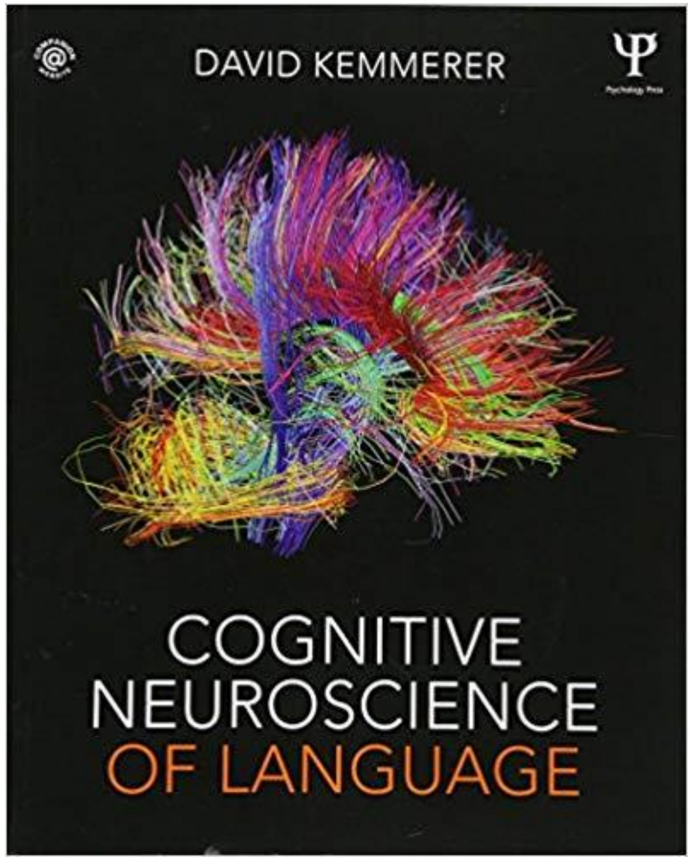
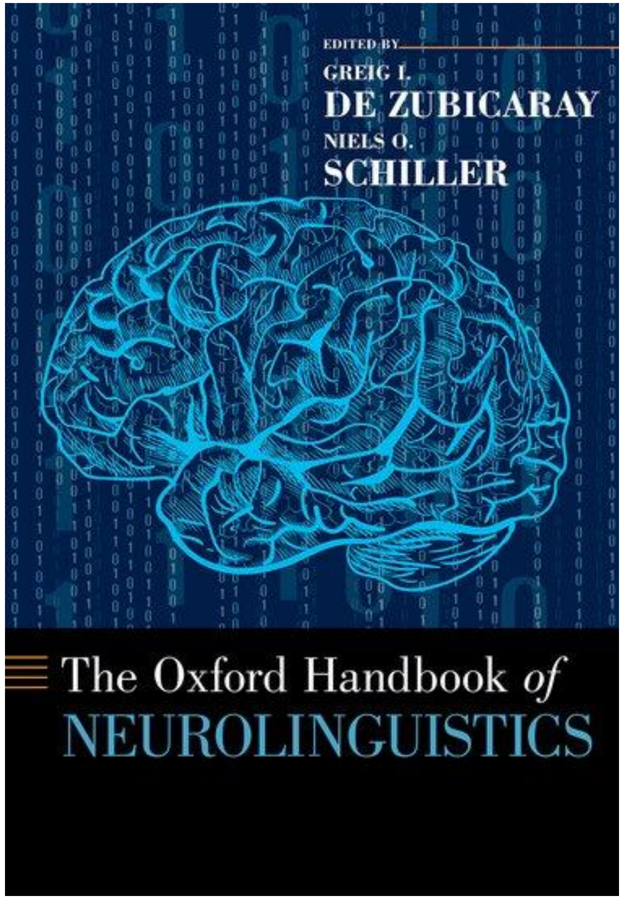
NEURAL BASIS OF LANGUAGE PRODUCTION

Jana Klaus | klaus@cbs.mpg.de



Chapter 6

Speech Production



Chapter 19

Investigating the spatial and temporal components of speech production

Greig de Zubicaray & Vitoria Piai

https://www.researchgate.net/publication/328043071_Investigating_the_spatial_and_temporal_components_of_speech_production

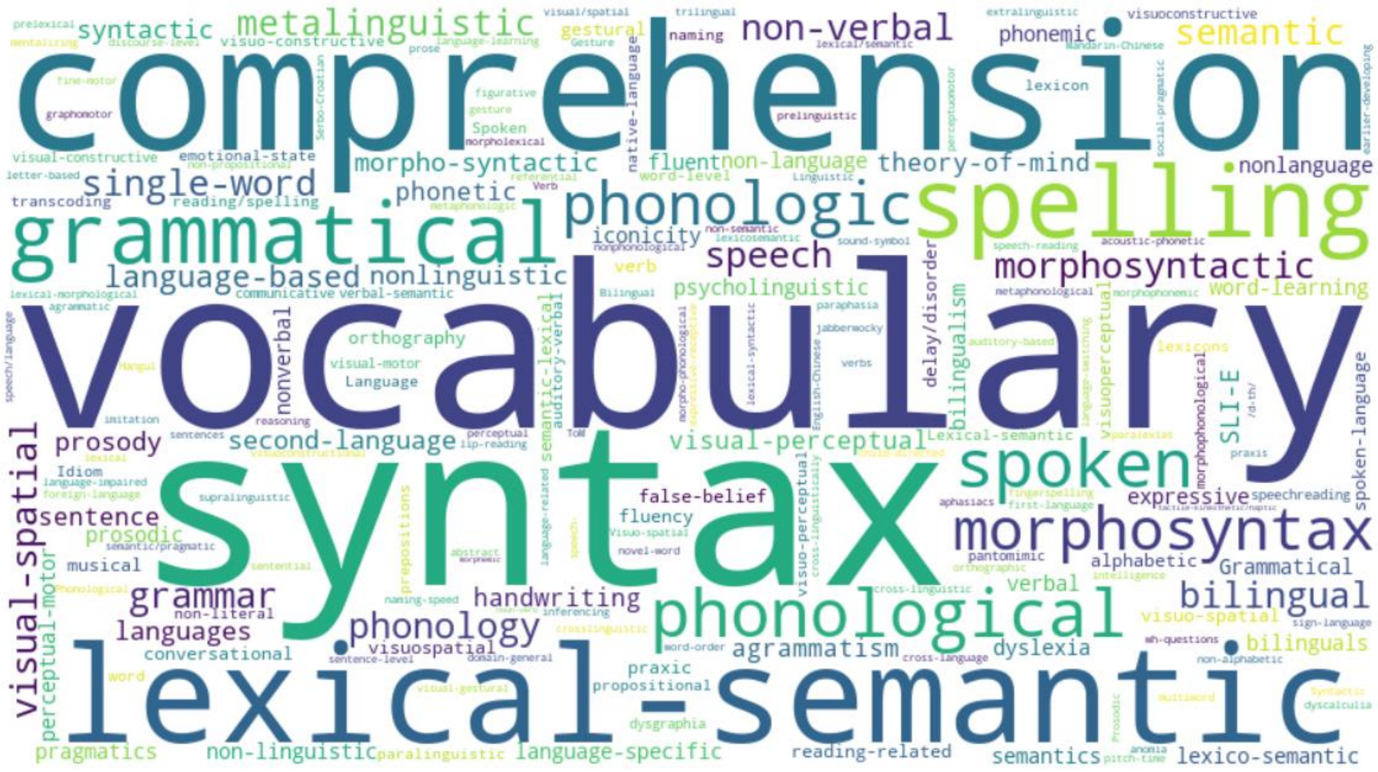
LANGUAGE PRODUCTION IS IMPRESSIVE

We speak about 2 to 5 words per second

We have a vocabulary of ~30,000 words

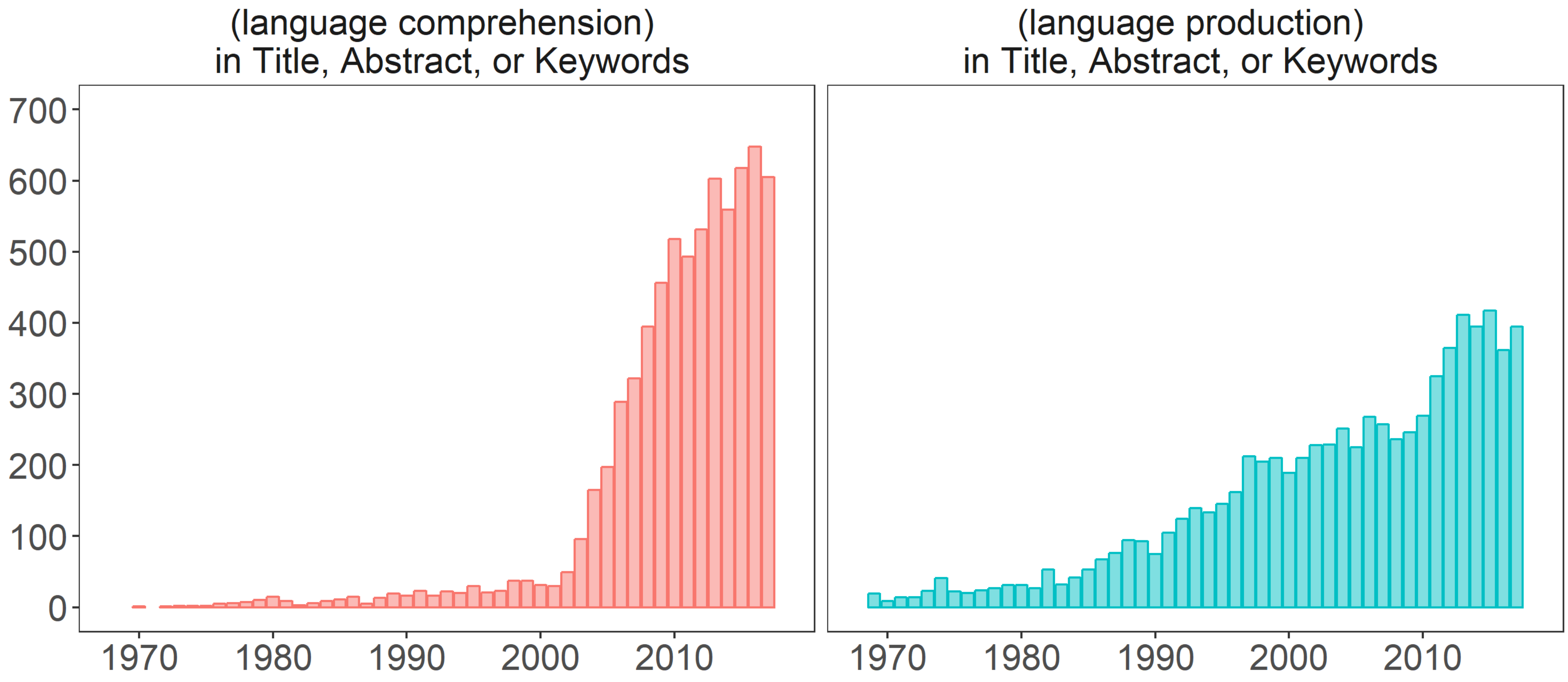
Only about 1 in 1,000 words is a speech error

LANGUAGE PRODUCTION IS NOT VERY POPULAR...



Courtesy of Emiliano Zaccarella

LANGUAGE PRODUCTION IS NOT AS POPULAR



SOME 70S GRUMPINESS AND PESSIMISM

"Practically anything that one can say about speech production must be considered speculative even by the standards in psycholinguistics.“

Fodor, Bever, & Garrett (1974)

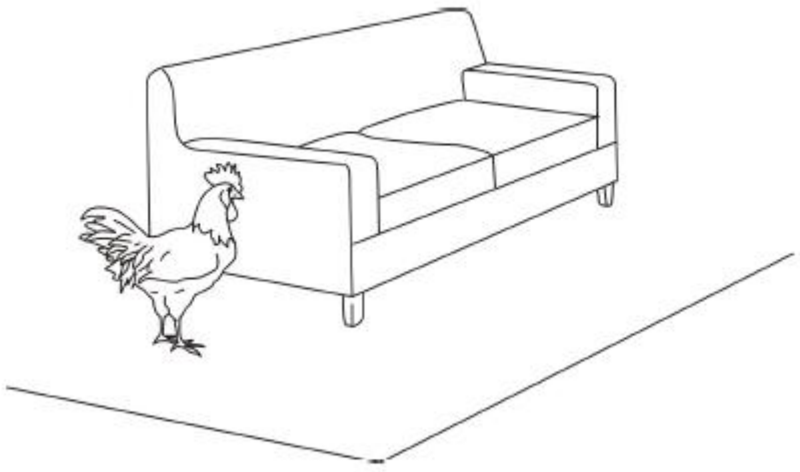
"It is extremely difficult to perform experiments dealing with production processes."

Foss & Hakes (1978)

CONCEPTUAL CHALLENGES

For **language comprehension**, the input (i.e. the speech stimulus) can be controlled and manipulated, and the output can be interpreted in a straight-forward way.

For **language production**, the output (i.e. the utterance) can be analysed in different ways (naming latency, fluency, duration, speech errors), but is difficult to control.



"The rooster is next to the couch."
"The sofa is next to the cock."
"An animal is to the left of a piece of furniture."
"The sitting device is to the right of the wake-up creature."

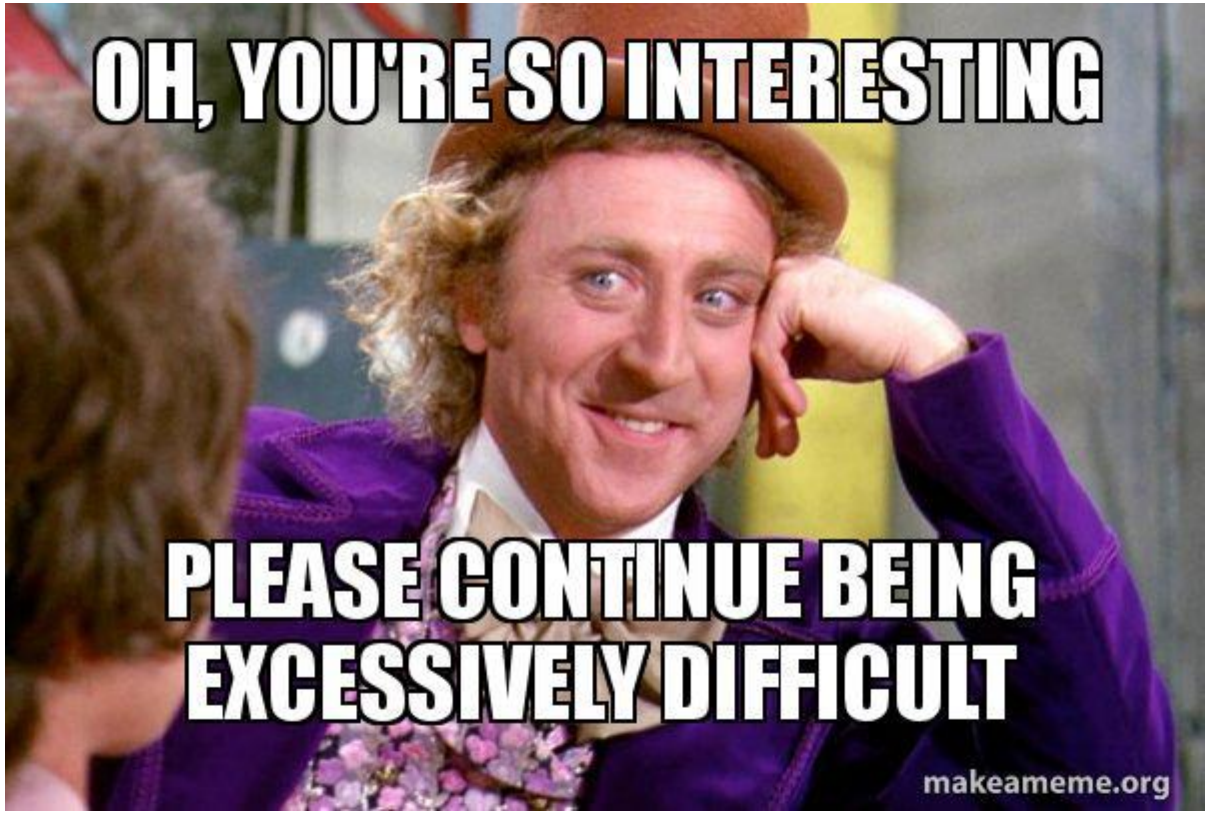
METHODOLOGICAL CHALLENGES

Speech-induced artefacts

Previously: covert production, but studies have shown that covert and overt production recruit different cortical regions

fMRI:

- Physical movements of speech production cause BOLD signal changes during continuous imaging, obscuring speech-related processes as they also localise to the perisylvian cortex
- Sparse temporal sampling


