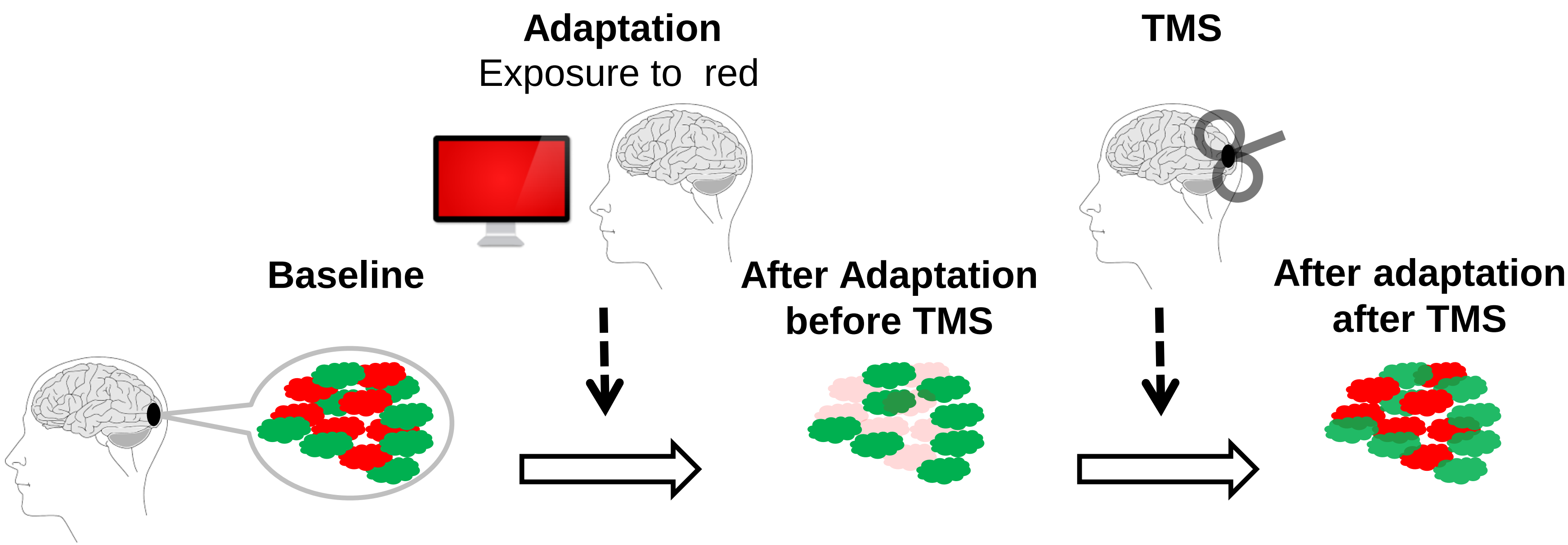


Main application: Causal role

If a brain area plays a causal role in the task under investigation, using TMS to interfere with the cortical excitability of the area should also modify task performance.

The effect of TMS can be inhibitory or facilitatory depending on stimulation parameters (e.g, frequency, intensity, timing, …) and **the initial state of the stimulated area** (e.g., resting state, active, task-demands, …)

State-dependent TMS effects (Silvanto et al. 2008): TMS effects are determined by initial neural activation state



All neurons have the same level of excitability

Excitability of neurons encoding red is reduced. Red becomes more difficult to detect.

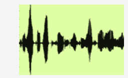
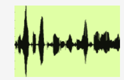
TMS selectively facilitates the detection of red (i.e., the attribute encoded by suppressed neurons)

• By manipulating the state of neurons before application of TMS, one can selectively target specific, even spatially overlapping neural populations within the affected region, **if those populations exist.**

