How to give ACT-R a brain?

Jelmer Borst

university of groningen

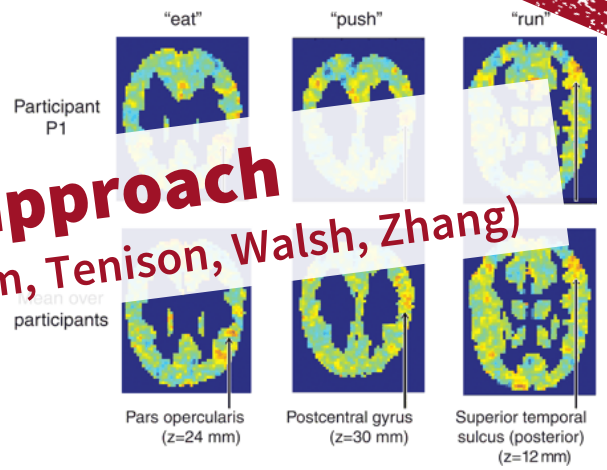
Post-Graduate Summer School

July 19, 2011

How to improve neuroscience for ACT-R?

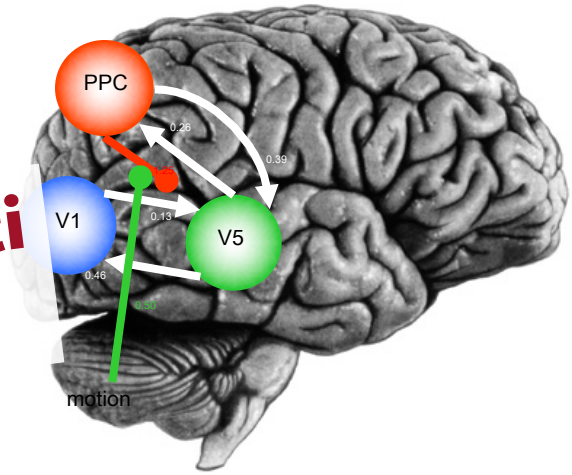
PGSS 2011

- Model-based multi-voxel pattern analysis ('mind-reading')
  → **HMM-MVPA approach**
  (5+ papers, Anderson, Borst, Fincham, Tenison, Walsh, Zhang)



- Dynamic Causal Modeling (DCM)
  → **Andrea Stocco**

- EEG/MEG?
  → **Daniel Cassenti + this talk**



How to give ACT-R a faster brain?

What Did We Learn from EEG and MEG?

Jelmer Borst

university of groningen

Post-Graduate Summer School

August 7, 2016

Studies

- EEG 1: Fan

  Borst, Schneider, Walsh, & Anderson, *JOCN,* 2013; Borst & Anderson, *NeuroImage,* 2015; Anderson, Zhang, Borst, & Walsh, *Psych Review,* 2016

- MEG: Fan

  Borst & Anderson, *NeuroImage*, *accepted*

- EEG 2: Complex Fan

  Zhang, Walsh, & Anderson, *draft*

The task: associative recognition

Associative Recognition Task

Study Phase	Test Phase
COMFORT – MUSTARD	COMFORT – MUSTARD
FLAME – CAPE	FLAME – DECK
METAL – SPARK	BERRY – CREAM
EXCHANGE – HARVEST	DRUNKARD - HARVEST
JELLY – MOTOR	METAL – MOTOR
DUNGEON – GODDESS	EXCHANGE – HARVEST
DRUNKARD – HARVEST	FINANCE – TOURIST
CAPE – DECK	JELLY – MOTOR
	…

Associative Recognition Task

Study Phase	Test Phase
COMFORT – MUSTARD	COMFORT – MUSTARD
FLAME – CAPE	FLAME – DECK
METAL – SPARK	BERRY – CREAM
EXCHANGE – HARVEST	DRUNKARD - HARVEST
JELLY – MOTOR	METAL – MOTOR
DUNGEON – GODDESS	EXCHANGE – HARVEST
DRUNKARD – HARVEST	FINANCE – TOURIST
CAPE – DECK	JELLY – MOTOR

Target vs Re-paired Foil vs New Foil

Associative Recognition Task

Study Phase	Test Phase
COMFORT – MUSTARD	COMFORT – MUSTARD
FLAME – CAPE	FLAME – DECK
METAL – SPARK	BERRY – CREAM
EXCHANGE – HARVEST	DRUNKARD - HARVEST
JELLY – MOTOR	METAL – MOTOR
DUNGEON – GODDESS	EXCHANGE – HARVEST
DRUNKARD – HARVEST	FINANCE – TOURIST
CAPE – DECK	JELLY – MOTOR