OH, YOU'RE SO INTERESTING
PLEASE CONTINUE BEING EXCESSIVELY DIFFICULT
makeameme.org

OUTLINE

I. A model of word production

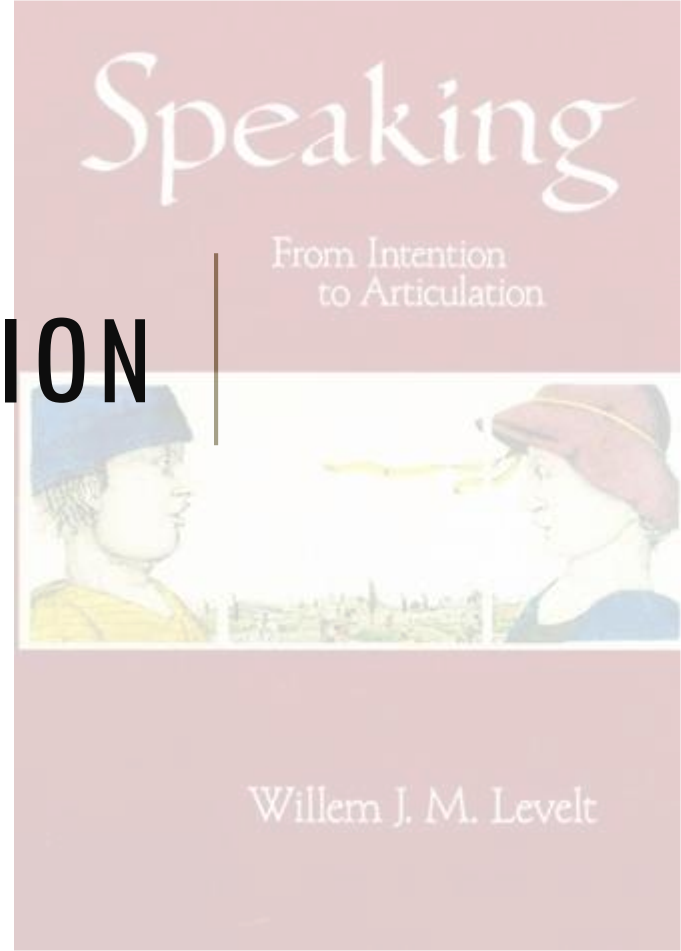
II. Behavioural methods to investigate speech production

- Speech errors
- Picture-word interference

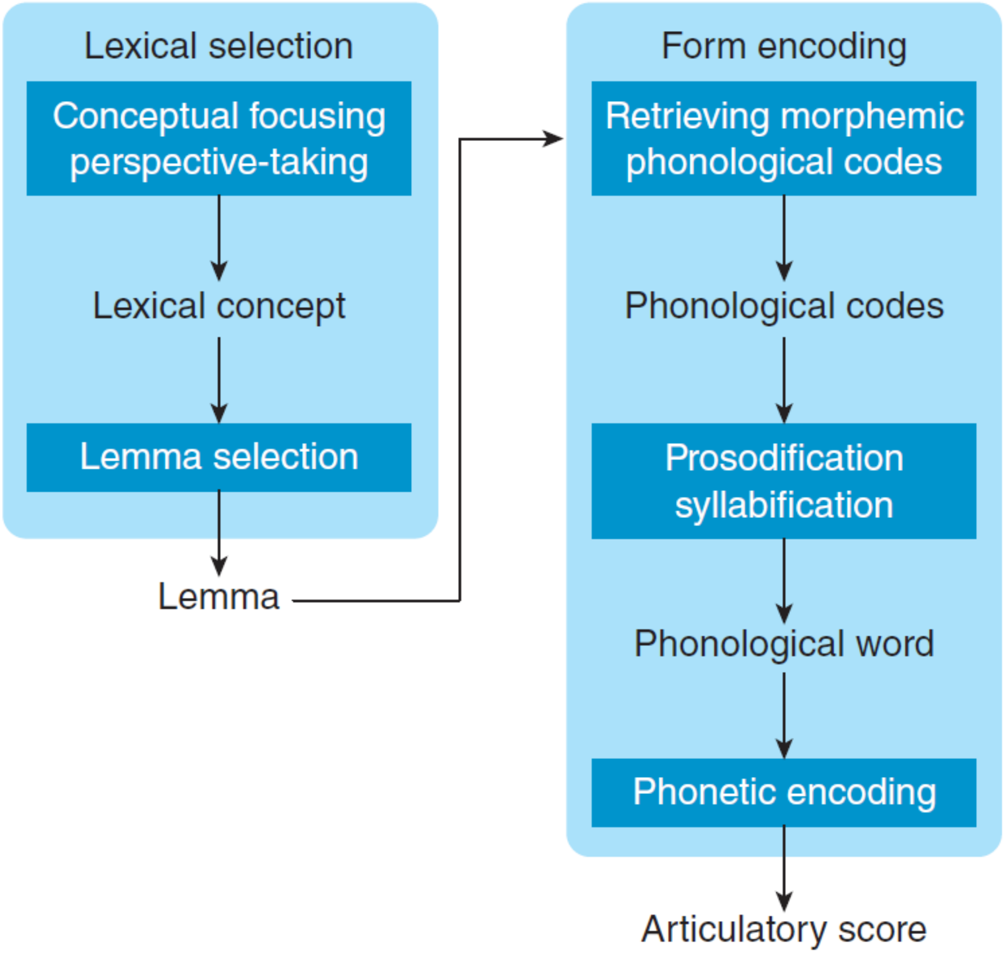
III. Functional neuroanatomy

- Semantic and phonological networks as revealed by fMRI
- A temporospatial model of word production
- PWI studies

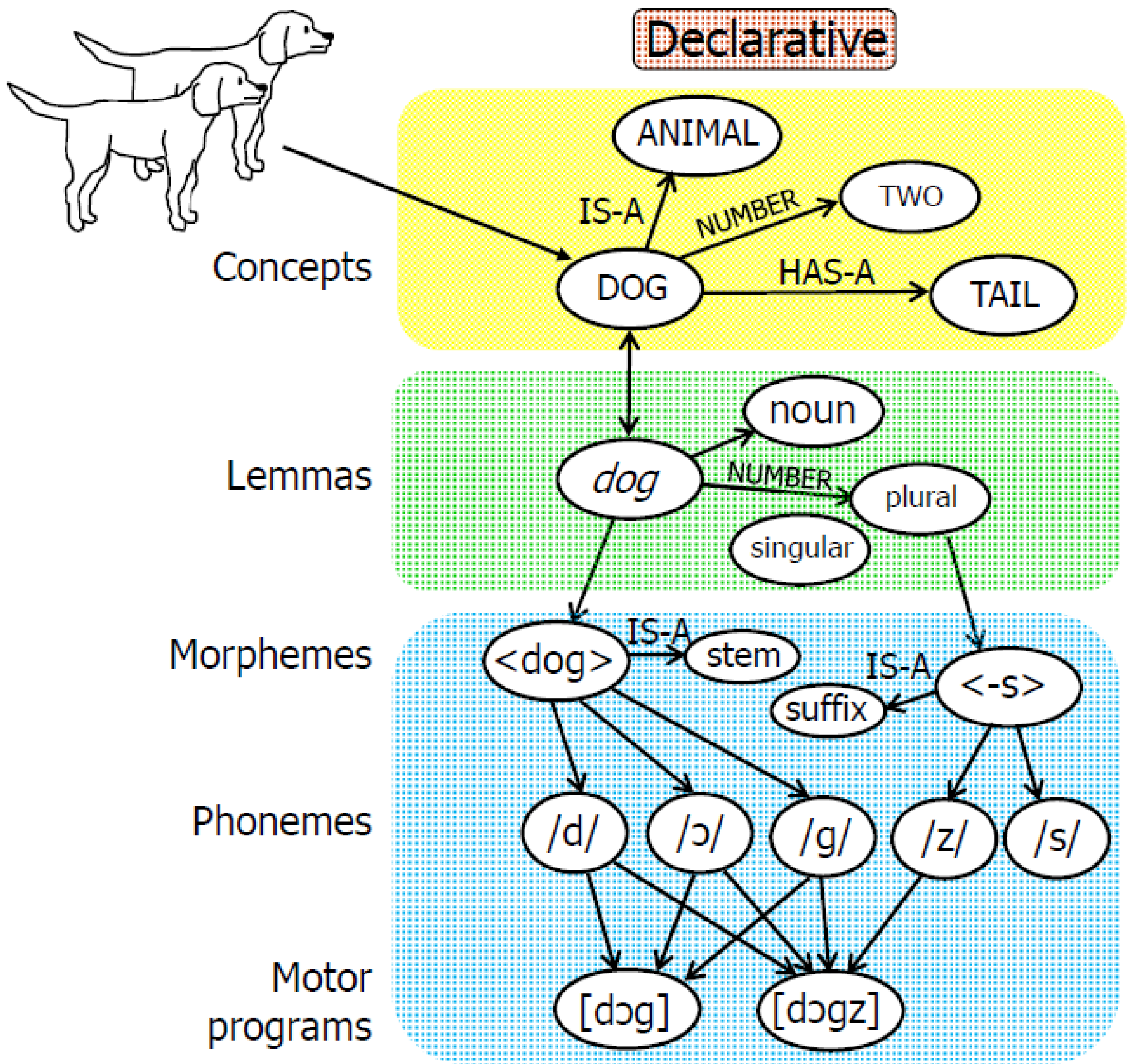
I. A MODEL OF WORD PRODUCTION



A MODEL OF WORD PRODUCTION



Levelt (2001), *PNAS*



Procedural

Morphological rule

IF number is plural
THEN select stem + suffix

Phonological rule

IF stem-final segment is voiced
THEN select /z/

Courtesy of Ardi Roelofs

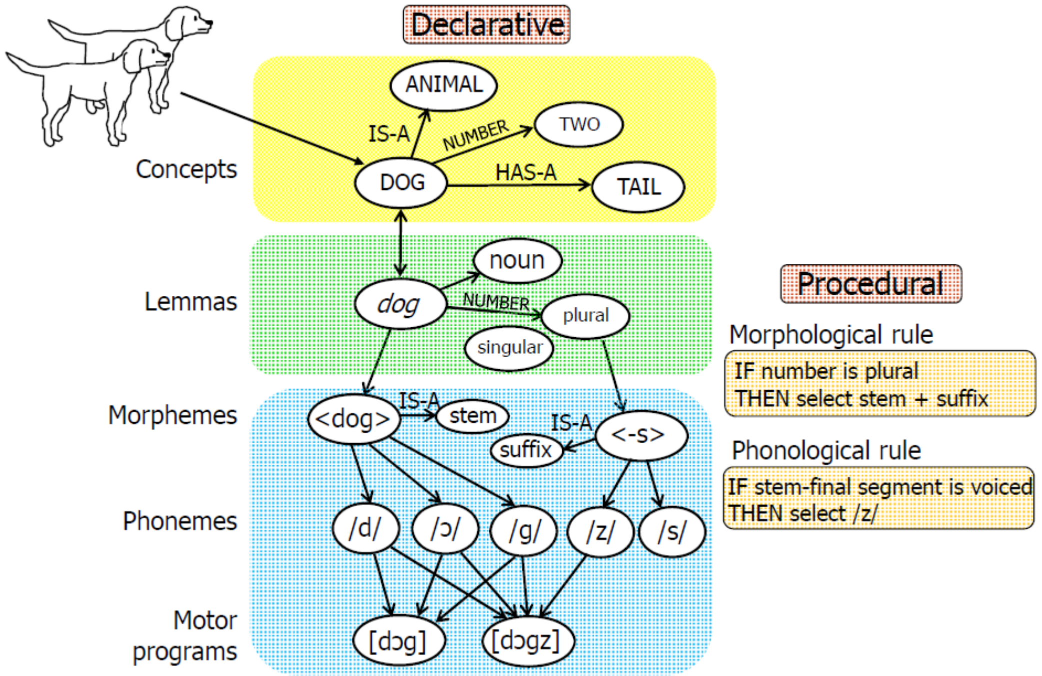
CONCEPTUALISATION

Transforming mental states into linguistic representations: What do we want to say? To whom? What's the context?

Perspective-taking, theory of mind

Product: **LEXICAL CONCEPT** = A unit integrating the semantic features that make up the meaning of a word

Parallel activation of several related concepts next to the target concept



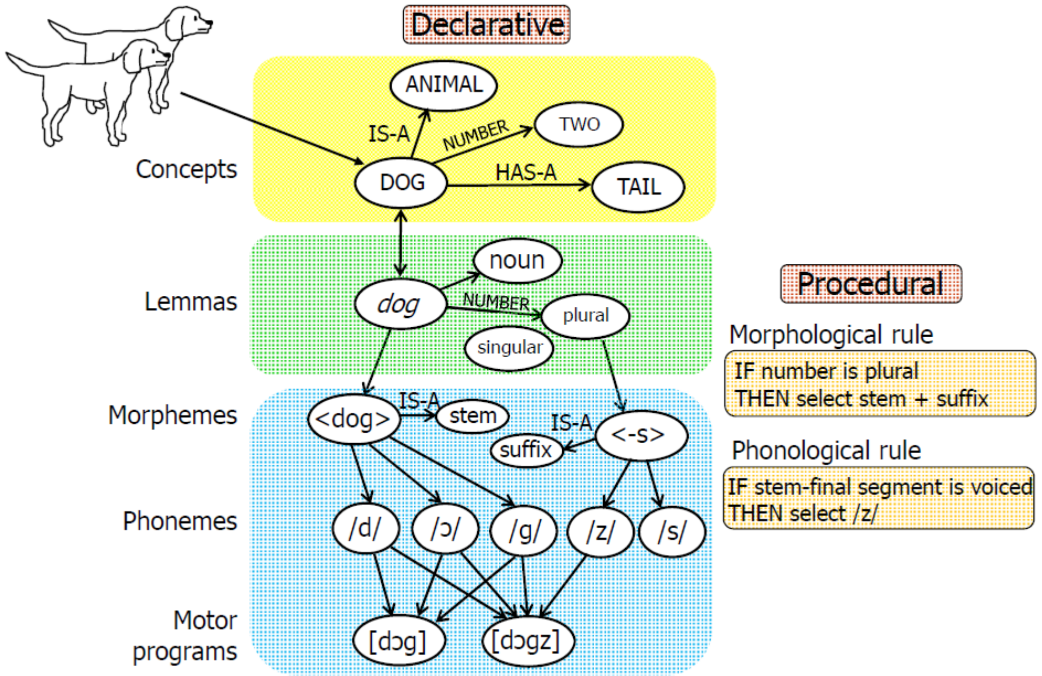
LEMMA SELECTION

Retrieval of semantic, phonological, and morphological characteristics of selected concept

Alternatives need to be actively inhibited

Product: **LEMMA** = abstract unit containing information about semantic, phonological, morphological attributes (gender, grammatical category, transitivity)

WEAVER++ (Roelofs, 1992): likelihood of selection of specific lemma = degree of lemma activation / degree of activation of all concurrently active lemmas



FORM ENCODING

Accessing morphemic representation and spelling out segmental content

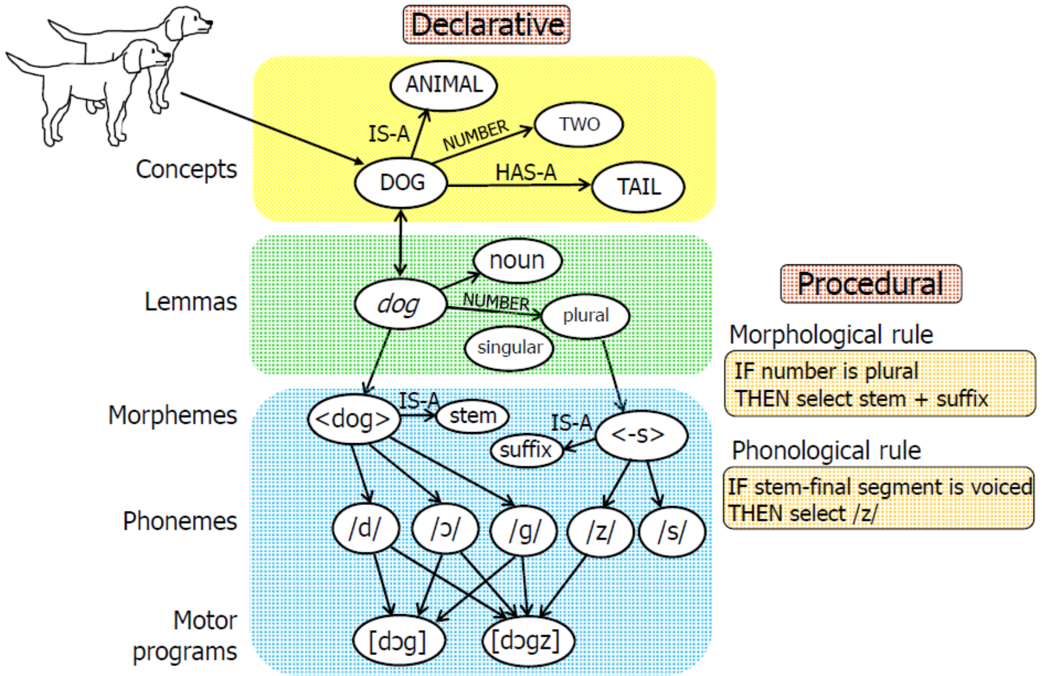
Debate whether this only happens for the selected lemma (serial processing) or also for competitor lemmas (cascaded processing)