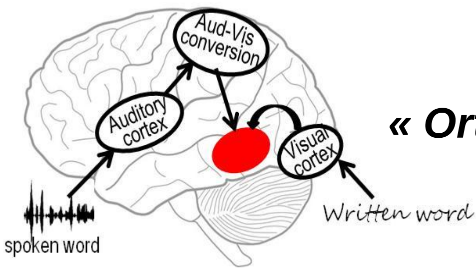
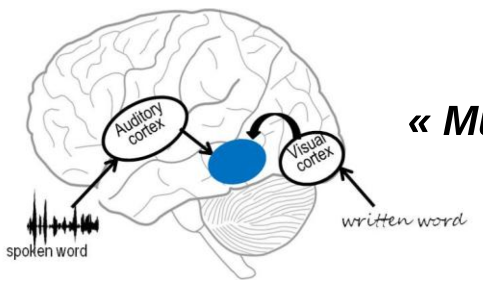
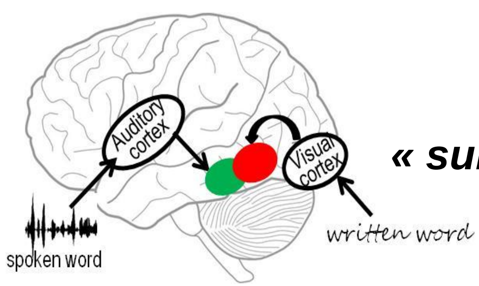
Experimental paradigm & Predictions

Manipulation of the modality of language input → **Adaptation** / **Task**

Experimental conditions

Adaptation		word	word	
Task			word	word

TMS facilitatory effect

 ***« Orthographic »***	x	x	✓	x
 ***« Multimodal »***	✓	✓	✓	✓
 ***« subpopulations »***	✓	x	✓	x

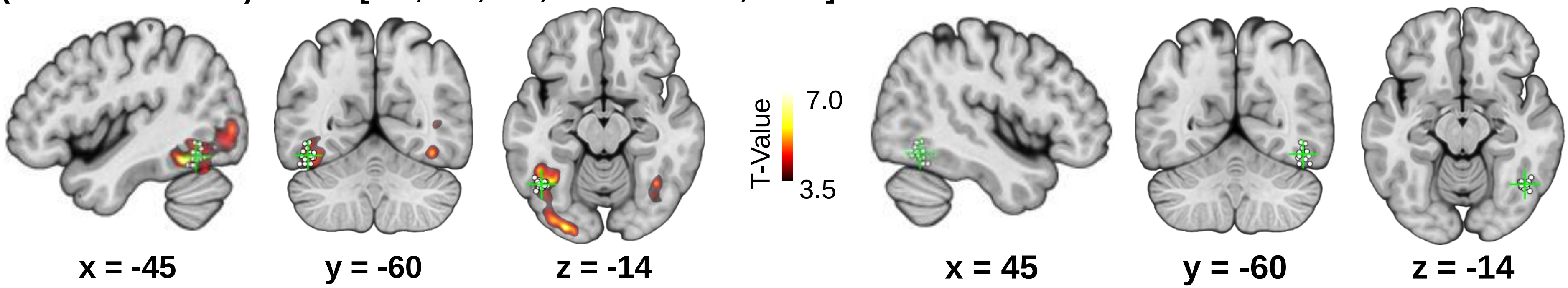
Experimental protocol

N = 17 (8 women, 20-27 yrs, right-handed, native French speakers)

LEFT-vOT (VWFA)

(Word > Fixation) ∩ MNI [-44, -58, -15, Jobard et al., 2003]