short vs long words

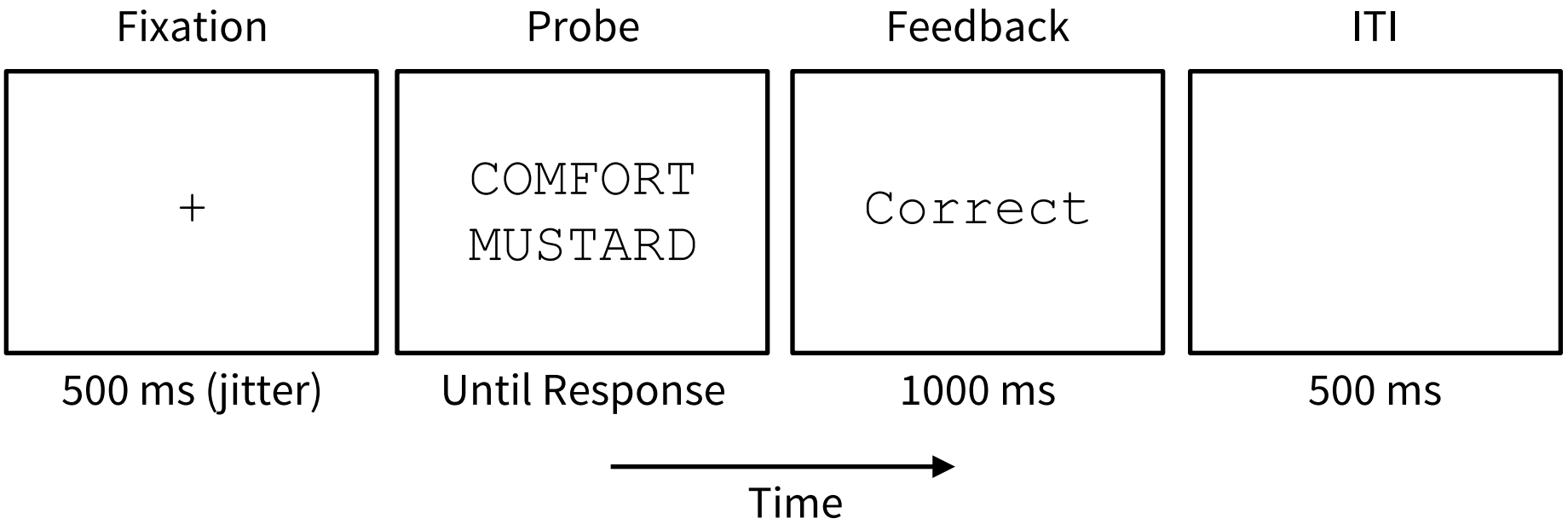
…

Associative Recognition Task

Study Phase	Test Phase
COMFORT – MUSTARD	COMFORT – MUSTARD
FLAME – CAPE	FLAME – DECK
METAL – SPARK	BERRY – CREAM
EXCHANGE – HARVEST	DRUNKARD - HARVEST
JELLY – MOTOR	METAL – MOTOR
DUNGEON – GODDESS	EXCHANGE – HARVEST
DRUNKARD – HARVEST	FINANCE – TOURIST
CAPE – DECK	JELLY – MOTOR

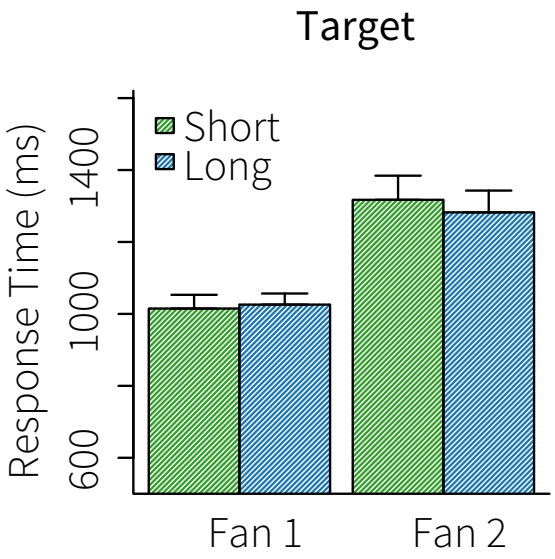
associative fan of 1 or 2

Test Phase



+ M/EEG

Behavioral Results



Theories of Associative Recognition

Global Matching
(e.g., Gillund & Shiffrin, 1984; Hintzman, 1988; Murdock, 1993; Wixted & Stretch, 2004)

Encoding | *Matching* | *Response*

Dual-process
(e.g., Diana et al., 2006; Malmberg, 2008; Rugg & Curran, 2007; Yonelinas, 2002)

Encoding | *Familiarity* | *Recollection* | *Response*

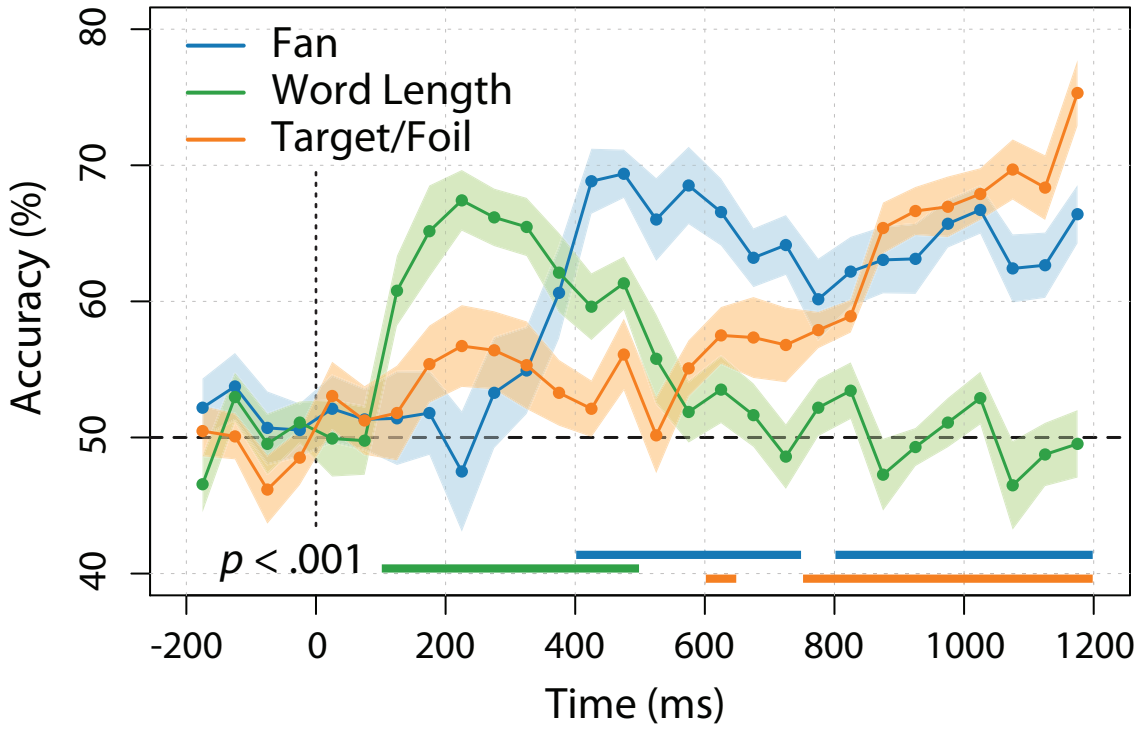
ACT-R
(e.g., Anderson, 2007; Anderson & Reder, 1999; Schneider & Anderson, 2012)