Retrieval of phonological codes is influenced by word frequency:

- Homophone effects: RT(moor) = RT(more)

Incremental (“left-to-right”) retrieval

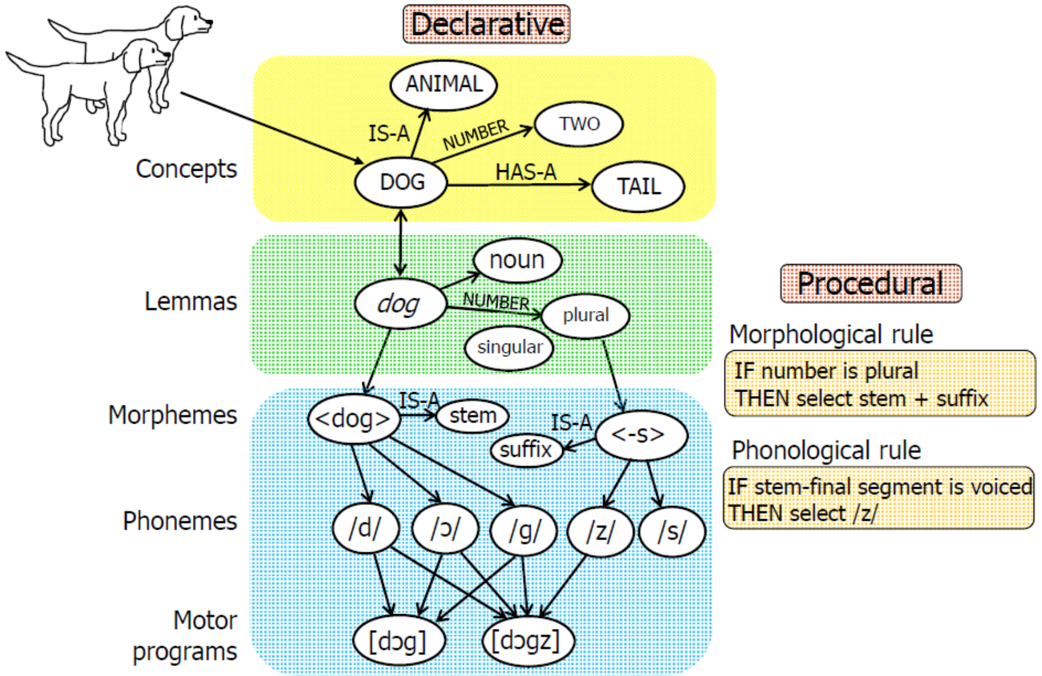
Product: **PHONOLOGICAL CODES**



PROSODIFICATION AND SYLLABIFICATION

Bundling of selected ordered phonological codes into syllables according to metric rules

Product: **PHONOLOGICAL WORD**



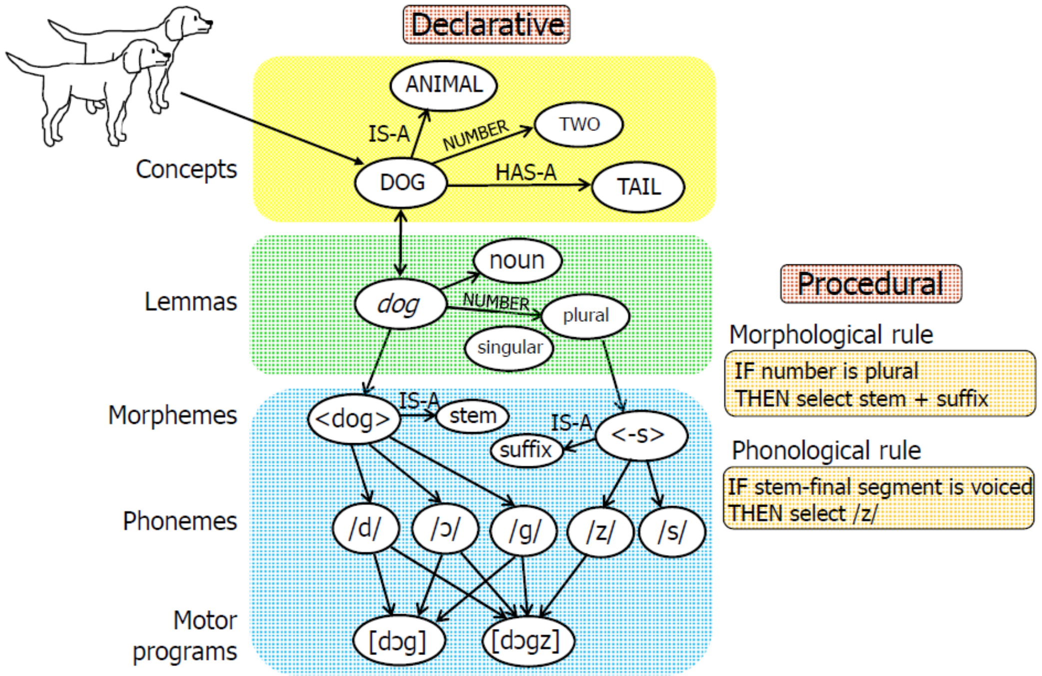
PHONETIC ENCODING AND ARTICULATION

Access to mental syllabary = an inventory of highly practiced syllabic gestures

Highly automatic: 500 syllables suffice to produce 80 percent of all speech tokens in English

Execution of necessary motor programs

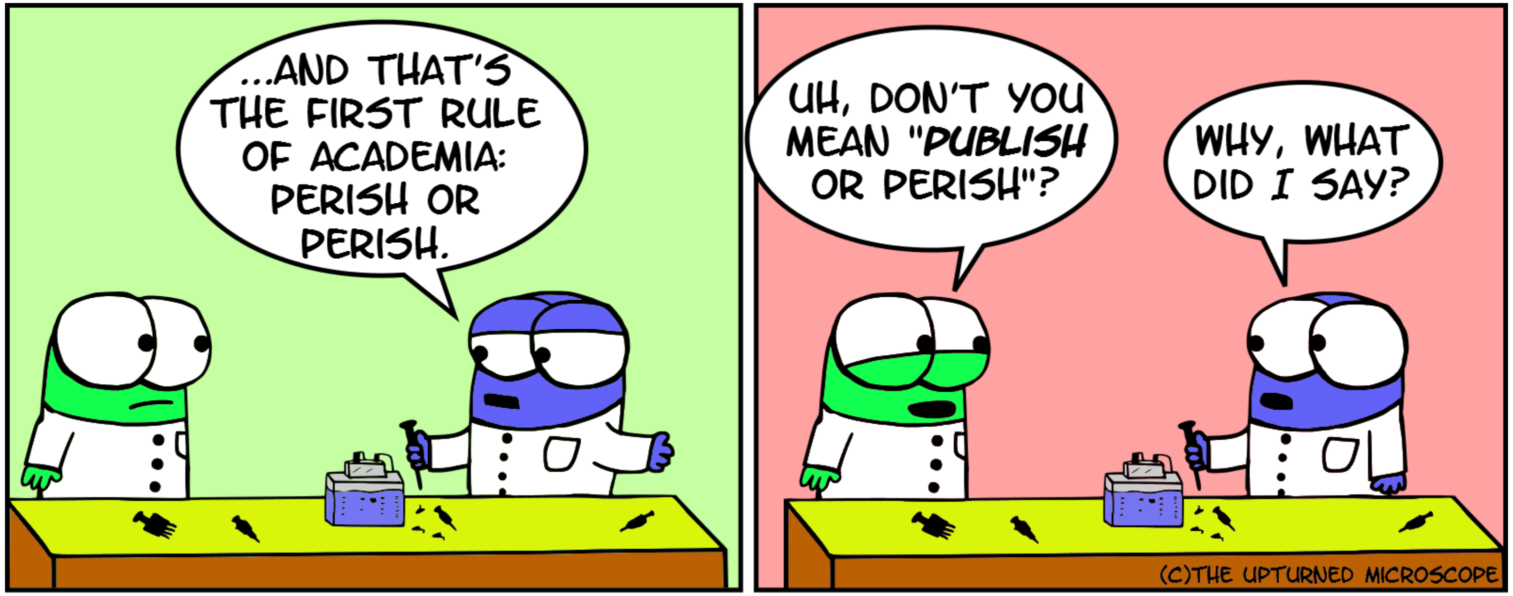
Product: **UTTERANCE**



Success!

You now know the computations involved to utter a single word.

II. BEHAVIOURAL METHODS



https://www.youtube.com/watch?v=hD6c5n4Vi0I

SPEECH ERRORS

"A slip of the tongue [...] is an involuntary deviation in performance from a speaker's current phonological, grammatical or lexical intention"

Boomer & Laver (1968), *Br J Disord Commun*

<u>Word exchange errors</u>

- Is there a cigarette building in this machine?
- Funny to get your nose remodelled
- Older men choose to tend younger women
- Origin: grammatical encoding (functional level)
- Constrained by syntactic factors
- Planning units: lemmas

<u>Sound exchange errors</u>

- Queer old dean
- Foon speeding
- Deed the fog
- Origin: phonological encoding (positional level)
- Constrained by surface distance
- Planning units: segments

SPEECH ERRORS

Different types of errors follow different constraints (Garrett, 1980)

- Constraint: phrase (same or different)

	Within phrase	Between phrases
Word exchanges	19 %	81 %
Sound exchanges	87 %	13 %

- Constraint: grammatical category (same or different)

	Same category	Different category
Word exchanges	85 %	15 %
Sound exchanges	39 %	61 %

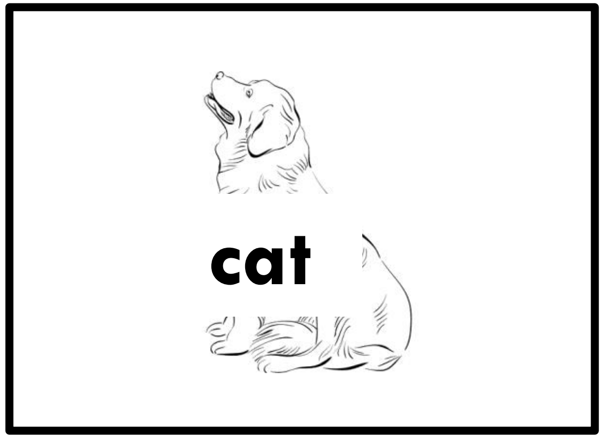
- Some degree of lexical bias

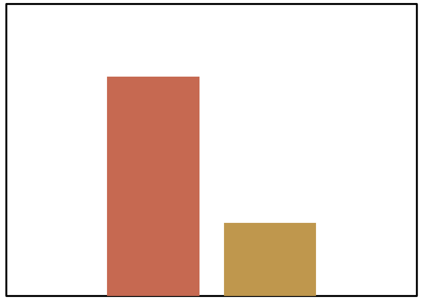
PICTURE-WORD INTERFERENCE PARADIGM

Allows for the investigation of the time-course of semantic and phonological activation in production

Picture naming in the presence of a distractor word that has a specific relation to the target utterance

- Semantically related
- Phonologically related
- Unrelated





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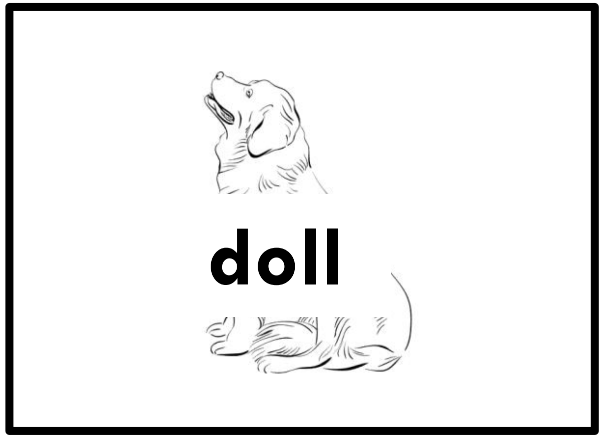

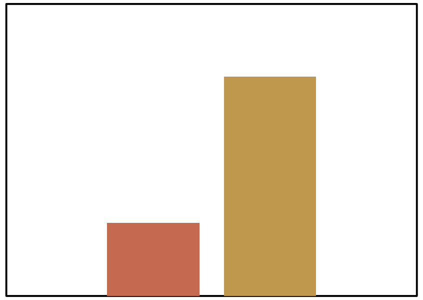

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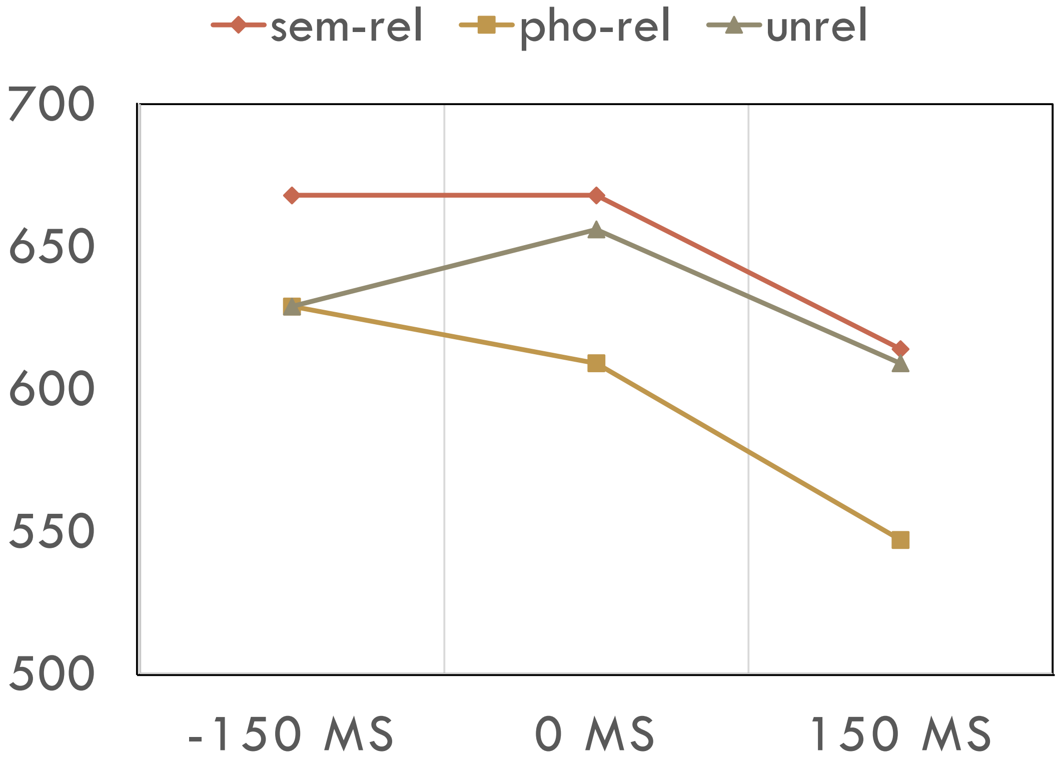
PICTURE-WORD INTERFERENCE PARADIGM: TIMING

Manipulation of onset of distractor word relative to picture onset (stimulus onset asynchrony, SOA) allows for time-specific investigation of word production



Schriefers et al. (1990), *J Mem Lang*

SENTENCE PRODUCTION & ADVANCE PLANNING

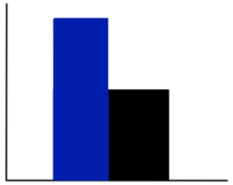
SOAs 0 and 150 ms

1000 ms

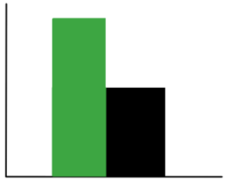
"The monk read the book"

„the **monk** read the **book**"

subj-rel: „priest"
subj-unr: „hammer"
→ interference



obj-rel: „newspaper"
obj-unr: „toddler"
→ interference



Meyer (1996), *J Mem Lang*
Wagner et al. (2010), *J Exp Psychol Learn Mem Cogn*

SENTENCE PRODUCTION & ADVANCE PLANNING

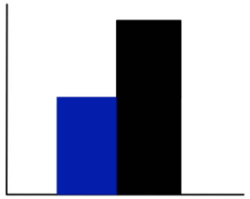
SOAs 150 and 300 ms

1000 ms

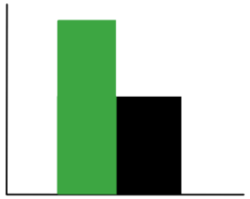
"The monk read the book"