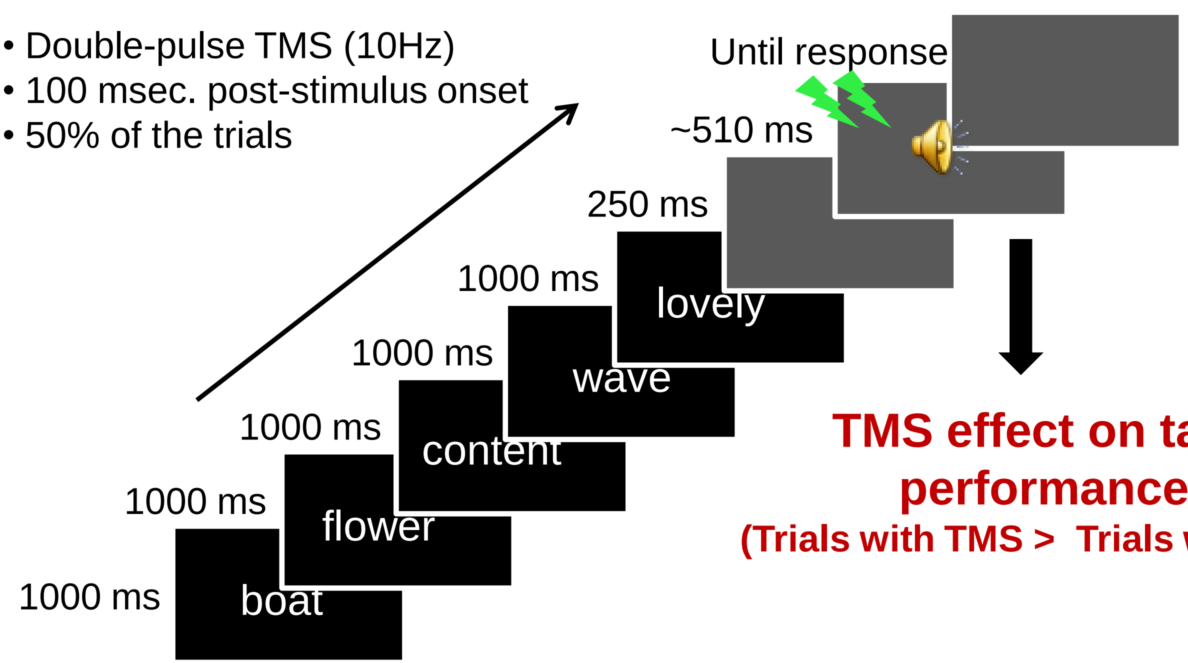
RIGHT-vOT (Control site)



Test phase (lexical decision)

- Double-pulse TMS (10Hz)
- 100 msec. post-stimulus onset
- 50% of the trials

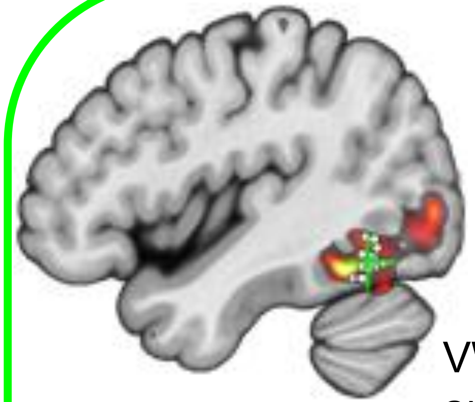
Adaptation phase (passive listening or viewing)



TMS effect on task performance

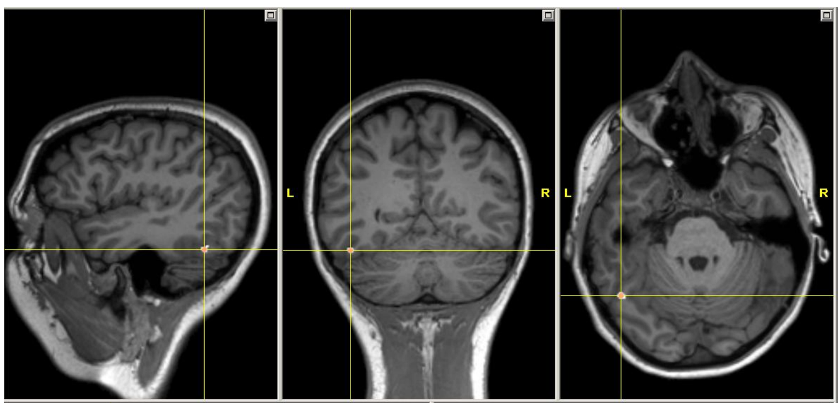
(Trials with TMS > Trials w/o TMS)