Encoding | *Associative retrieval* | | *Response*

Decision

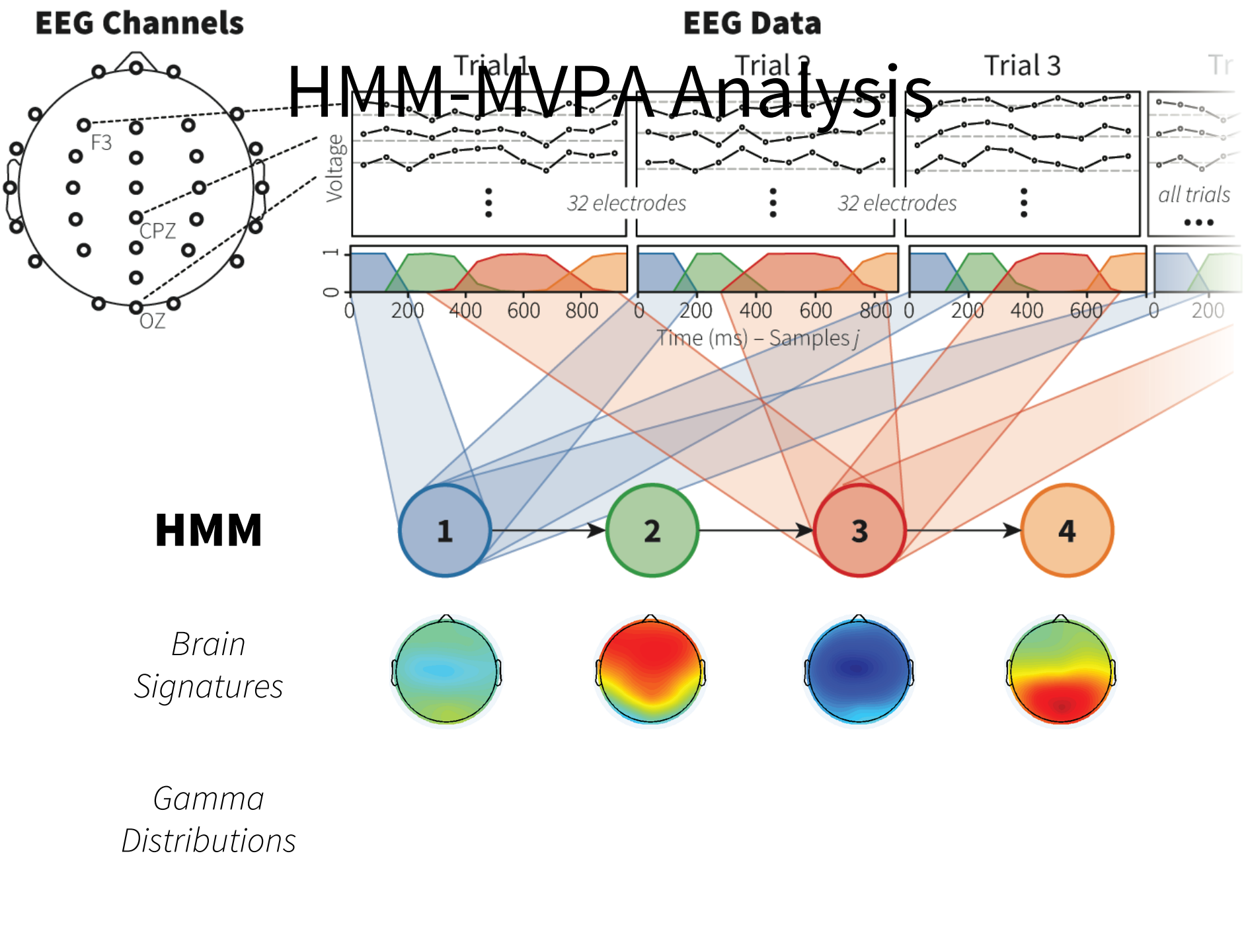
EEG 1: Fan

Classifier

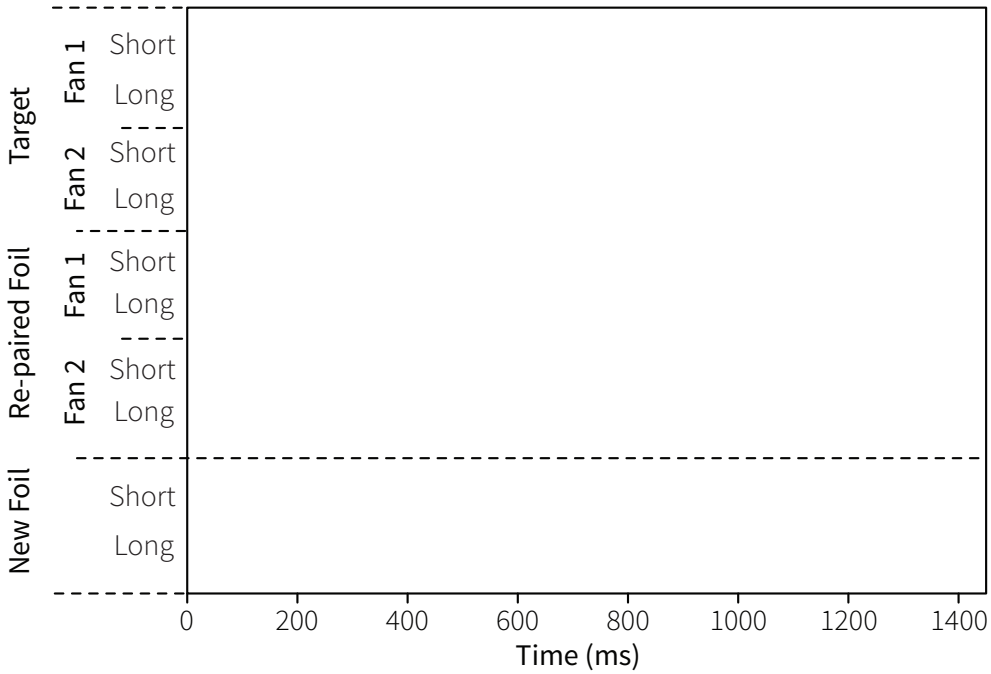


Borst, Schneider, Walsh, & Anderson, *JOCN*, 2013

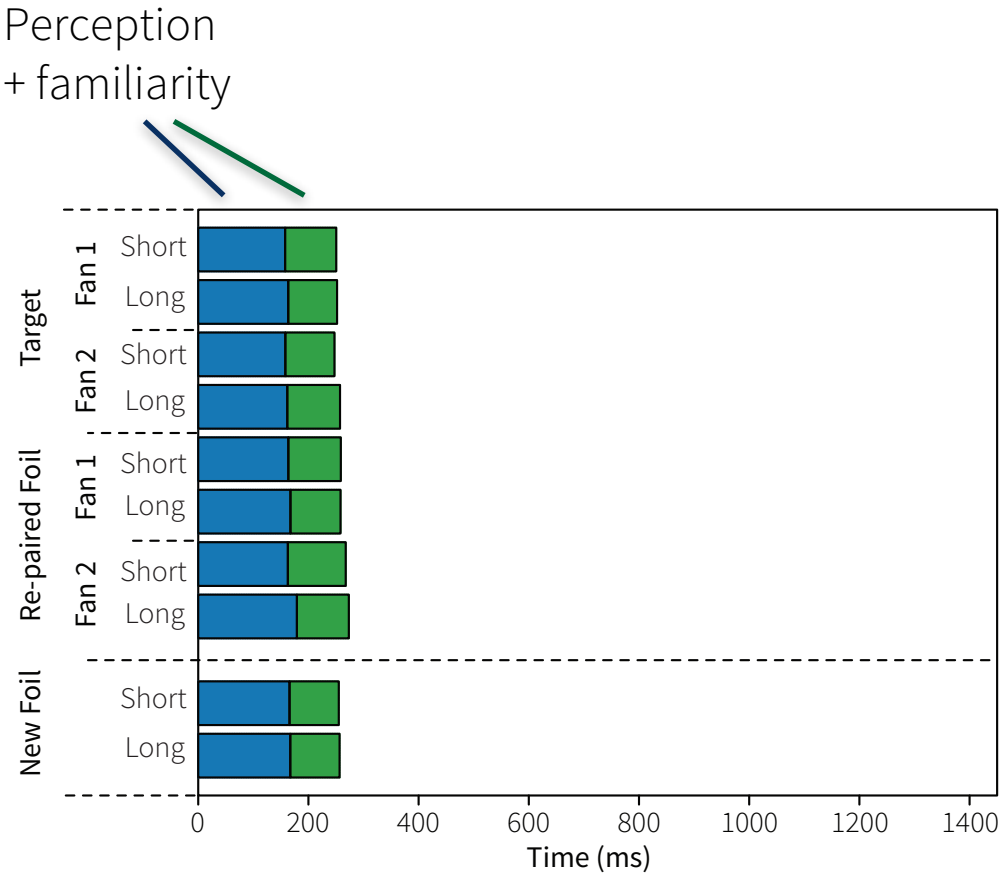