„the **monk** read the **book**"

subj-rel: „molk"
subj-unr: „fes"
→ facilitation

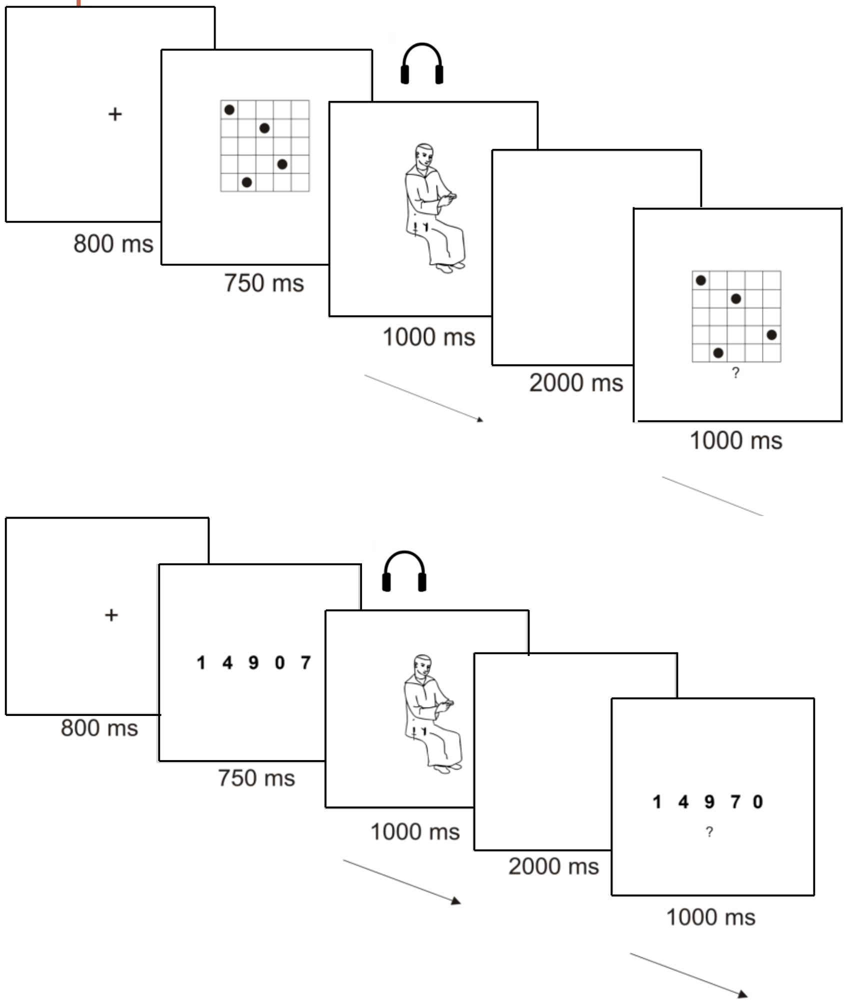


obj-rel: „boos"
obj-unr: „wibe"
→ interference

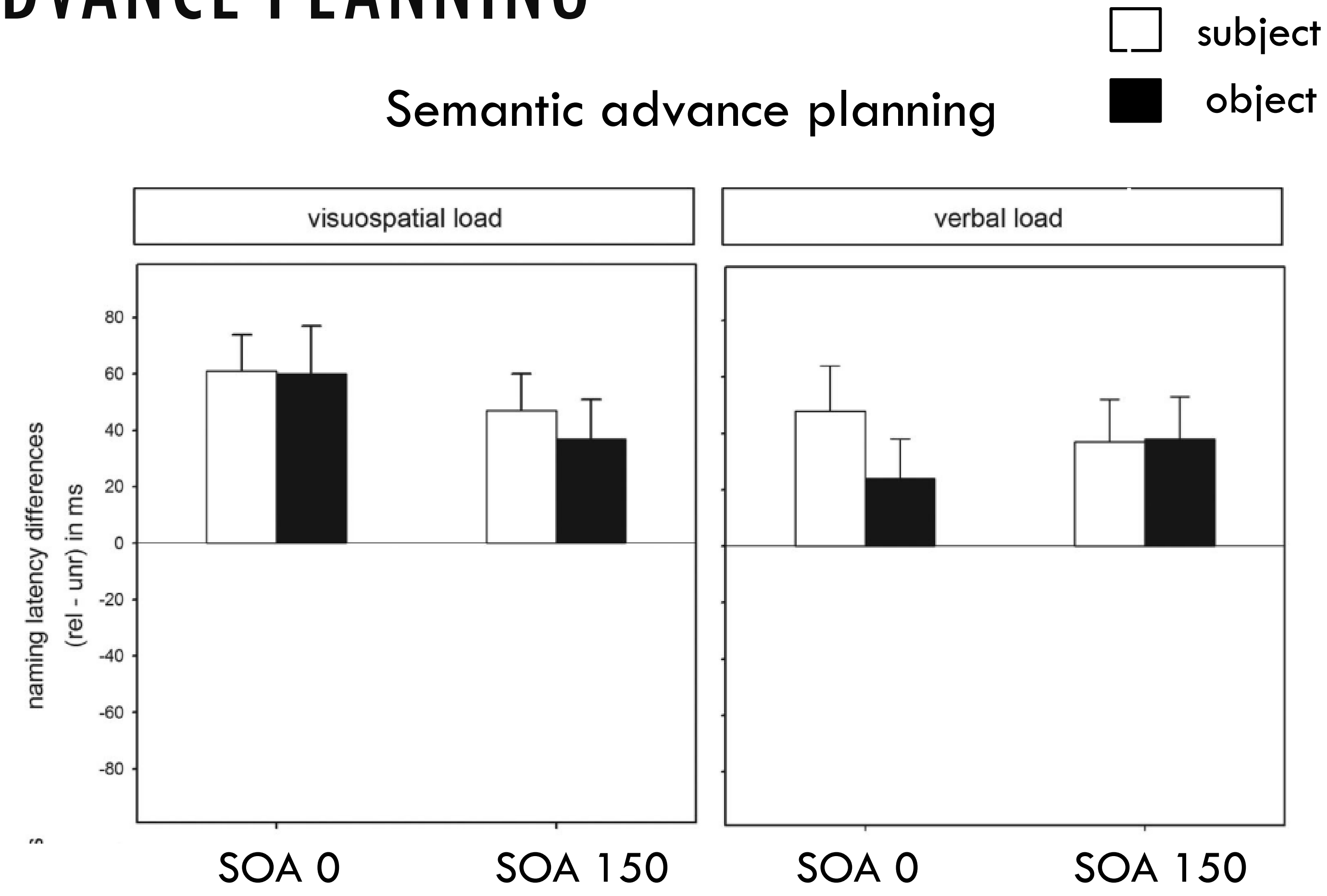


Jescheniak et al. (2003), *J Exp Psychol Hum Percept Perform*
Oppermann et al. (2010), *J Mem Lang*

SENTENCE PRODUCTION & ADVANCE PLANNING

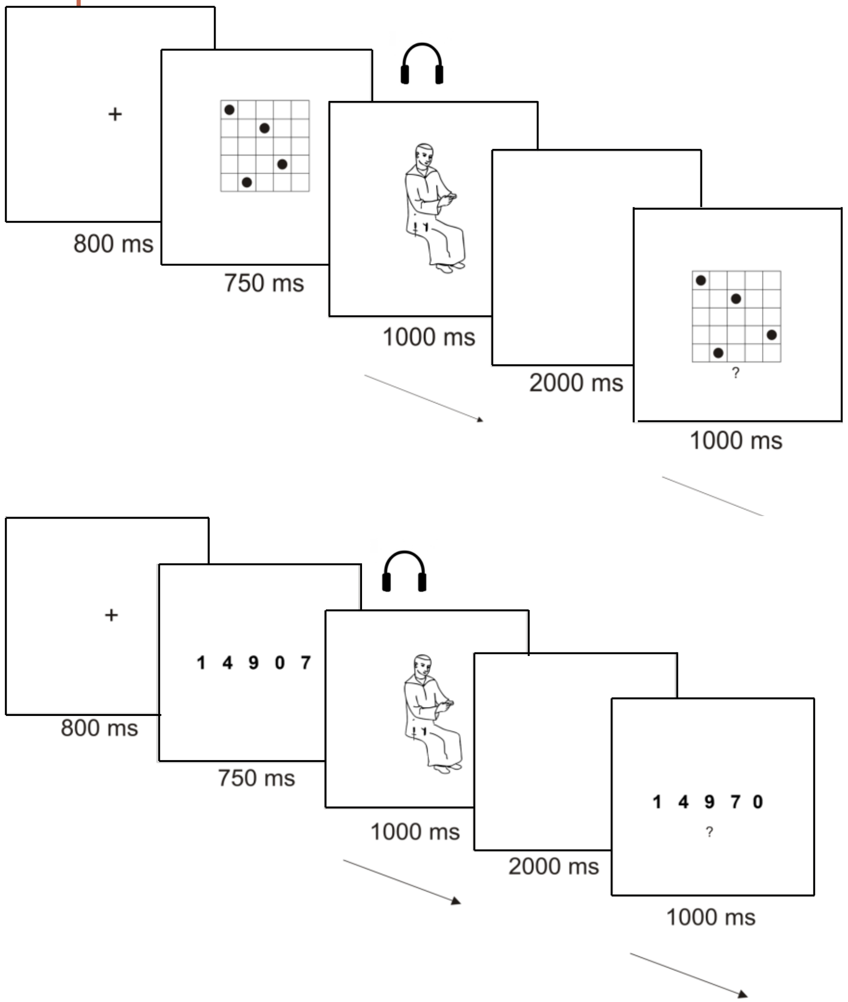


Semantic advance planning

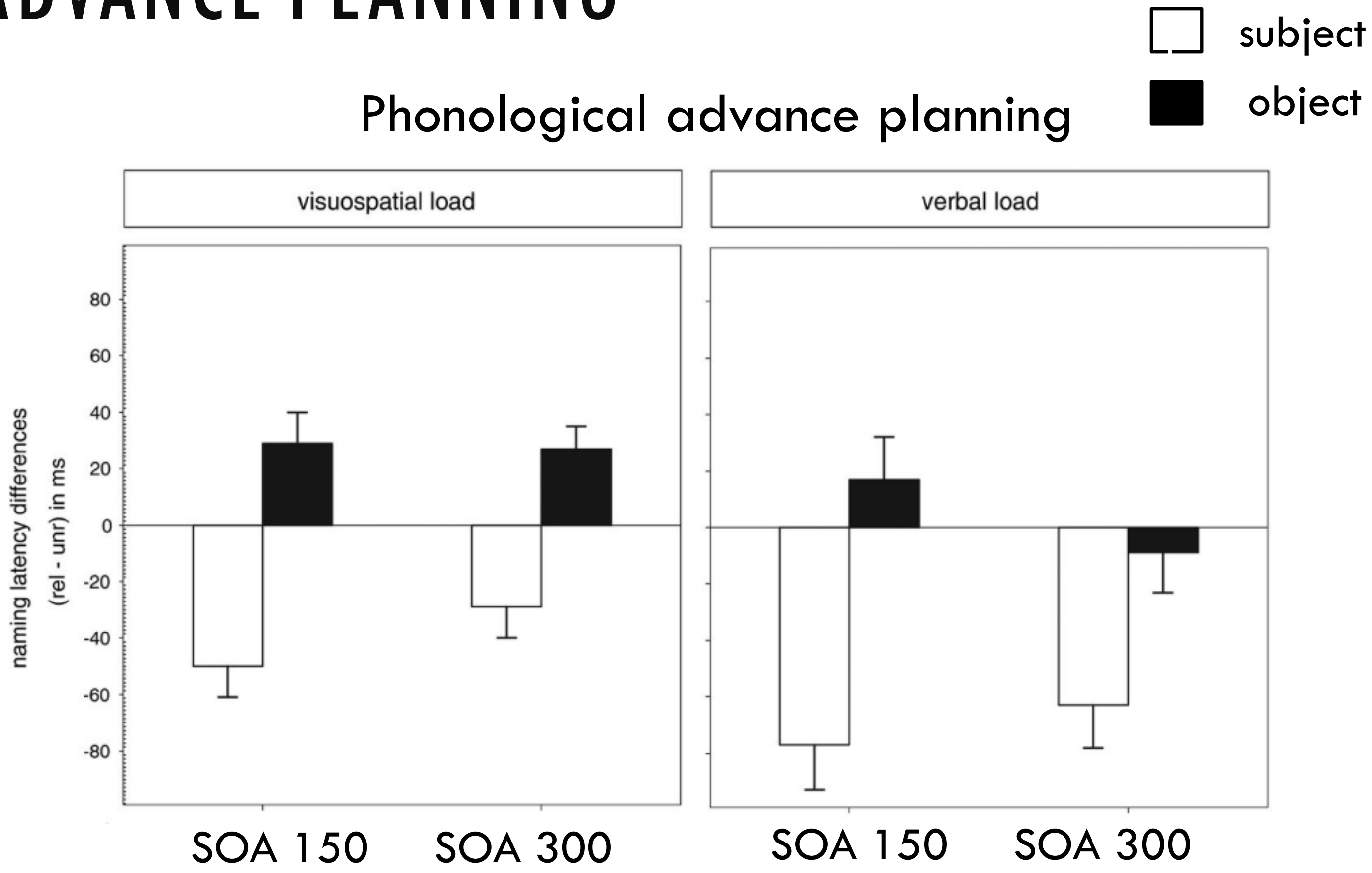


Klaus et al. (2018), *Q J Exp Psychol*

SENTENCE PRODUCTION & ADVANCE PLANNING



Phonological advance planning



Klaus et al. (2018), *Q J Exp Psychol*

INTERIM SUMMARY

Model of word production:

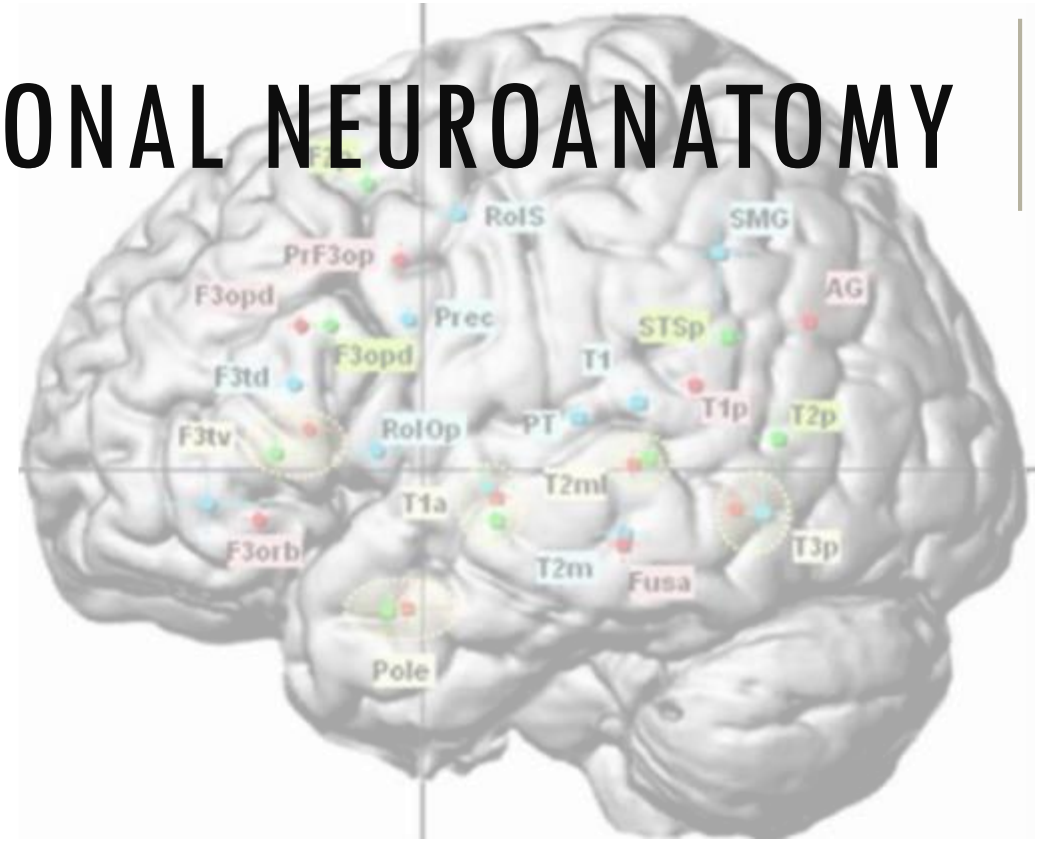
- Conceptualisation
- Lemma selection
- Phonological encoding
- Articulation

Speech errors follow particular linguistic constraints

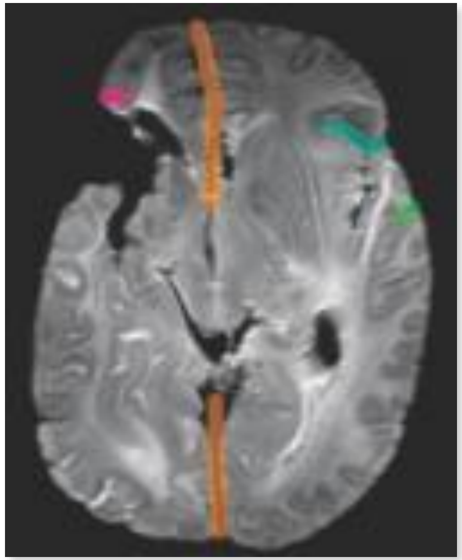
Picture-word interference paradigm allows for time-specific dissociation of semantic and phonological processes