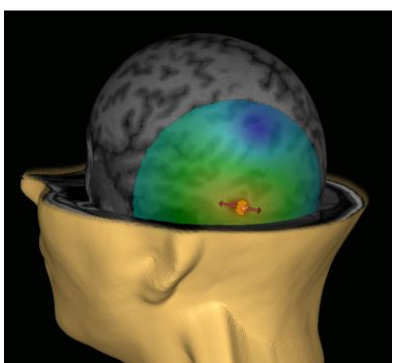
TMS & Neuronavigation system



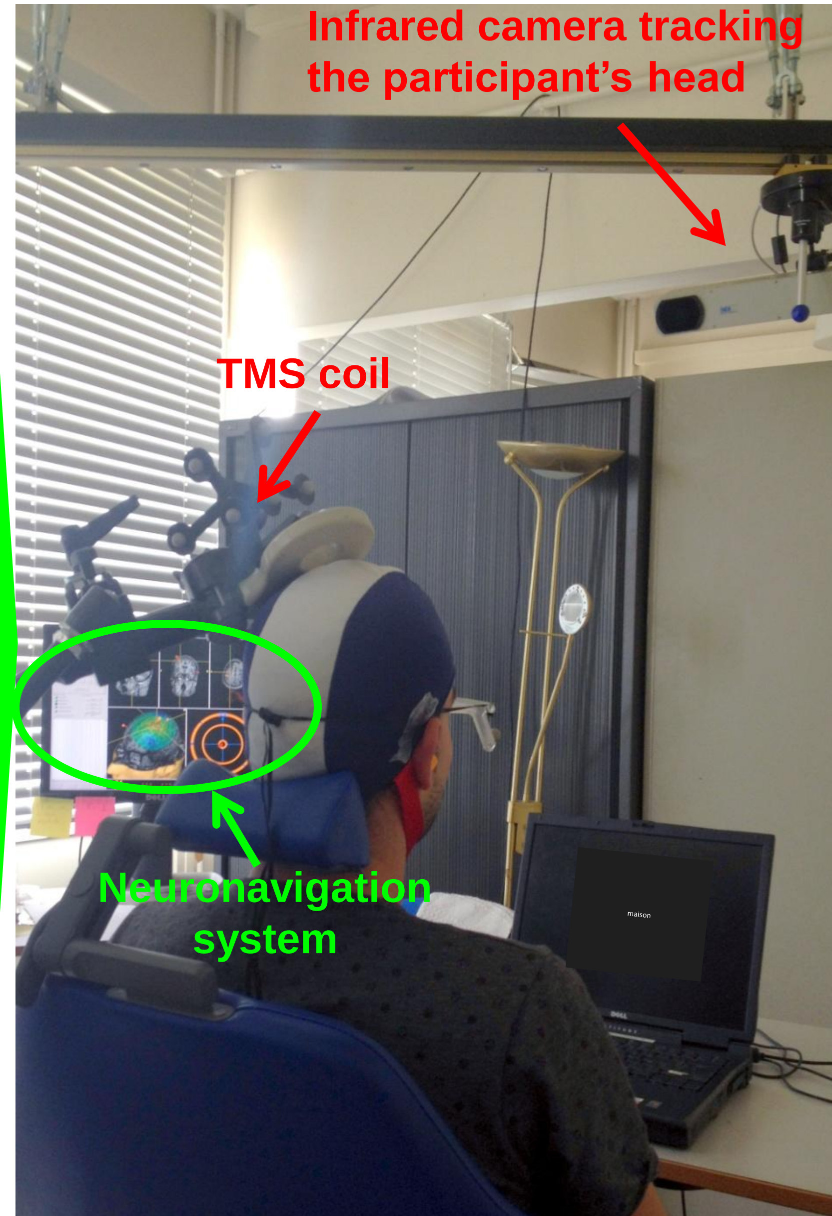
fMRI localizer task
Words > Fixation

VWFA area on participant’s anatomical scan