HMM-MVPA Analysis

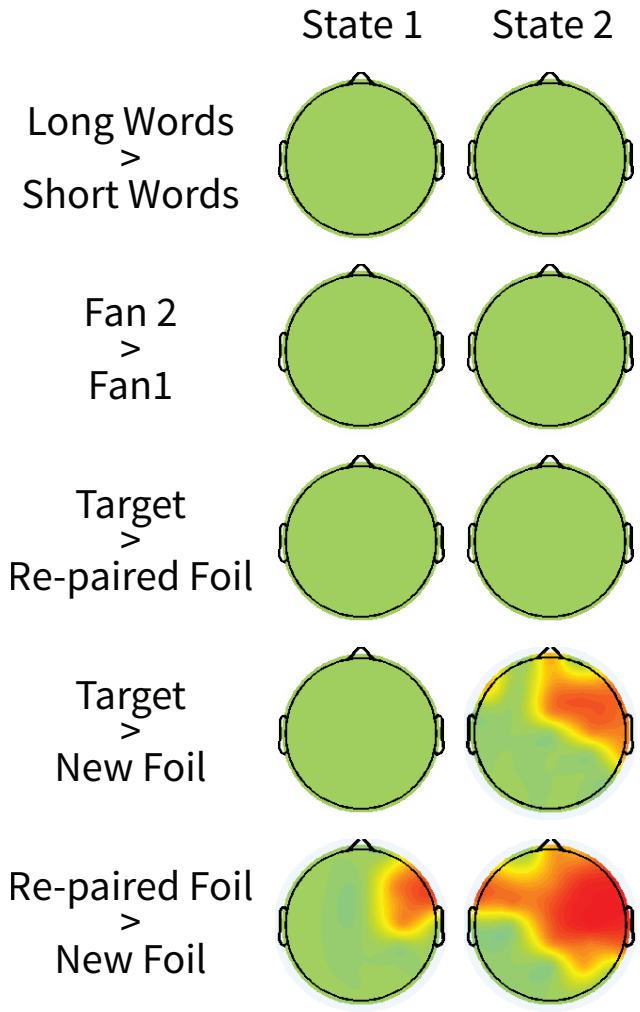


Stages 1 & 2

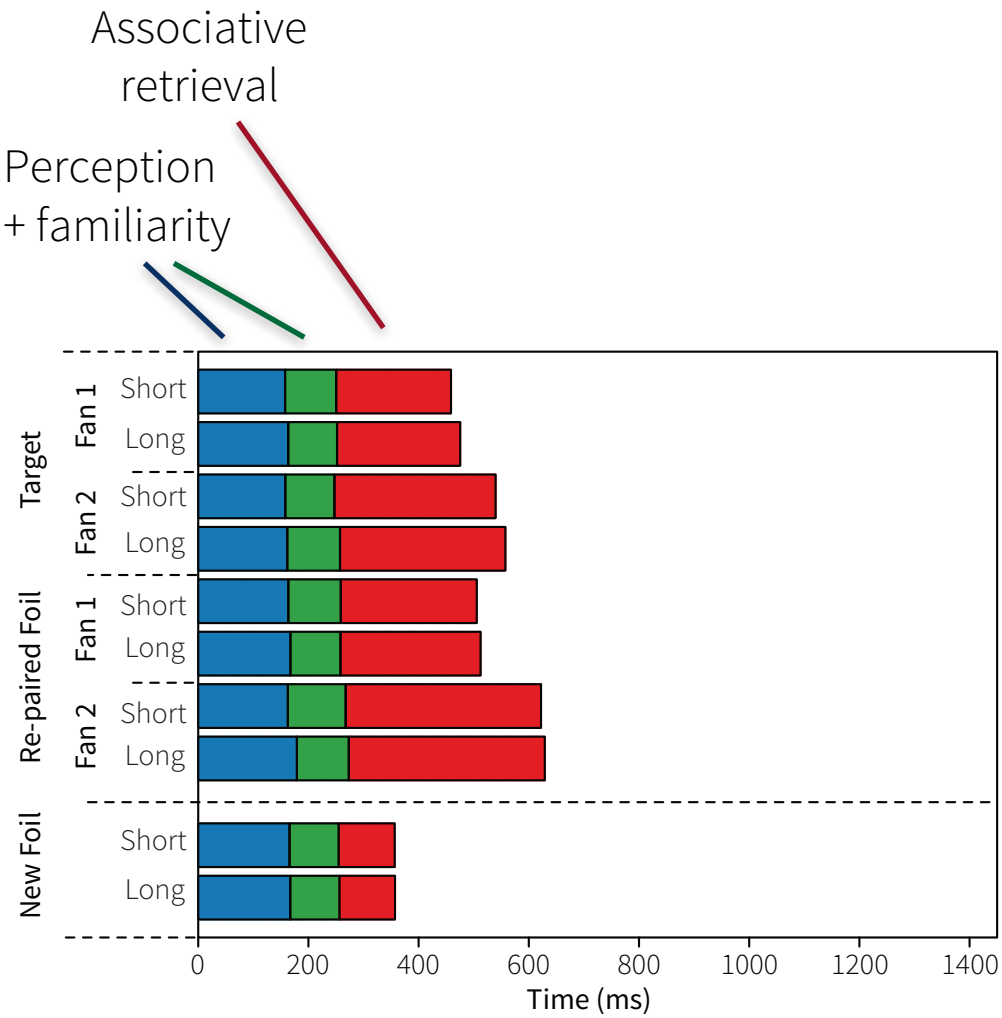

Target
Fan 1
Short
Long
Fan 2
Short
Long
Re-paired Foil
Fan 1
Short
Long
Fan 2
Short
Long
New Foil
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)