Only phonological advance planning scope in sentence production is variable under increased task difficulty

III. FUNCTIONAL NEUROANATOMY



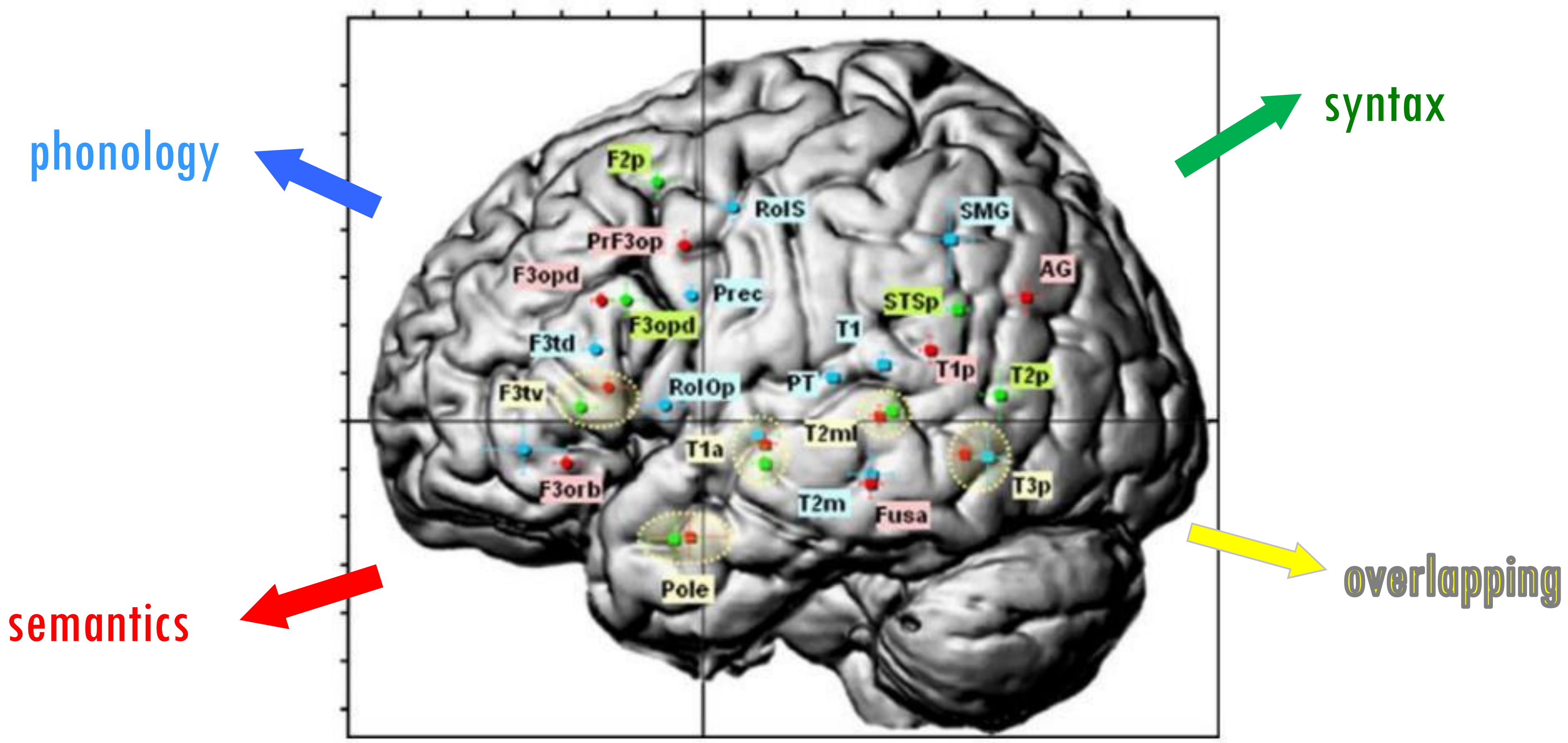
BROCA'S MONSIEUR LEBORGNE ("TAN")



- Broca originally suggested that the posterior IFG is responsible for intact language production
- Dronkers et al. (2007): re-examination of Tan's brain showed a larger lesion, also encompassing more anterior portions of the IFG (among others)

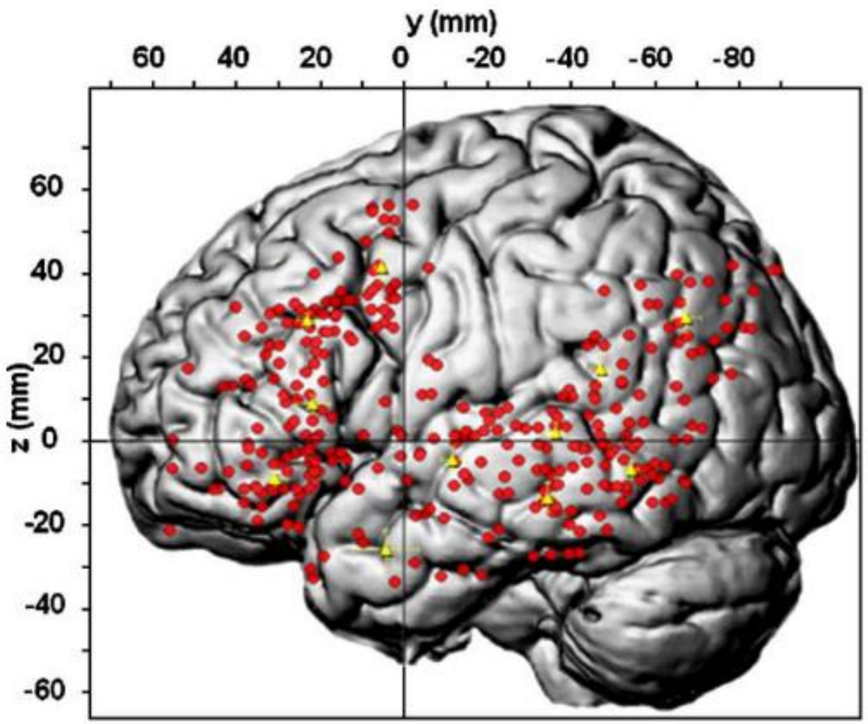
Dronkers et al. (2007), *Brain*

META-ANALYSIS OF 129 IMAGING STUDIES



Vigneau et al. (2006), *NeuroImage*

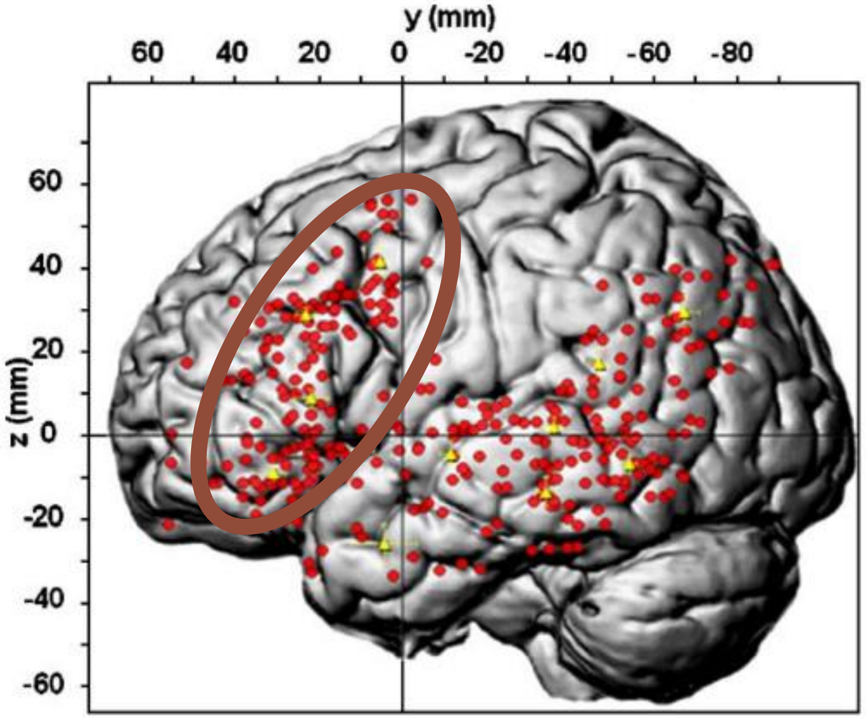
SEMANTICS



<u>322 activation peaks</u>

- 145 peaks in frontal regions in Broca's area and adjacent to precentral gyrus
- 177 peaks in temporal regions including angular gyrus and anterior fusiform gyrus

SEMANTICS



<u>Frontal regions</u>

Precentral gyrus/pars opercularis junction:

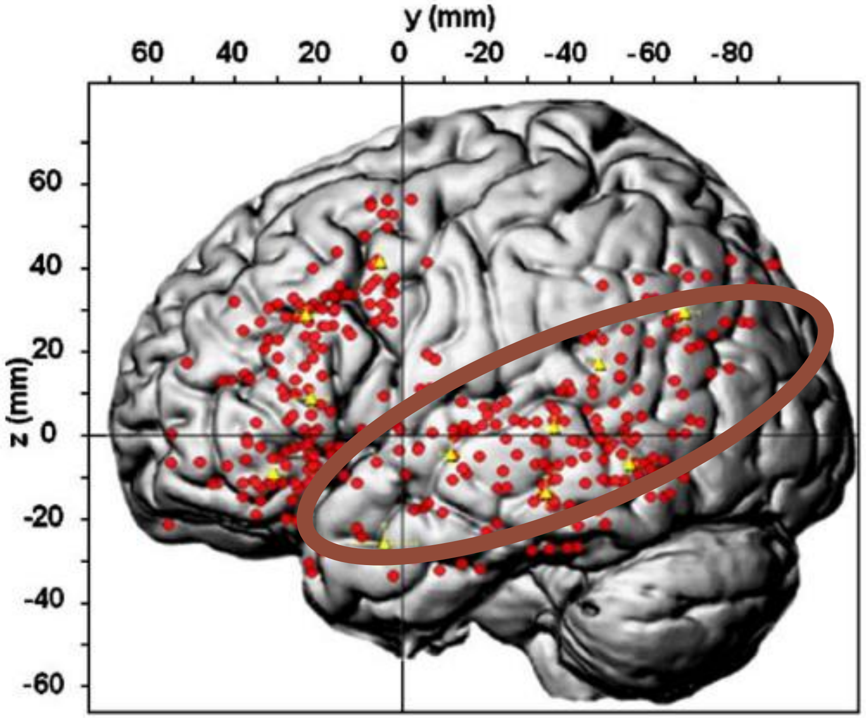
- Controlled semantic retrieval

Pars orbitalis:

- Online retrieval of semantic information

Co-activation of both areas modulated by degree of control that is required during semantic retrieval

SEMANTICS



<u>Three specifically semantic temporal clusters</u>

Modality-specific verbal area (pSTG):

- Based on semantic contrasts with written words

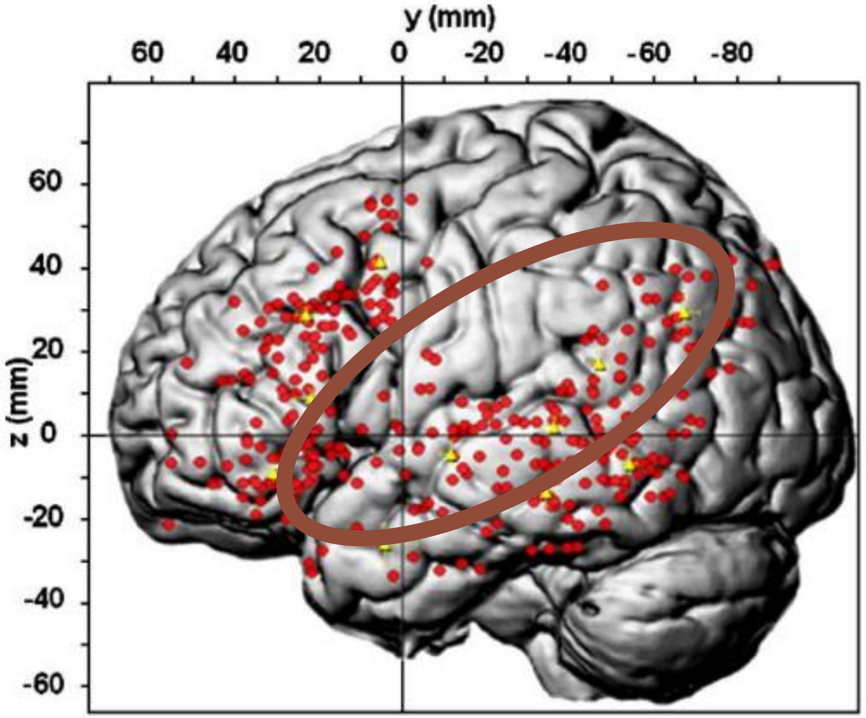
Modality-independent verbal area (MTG):

- Verbal knowledge
- Semantic tasks in visual and auditory domain

Amodal conceptual areas (angular gyrus, anterior fusiform gyrus):

- Conceptual knowledge
- Semantic processing of words and pictures

TEMPORO-FRONTAL SEMANTIC NETWORK



- Angular and fusiform gyrus and temporal pole linked to pars orbitalis: constructs overall meaning on the basis of external (auditory, visual) and internal (memory, emotion) messages
- Connected by inferior longitudinal fasciculus (temporal regions) and uncinate fasciculus (temporal pole → IFG)

TEMPORO-FRONTAL SEMANTIC NETWORK

Intraoperative stimulation of frontal, temporal, and insular regions of brain tumour patients

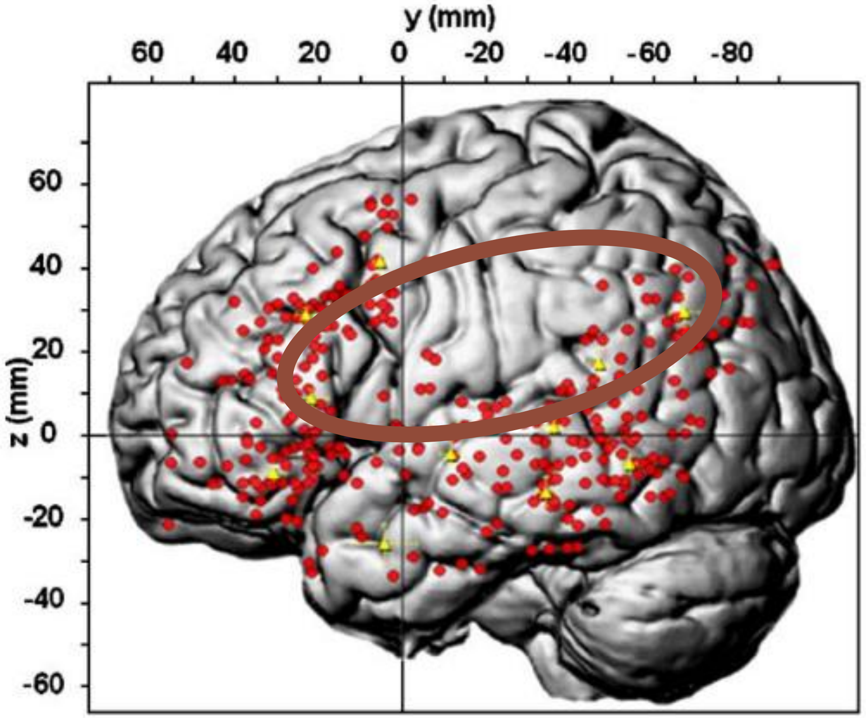
Patients with temporal gliomas showed semantic paraphasias (e.g. saying “zebra” instead of “giraffe”) during stimulation of posterior part of the superior temporal sulcus and adjacent subcortical structures

Patients with frontal gliomas showed semantic paraphasias during stimulation of inferior frontal sulcus regions and corresponding subcortical structures

→ Evidence for semantic network connecting posterior and superior temporal areas with frontal regions