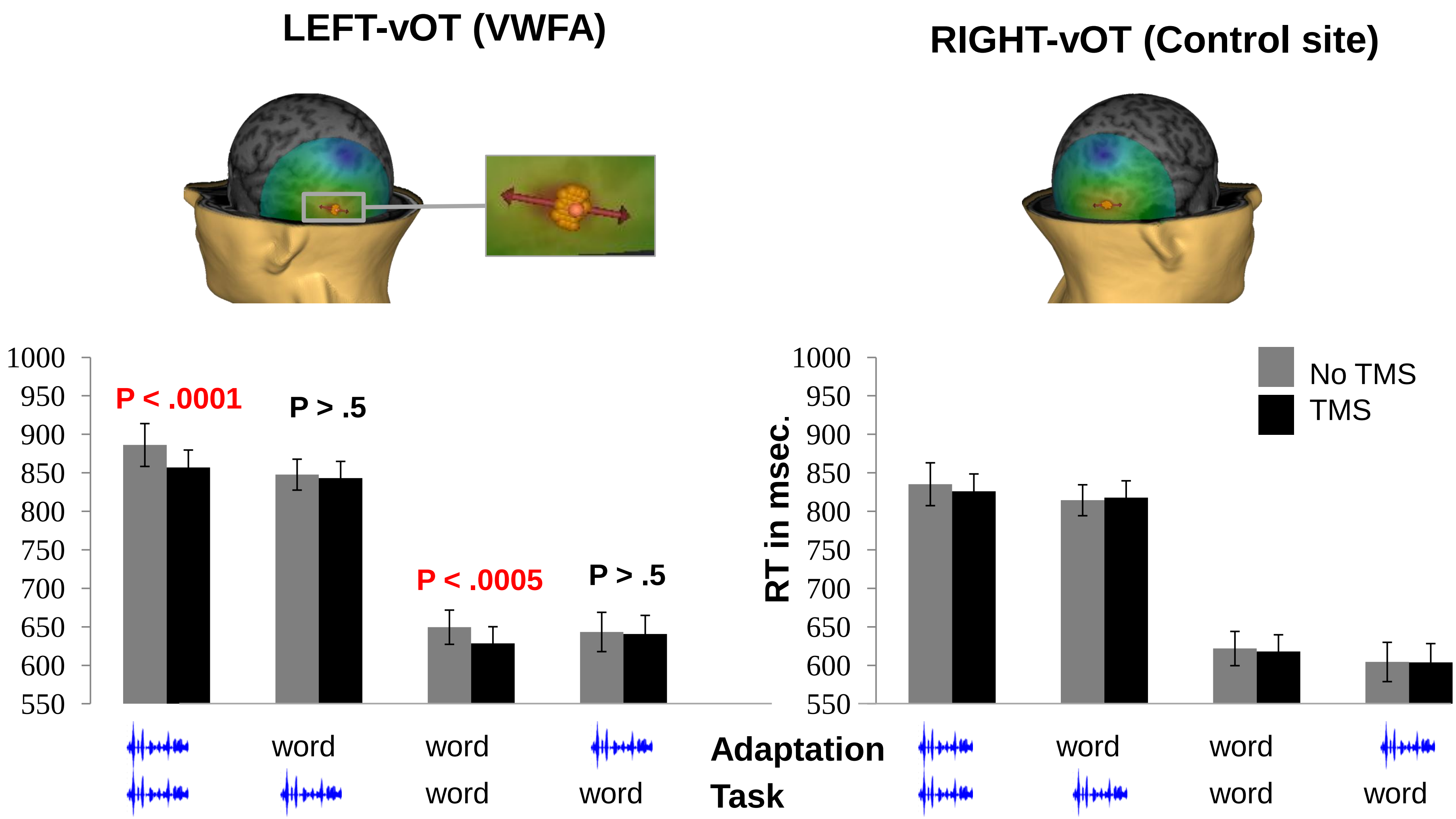




VWFA area targeted by TMS during the task



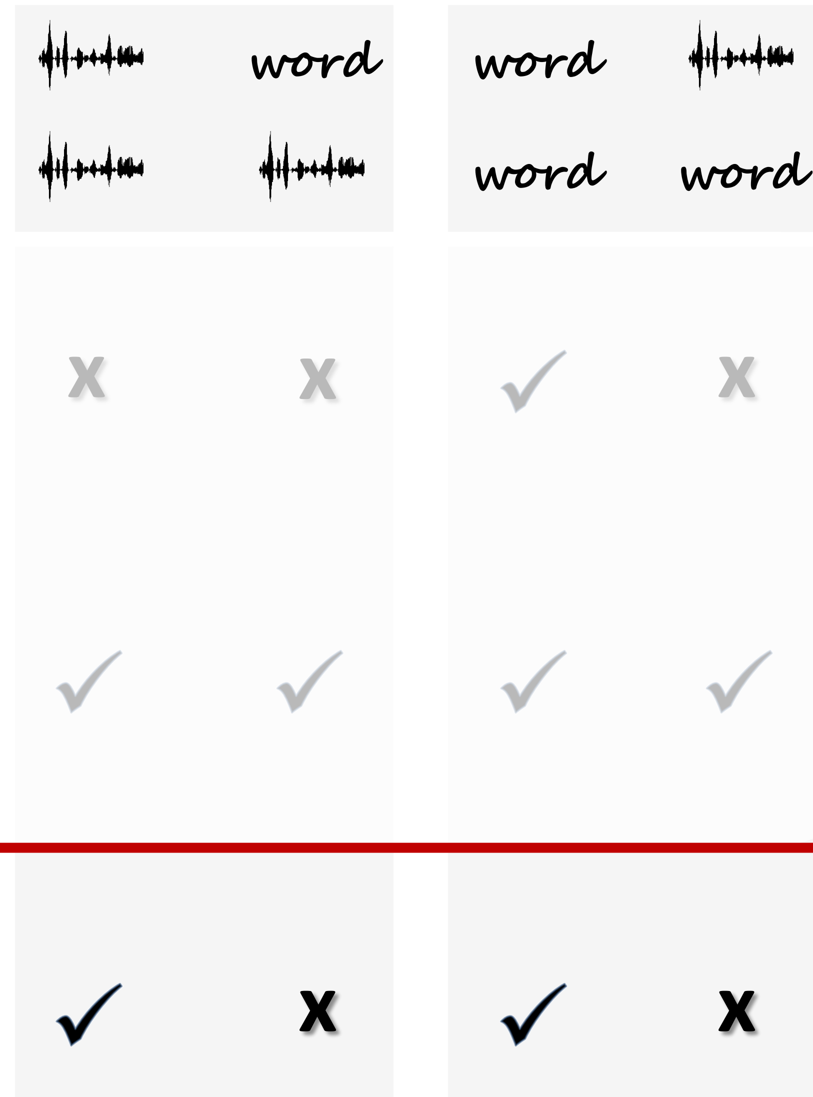
Linear mixed-effects model (RT data)
Fixed factors: TMS * Adaptation modality * Task modality * Lexicality * ROI
Random factors: Subjects and items
TMS * Adaptation modality * Task modality * ROI: $F(1,11657) = 4.3$, $p < .05$