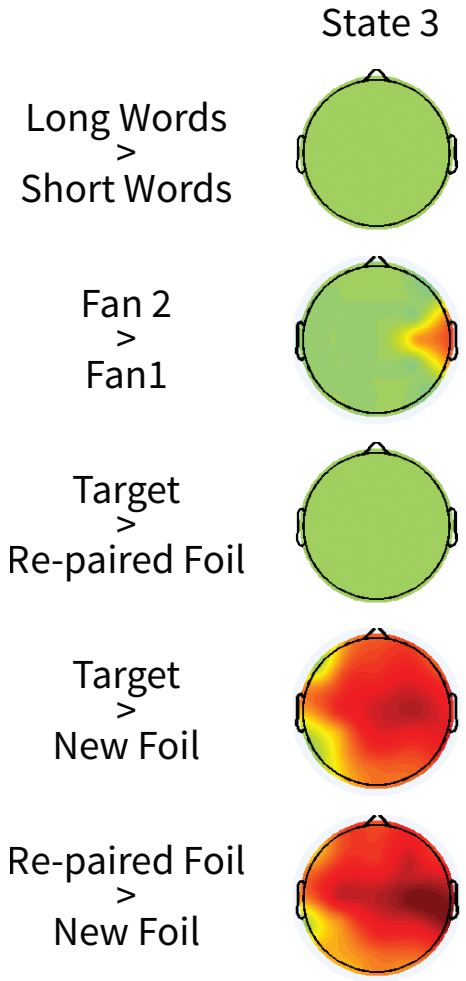
Stages 1 & 2


Perception
+ familiarity
Target
Re-paired Foil
New Foil
Fan 1
Fan 2
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)

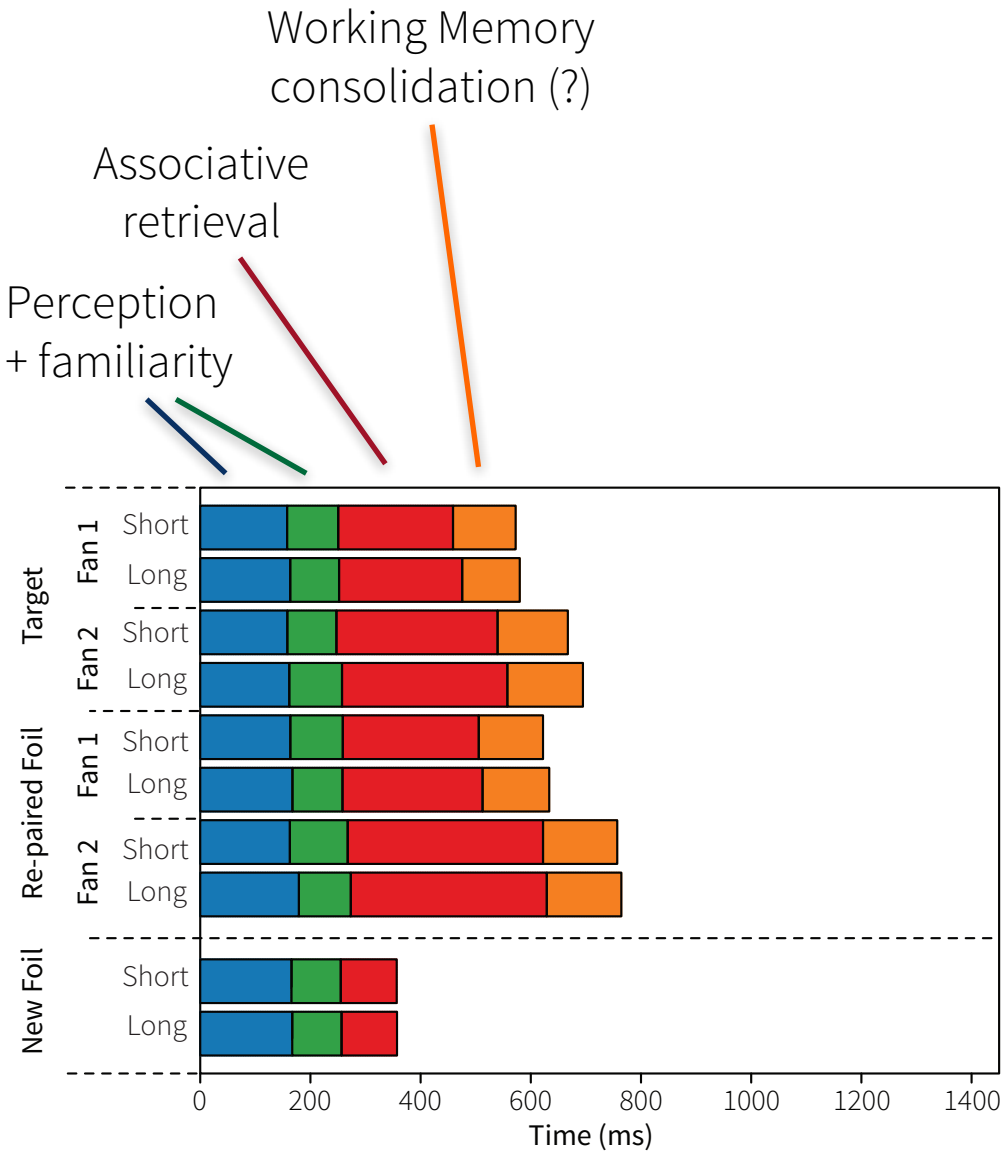

State 1
State 2
Long Words
>
Short Words
Fan 2
>
Fan1
Target
>
Re-paired Foil
Target
>
New Foil
Re-paired Foil
>
New Foil