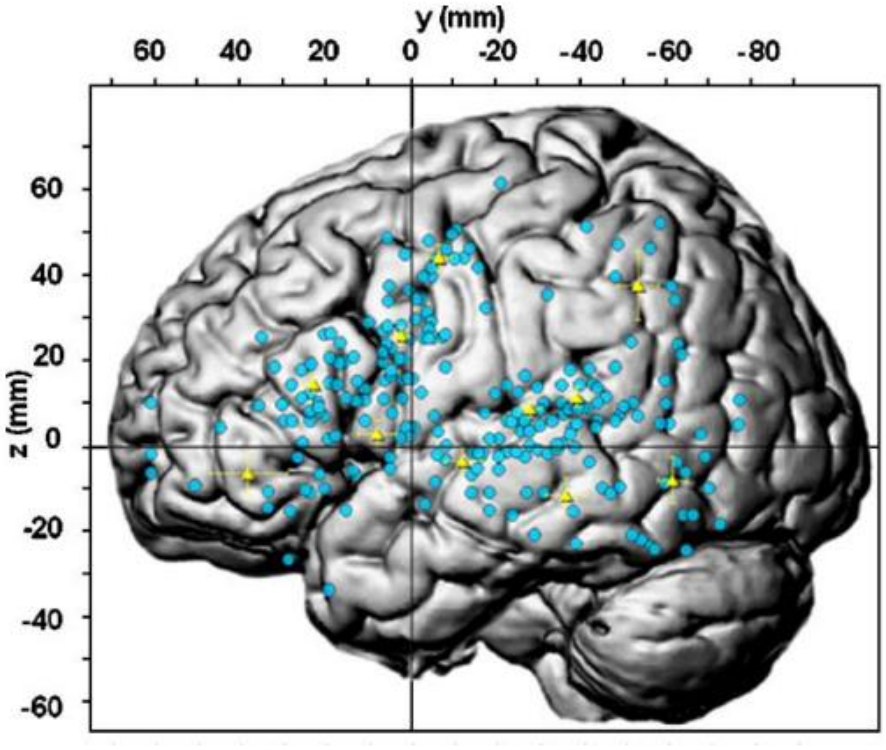
Duffau et al. (2005), *Brain*

FRONTO-PARIETAL SEMANTIC WORKING MEMORY NETWORK



- Junction of precentral gyrus and pars opercularis and angular gyrus, connected through arcuate fasciculus
- Angular gyrus evaluates semantic associations
- Pars opercularis executes selection among semantic knowledge

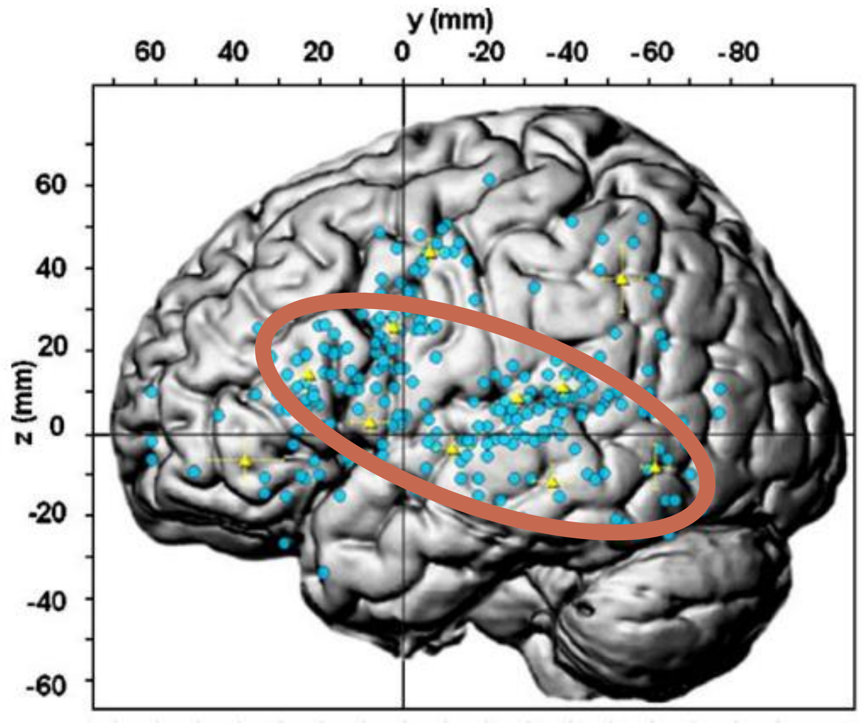
PHONOLOGY



<u>247 activation peaks</u>

- 125 peaks in frontal regions, including dorsal pars triangularis and posterior frontal regions along the precentral gyrus
- 122 peaks in temporal and parietal regions (STG, SMG)
- modality-dependent temporal clusters overlapping with semantic processing

PHONOLOGY: FRONTO-TEMPORAL AUDITORY MOTOR NETWORK FOR SENSORY-MOTOR CONTROL



Rolandic sulcus:

- Motor control and covert imitation

Lower precentral cluster:

- Silent rehearsal

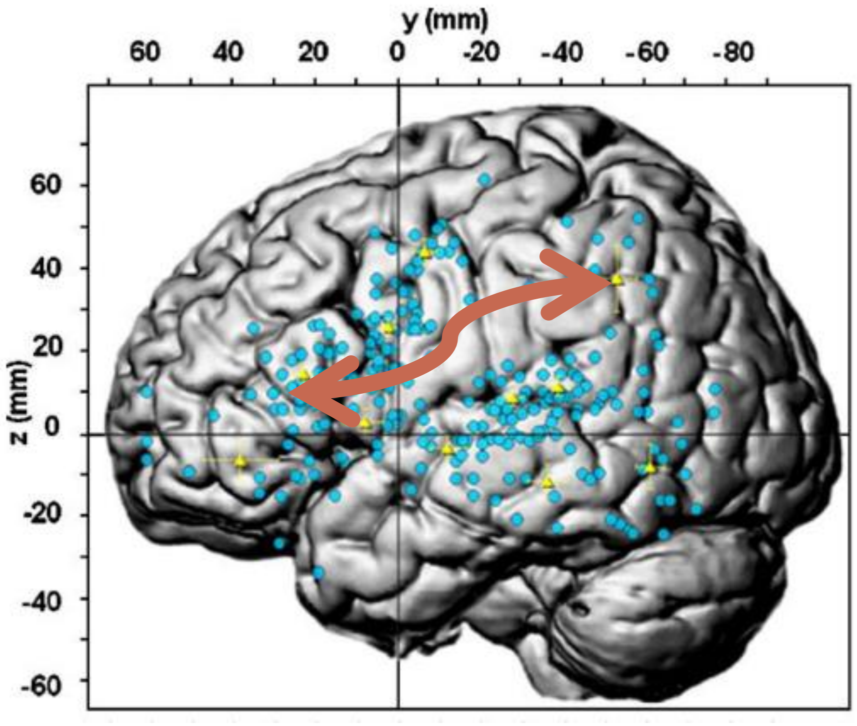
Rolandic operculum and postcentral gyrus of insula:

- Articulation and sensory integration

Arcuate fasciculus connects posterior portions of IFG to posterior STG and planum temporale:

- Involved in speech listening and covert speech production
- Motor-sound based phoneme representation

PHONOLOGY: FRONTO-PARIETAL PHONOLOGICAL WORKING MEMORY LOOP



Dorsal pars triangularis:

- Explicit working memory tasks requiring the active rehearsal of phonological content

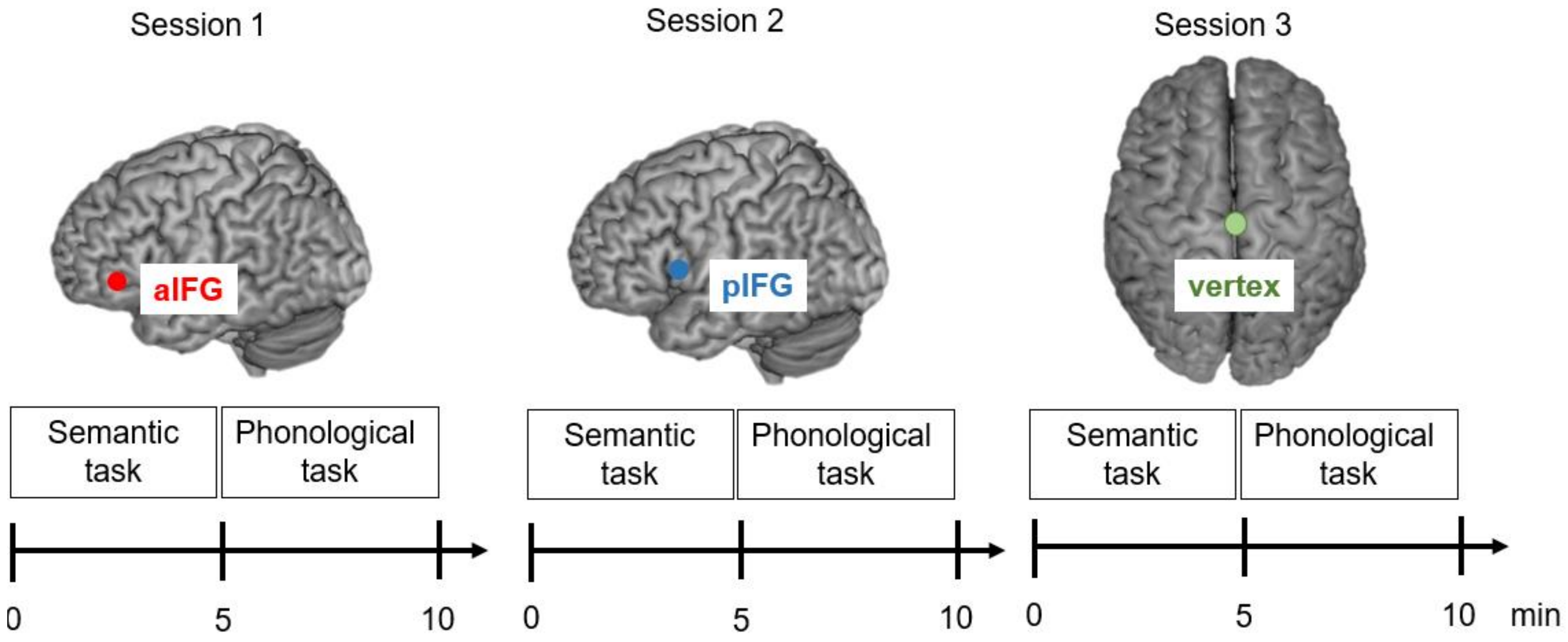
Supramarginal gyrus:

- Phonological store

Connected by arcuate fasciculus

DISSOCIATION OF SEMANTIC AND PHONOLOGICAL CONTENTS IN THE LEFT IFG

Task (semantic vs. phonological) x rTMS (aIFG vs. pIFG vs. vertex)

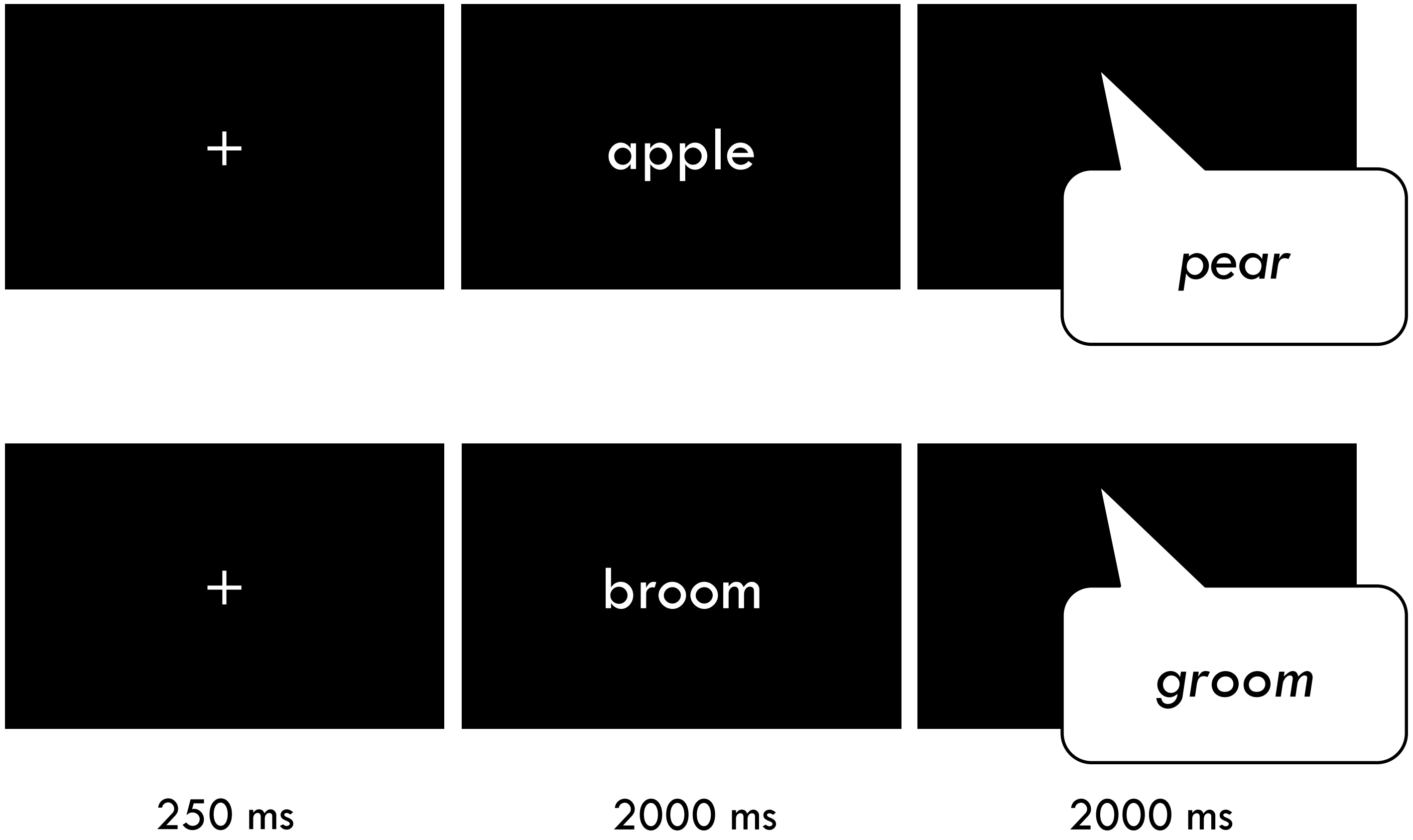


Klaus & Hartwigsen (under review)

DISSOCIATION OF SEMANTIC AND PHONOLOGICAL CONTENTS IN THE LEFT IFG

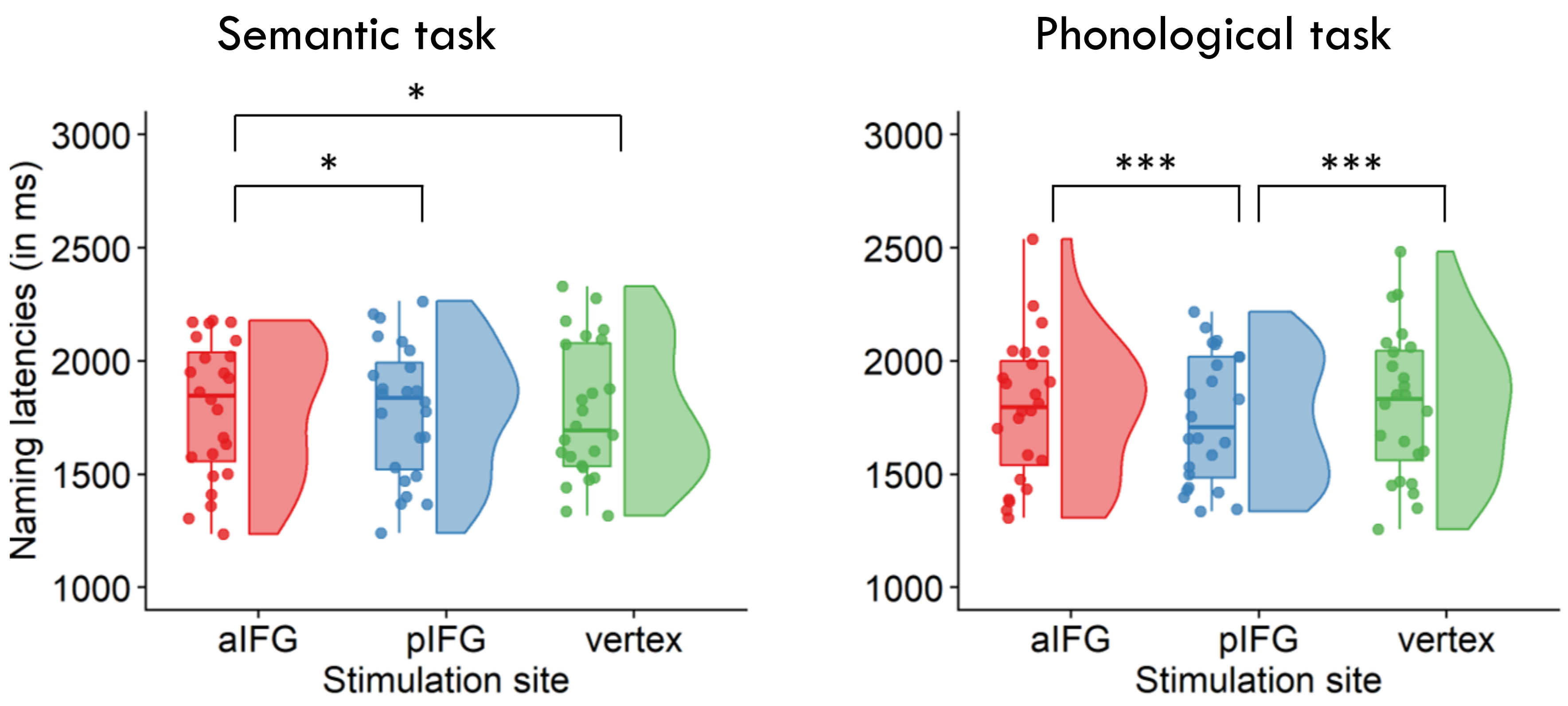
Semantic:
Category member generation task