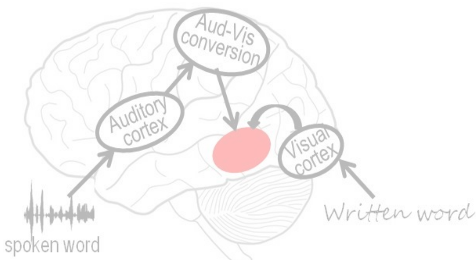


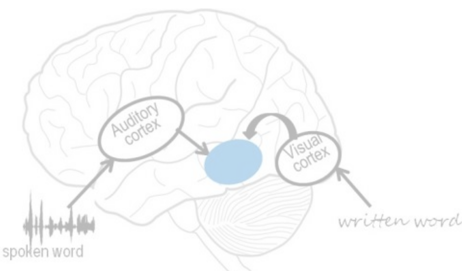
Experimental paradigm & Predictions

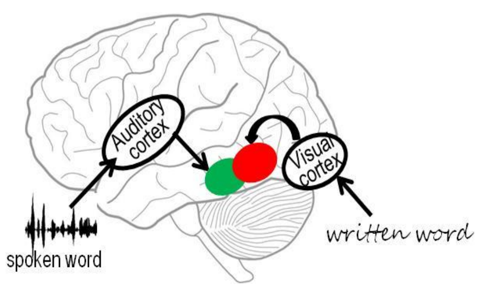
Experimental conditions

Manipulation of the modality of language input → **Adaptation** / **Task**

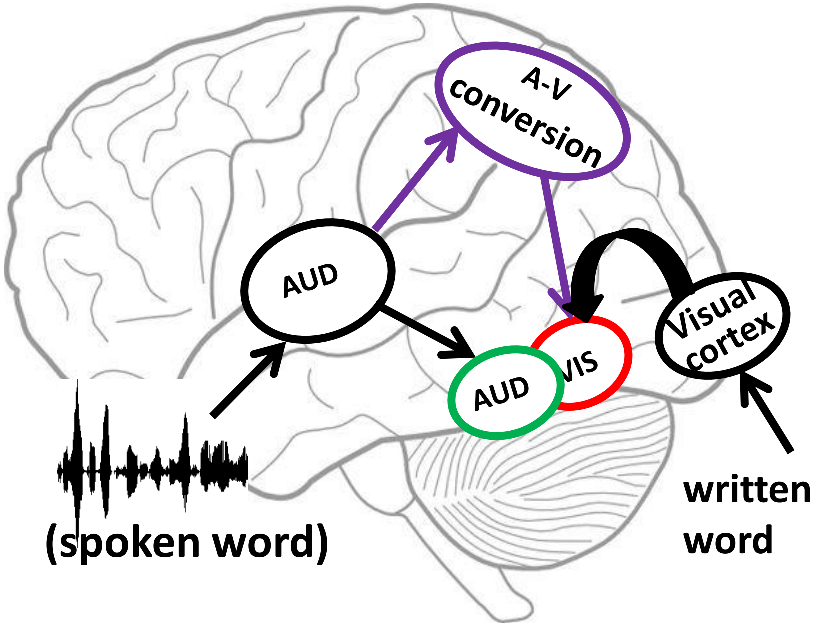








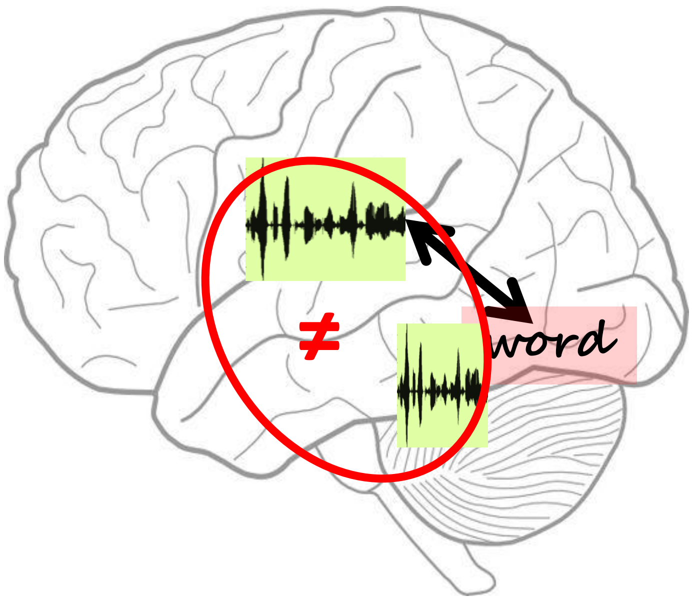
How does the VWFA respond to speech?



Heterogeneous neuronal populations hypothesis: functional segregated populations of neurons in the ventral visual system: **written-language coding** and **spoken language-coding** neuronal populations

Does not rule out the possibility that VWFA responses to spoken input could also be explained by a **top-down activation** of orthographic representations.

Reading acquisition and speech processing



Beyond simple connections between the auditory and visual systems

Profound changes within the auditory and visual systems

Emergence of spoken language coding neurons in the visual pathway:
Cortical reorganization induced by intensive training
-Task specific
- Depend on reading expertise (not in dyslexic or illiterates)

Functions =?
Fast communication between phonology and orthography in skilled readers and in high-level tasks?

Special thanks to...

Jean-Luc Anton

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Julien Sein

Valérie Chanoine

Mireille Bonnard

Samuel Planton

Christophe Pallier