Stage 3

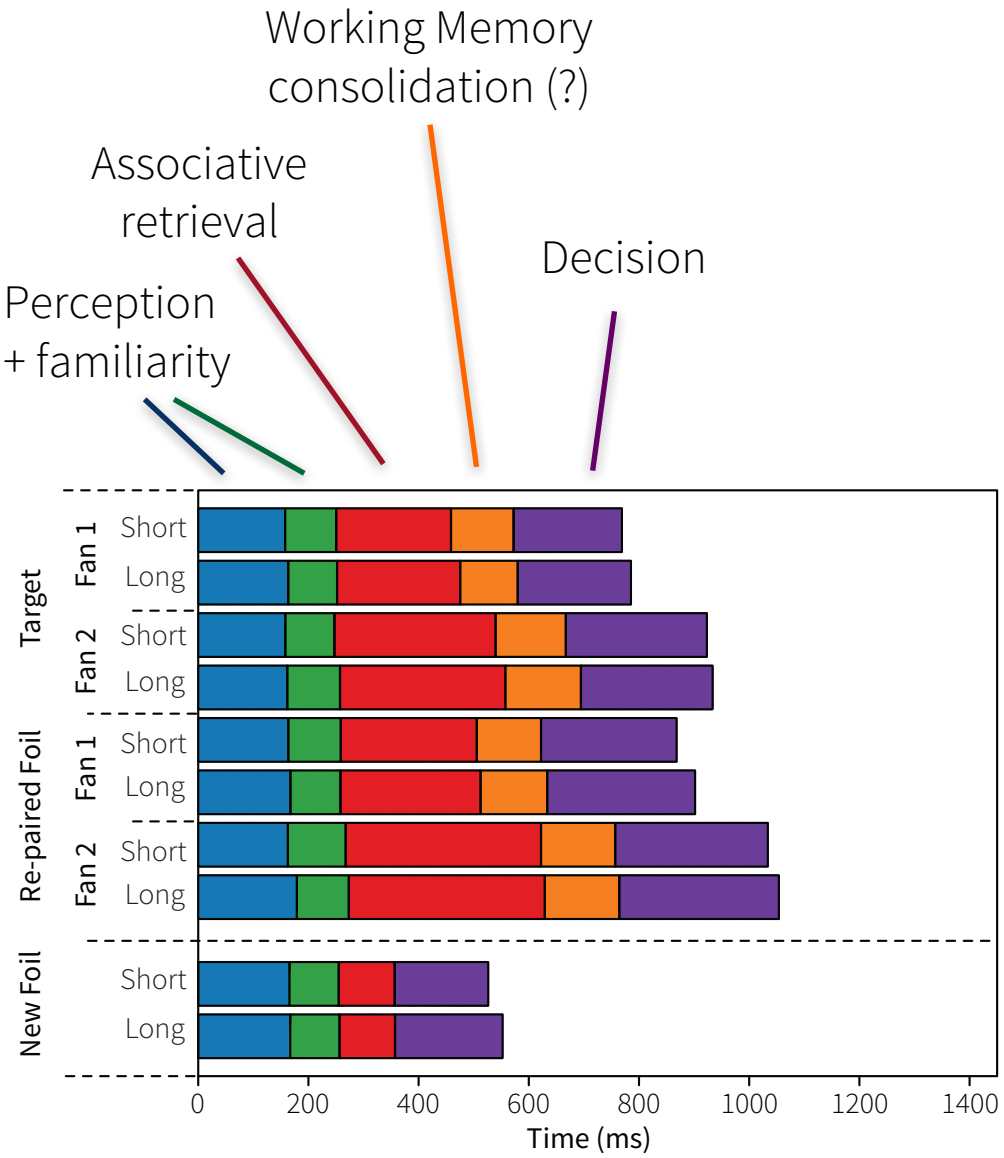

Associative retrieval
Perception + familiarity
Target
Re-paired Foil
New Foil
Fan 1
Fan 2
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)

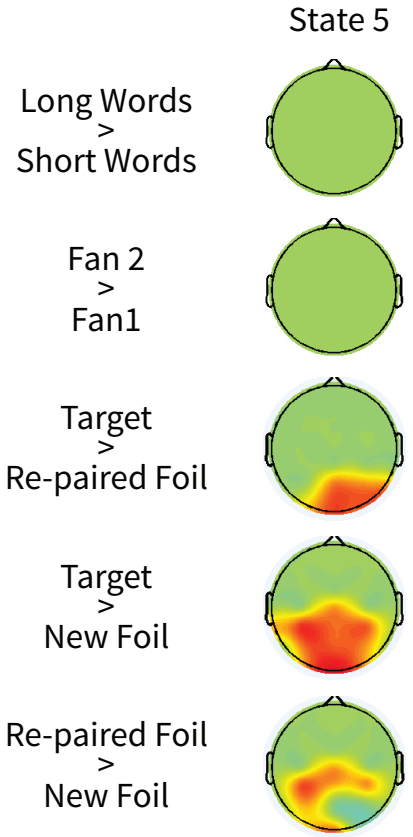

State 3
Long Words > Short Words
Fan 2 > Fan1
Target > Re-paired Foil
Target > New Foil
Re-paired Foil > New Foil