Phonological:
Rhyme generation task



Klaus & Hartwigsen (under review)

DISSOCIATION OF SEMANTIC AND PHONOLOGICAL CONTENTS IN THE LEFT IFG



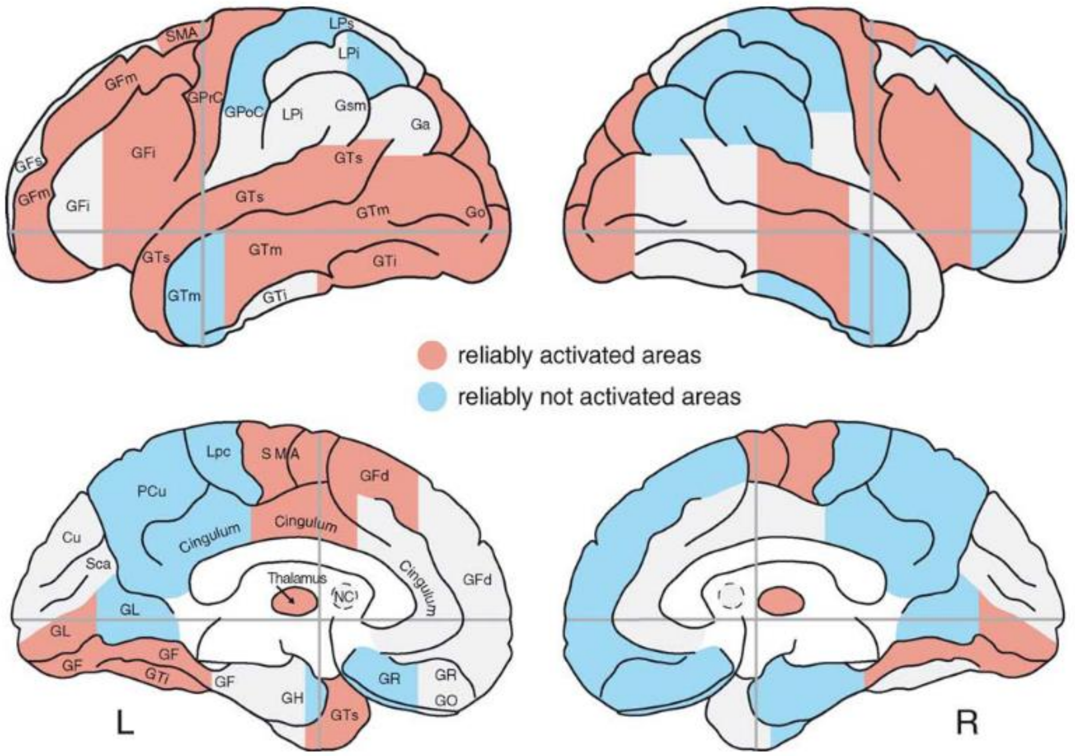
Klaus & Hartwigsen (under review)

SPATIAL MODEL OF PRODUCTION

Indefrey & Levelt (2004), *Cognition*

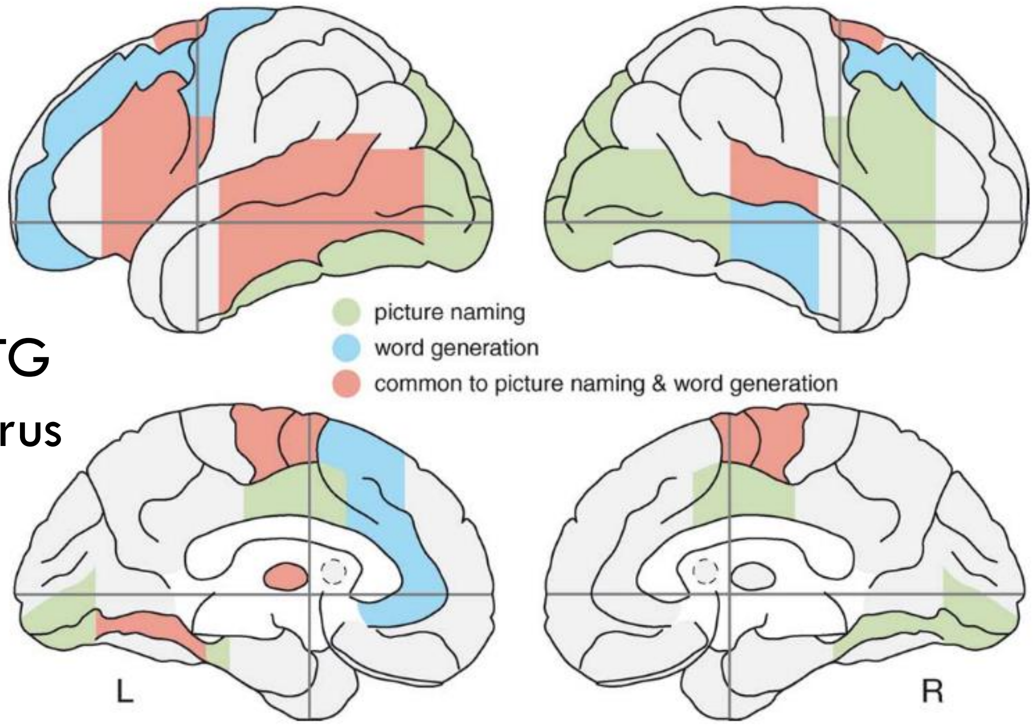
Meta-analysis of 82 word production studies

- Picture naming, word generation, word reading, pseudoword reading
- fMRI, PET, MEG
- Covert and overt articulation



CORE WORD PRODUCTION NETWORK

11 left-hemispheric regions
posterior IFG
ventral precentral gyrus
SMA
mid and posterior STG and MTG
posterior temporal fusiform gyrus
anterior insula
thalamus
medial cerebellum



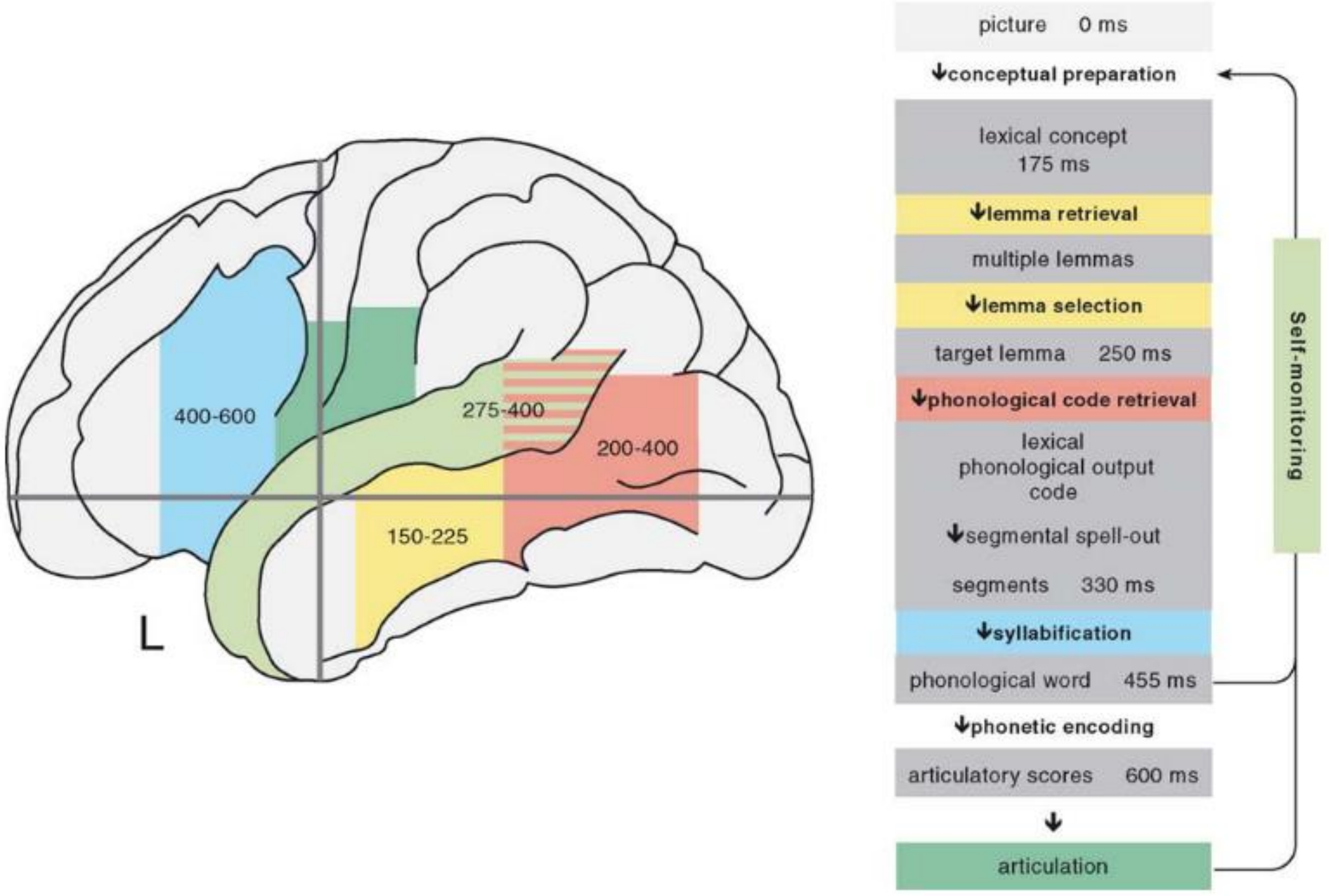
4 right-hemispheric regions
mid STG
SMA
medial and lateral cerebellum

Indefrey & Levelt (2004), *Cognition*

A TEMPOROSPATIAL PICTURE NAMING MODEL

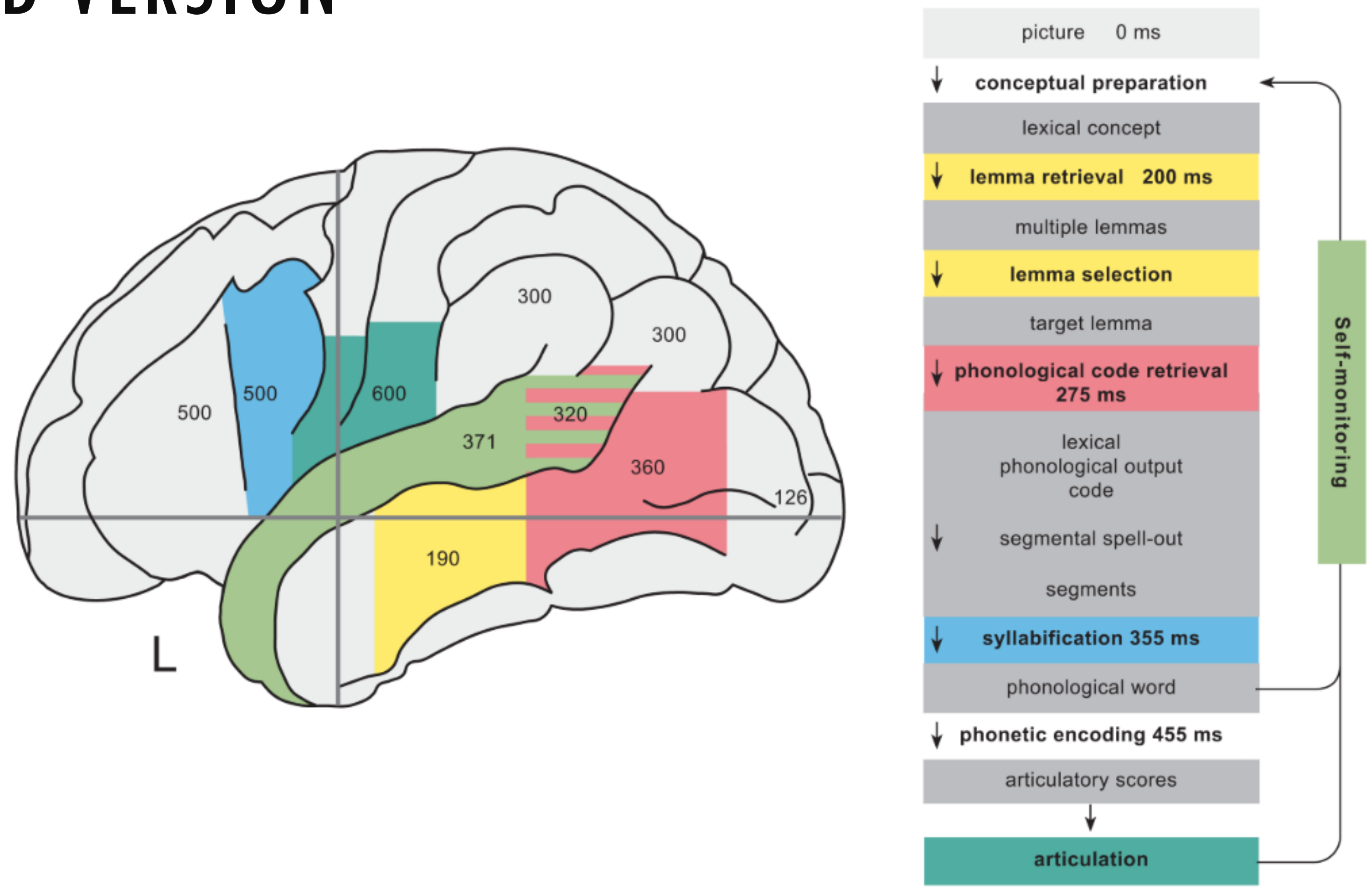
Temporal component based on chronometric behavioural and ERP studies of picture naming assuming an average naming latency of 600 ms

Spatial component based on meta-analysis of picture naming studies (see previous slides)