Stage 4

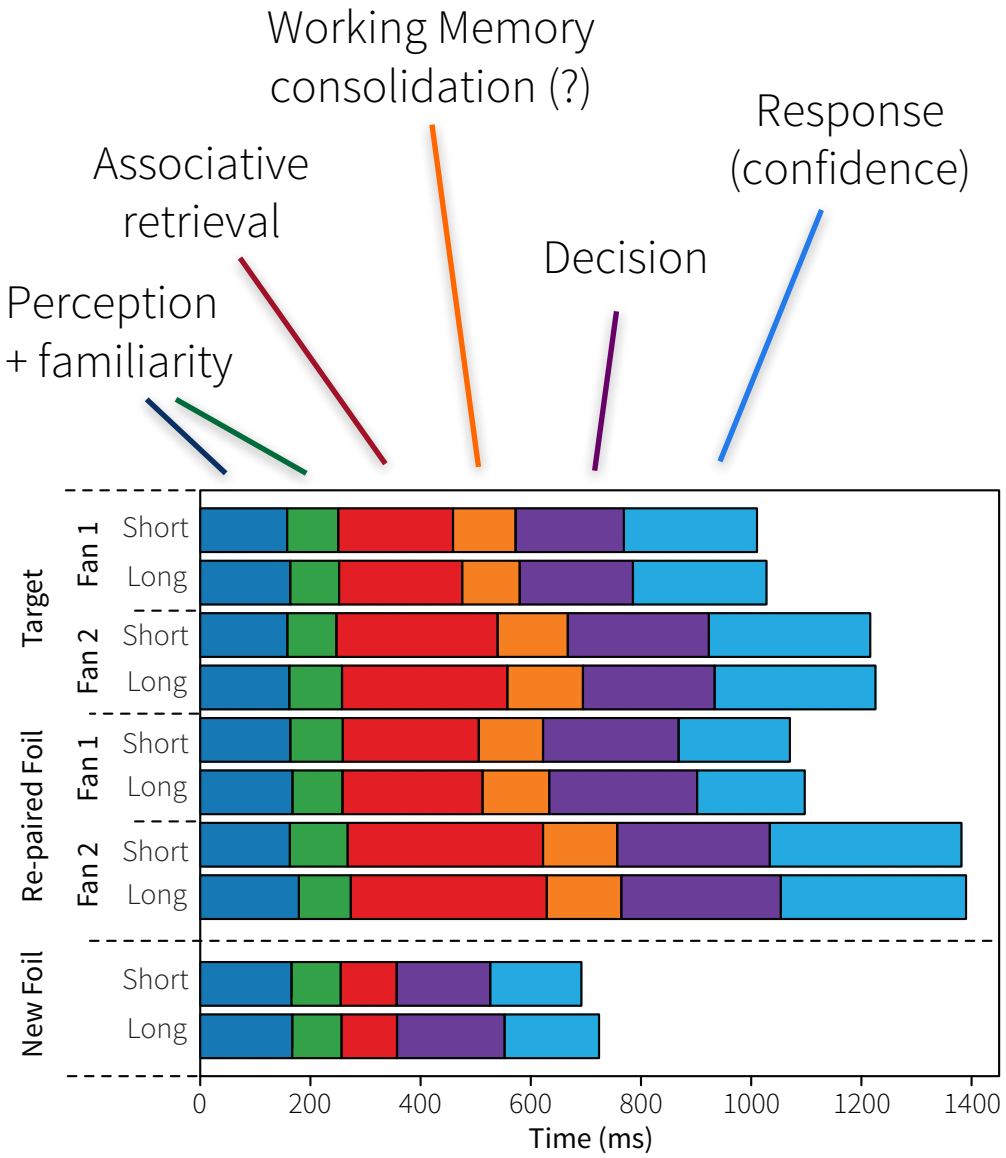

Working Memory consolidation (?)
Associative retrieval
Perception + familiarity
Target
Re-paired Foil
New Foil
Fan 1
Fan 2
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)

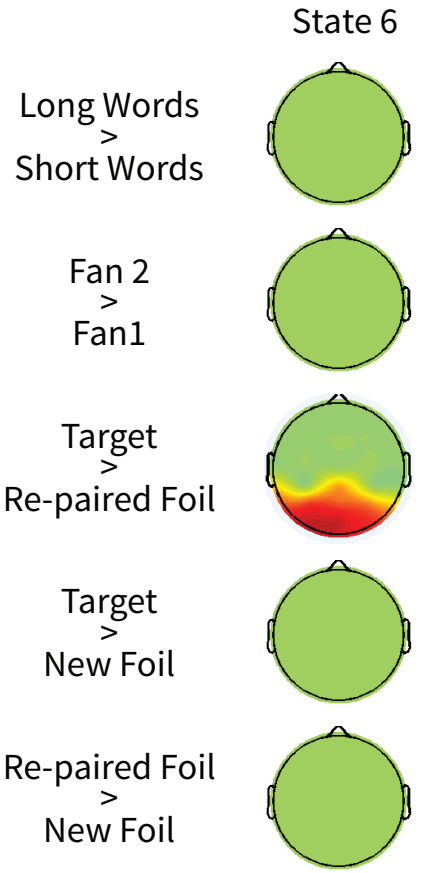
Stage 5


Working Memory consolidation (?)
Associative retrieval
Decision
Perception + familiarity
Target
Re-paired Foil
New Foil
Fan 1
Fan 2
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)


State 5
Long Words > Short Words
Fan 2 > Fan1
Target > Re-paired Foil
Target > New Foil
Re-paired Foil > New Foil

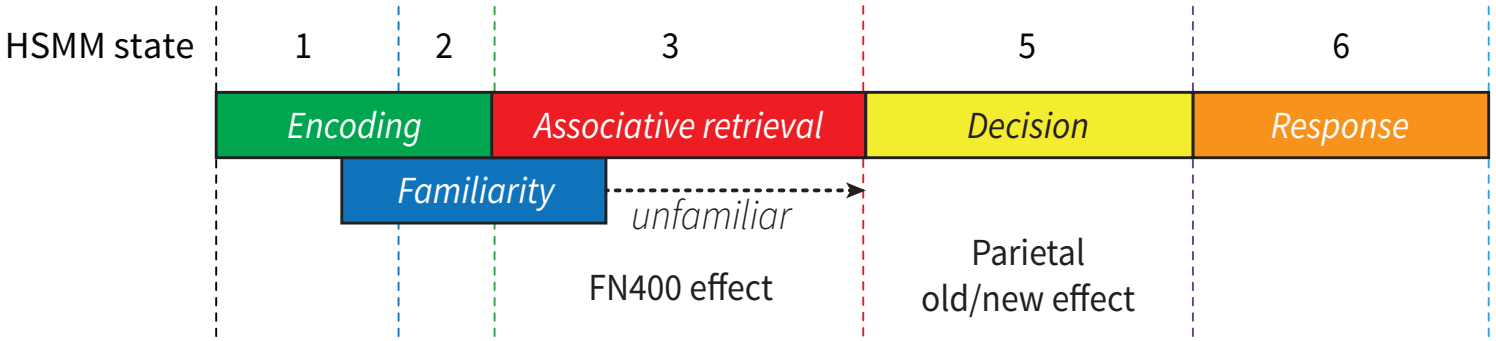
Stage 6


Working Memory
consolidation (?)
Response
(confidence)
Associative
retrieval
Decision
Perception
+ familiarity
Target
Re-paired Foil
New Foil
Fan 1
Fan 2
Short
Long
0
200
400
600
800
1000
1200
1400
Time (ms)


State 6
Long Words
>
Short Words
Fan 2
>
Fan1
Target
>
Re-paired Foil
Target
>
New Foil
Re-paired Foil
>
New Foil