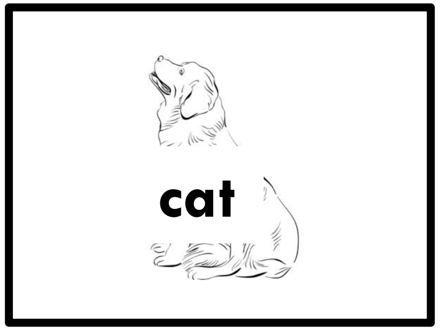
Indefrey & Levelt (2004), *Cognition*

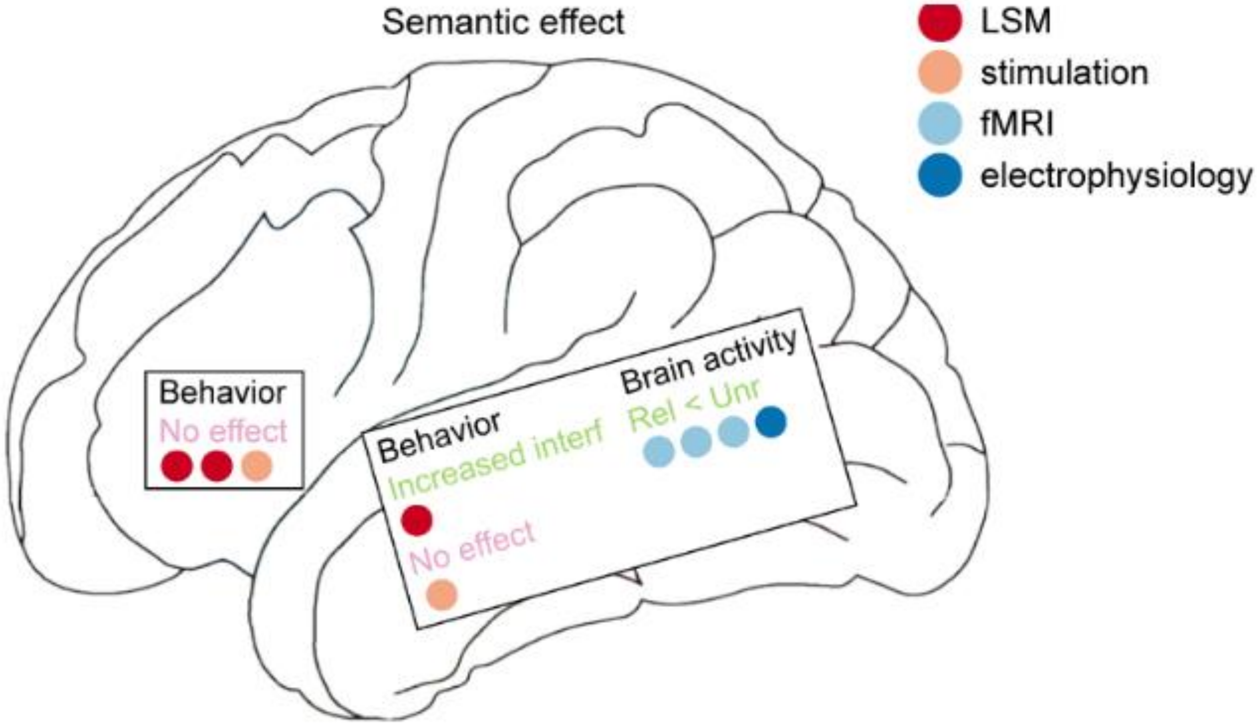
UPDATED VERSION



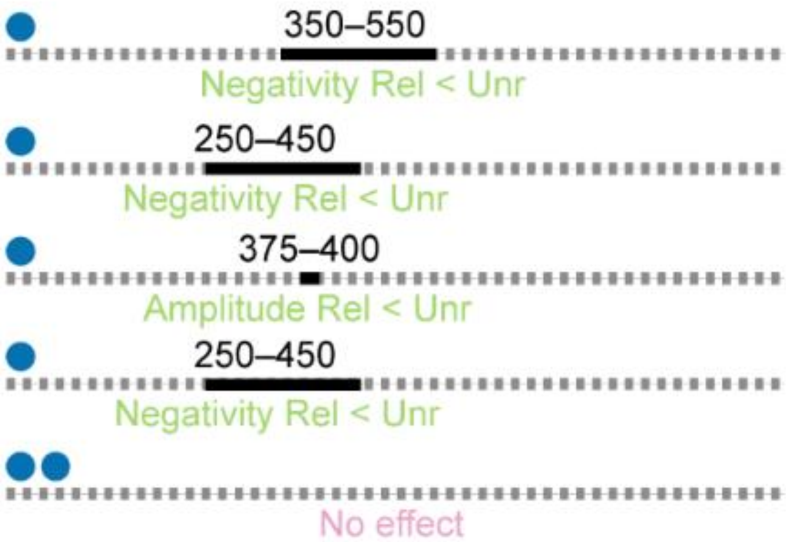
Indefrey (2011), *FiP*

SEMANTIC EFFECTS IN PWI: NEUROLINGUISTIC EVIDENCE



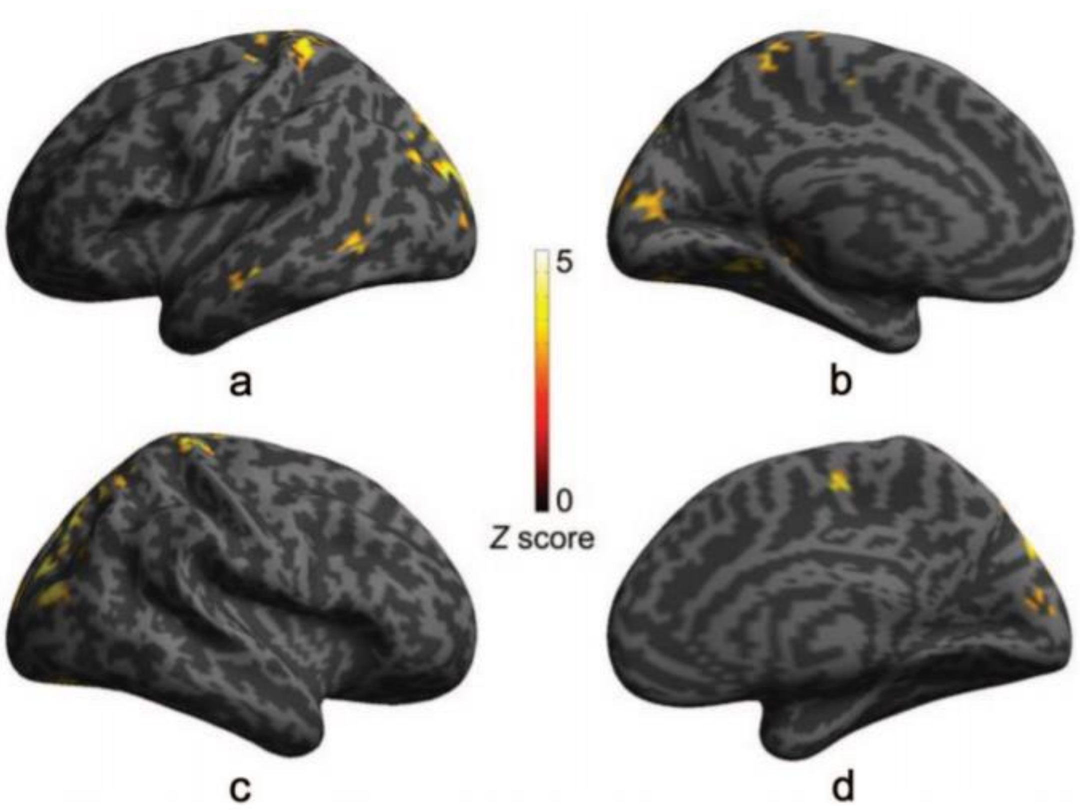


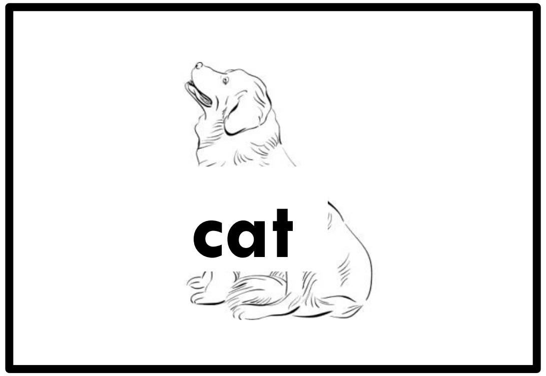
ERPs



from de Zubicaray & Piai (2019)

SEMANTIC INTERFERENCE EFFECTS



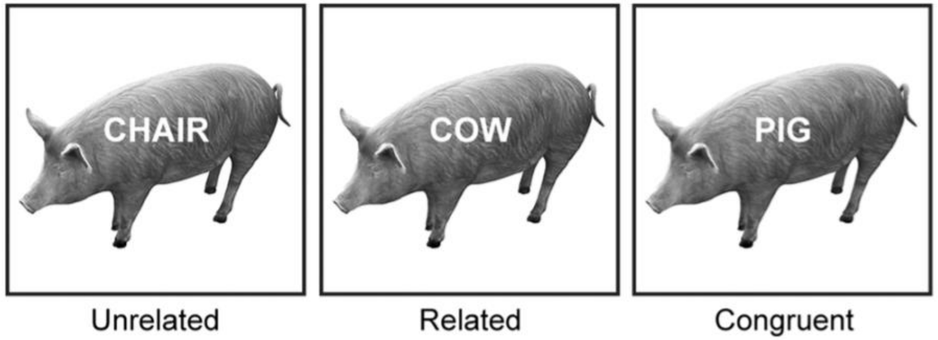


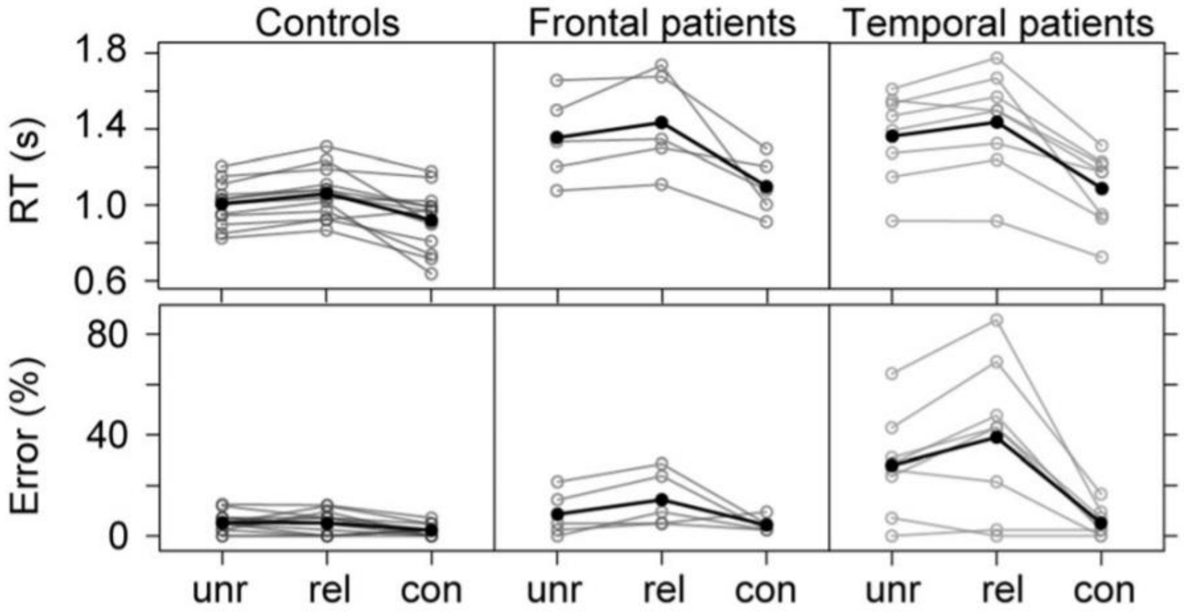
Reduced activity in left mid-to-posterior MTG and STG for related relative to unrelated distractor words – interpreted as lexical cohort activation

de Zubicaray et al. (2013), *J Exp Psychol Gen*

SEMANTIC INTERFERENCE IN PATIENTS WITH LEFT-HEMISPHERIC LESIONS

Patients with left prefrontal or left temporal lesions





Naming latencies:

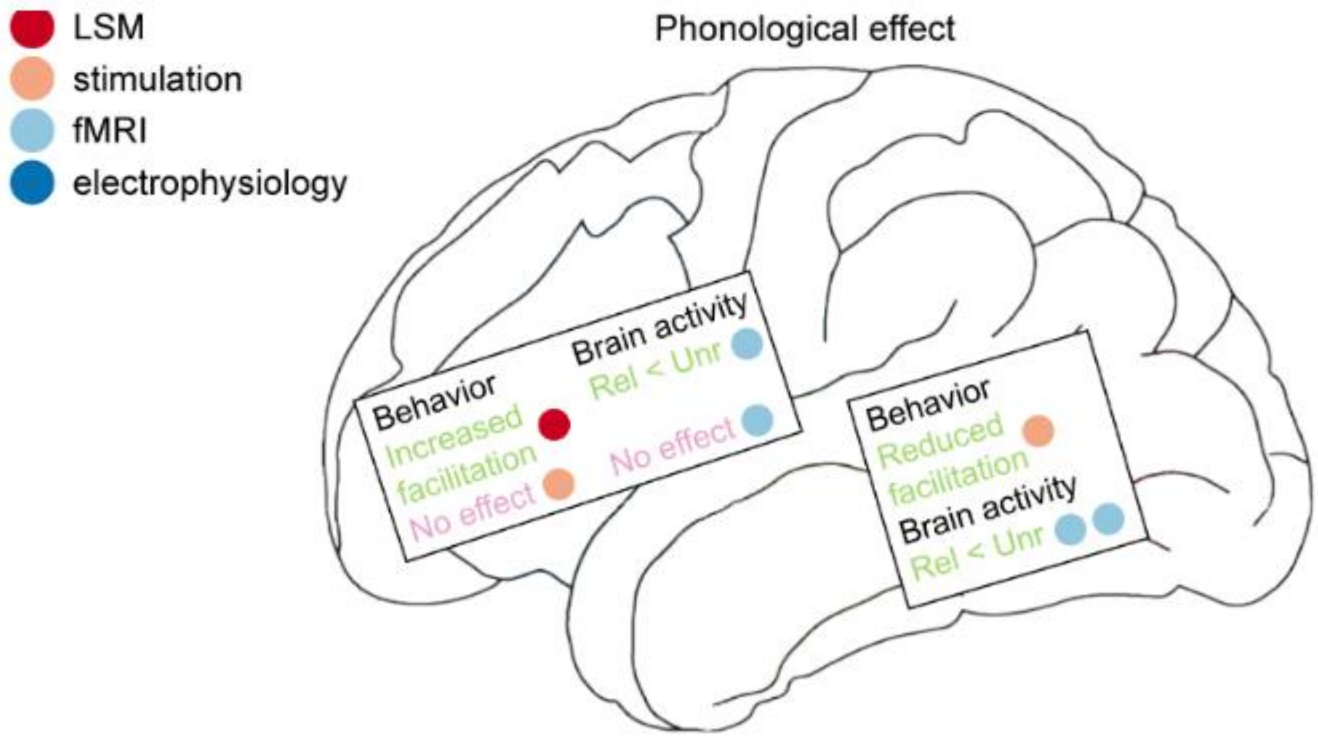
- rel > unr for controls and temporal patients
- rel = unr for frontal patients

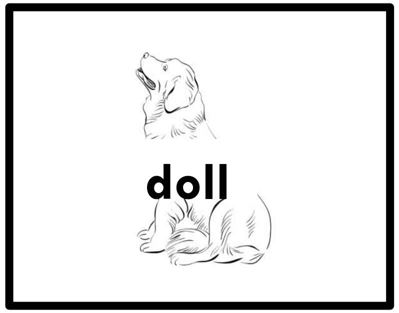
Error rates:

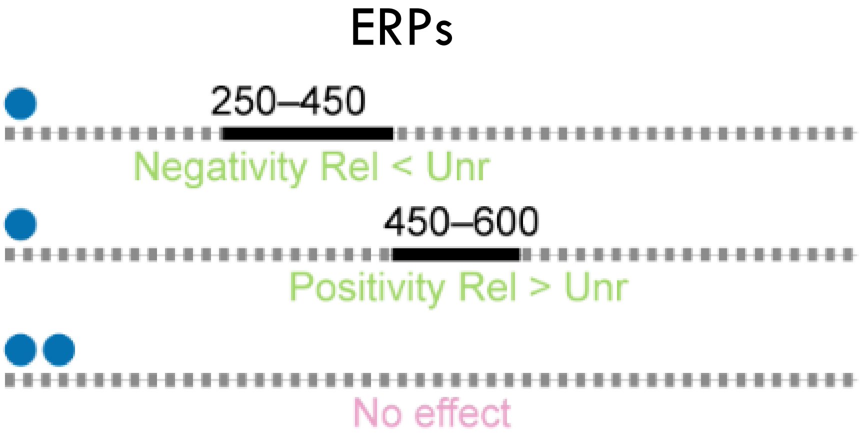
- rel > unr for frontal and temporal patients
- larger for temporal patients compared to controls

Piai & Knight (2017), *Psychon Bull Rev*

PHONOLOGICAL EFFECTS IN PWI: NEUROLINGUISTIC EVIDENCE

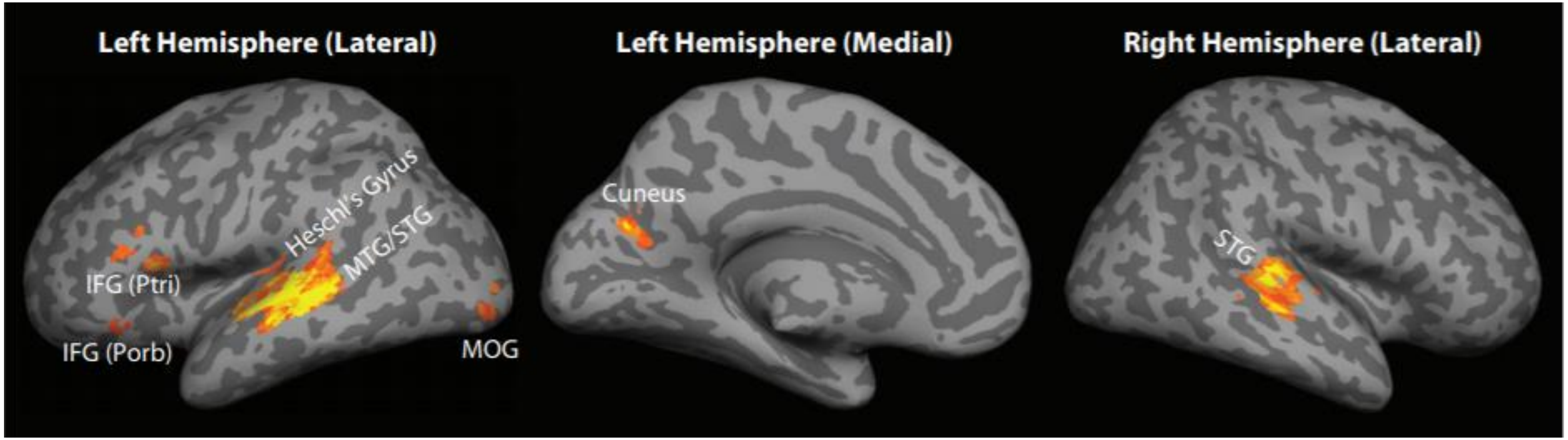






from de Zubicaray & Piai (2019)

PHONOLOGICAL EFFECTS IN PWI: NEUROLINGUISTIC EVIDENCE



BOLD decreases in left posterior MTG and STG and left IFG for both semantically and phonologically related distractors

de Zubicaray & McMahon (2009)

THANK YOU