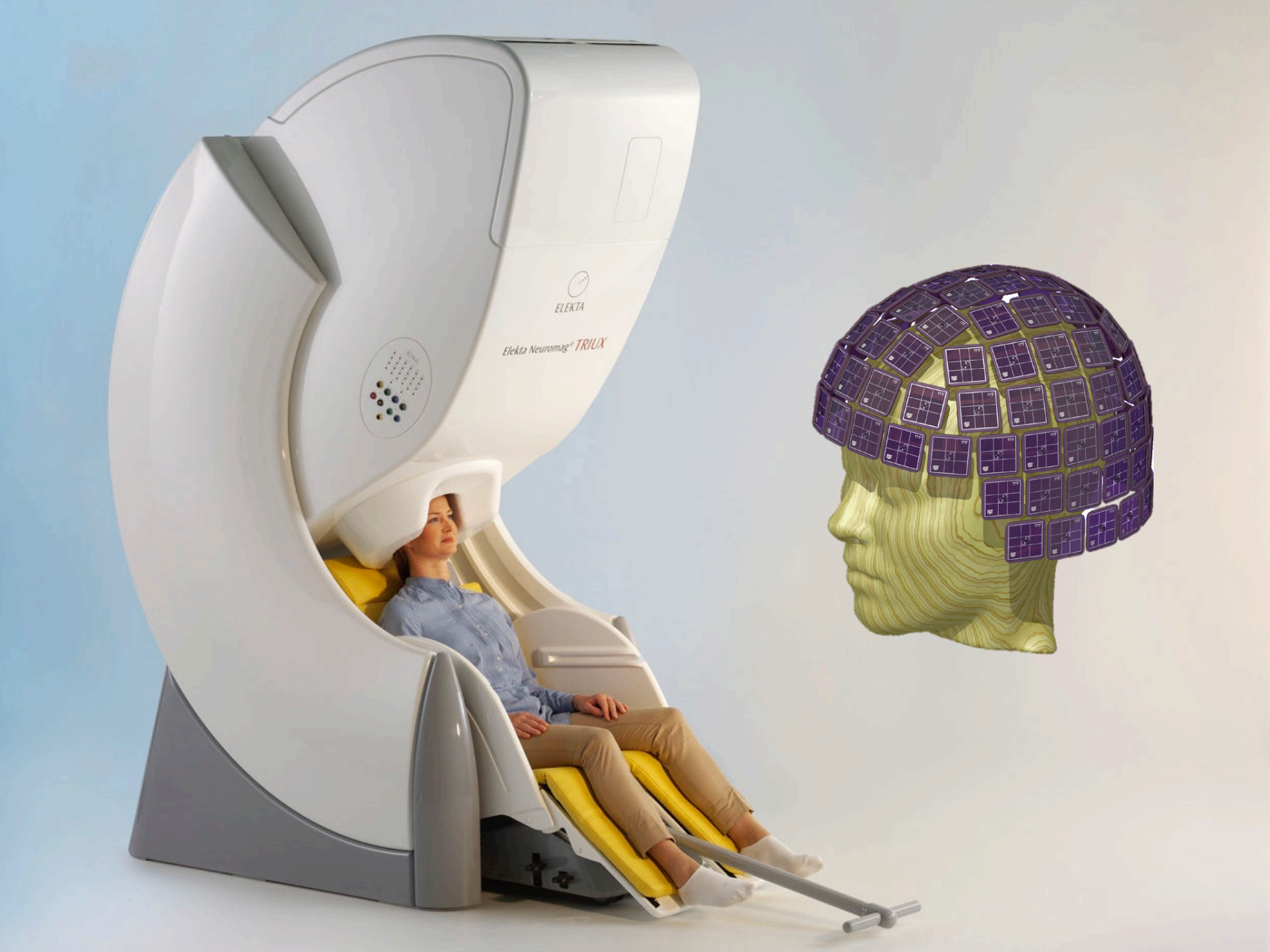
EEG 1: Conclusions

- Two memory stages: familiarity and associative retrieval
- More involved decision process, that feeds on retrieved information



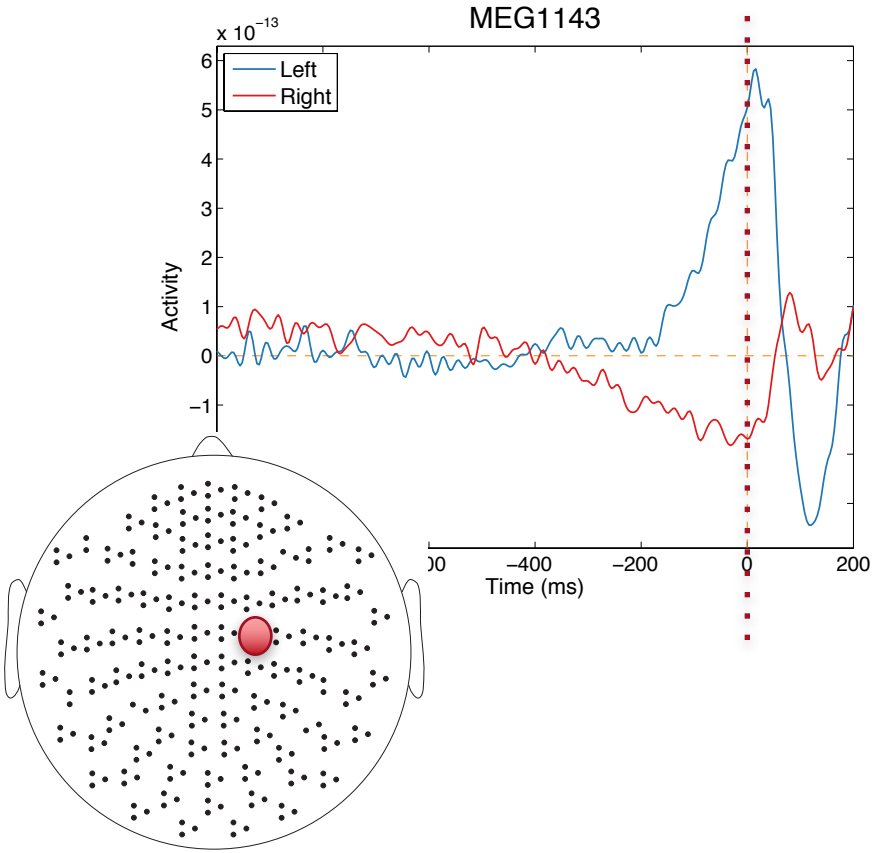
Borst, Ghuman, & Anderson, *NeuroImage, 2016*

MEG: Fan

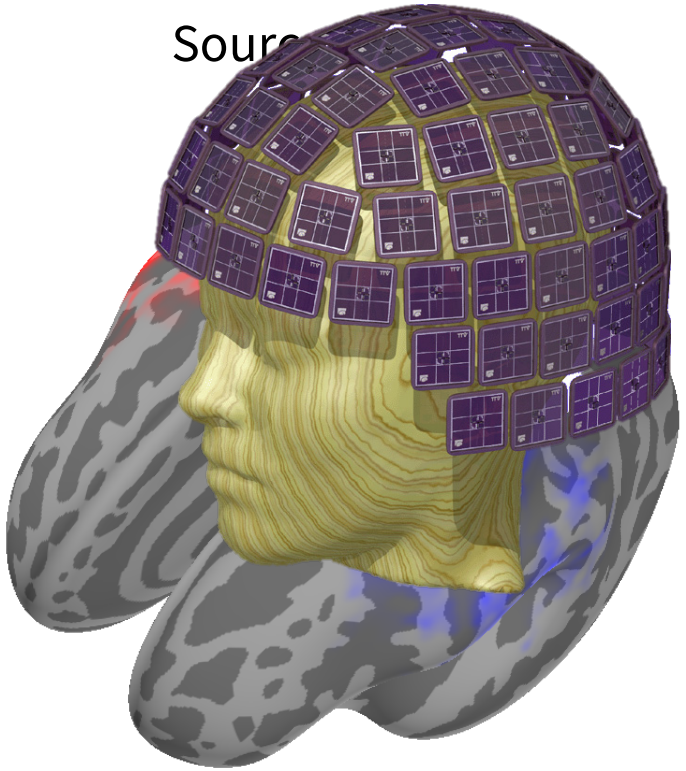

ELEKTA
Elekta Neuromag® TRIUX

Sensors and sources

Sensor space



Sour



Word Length

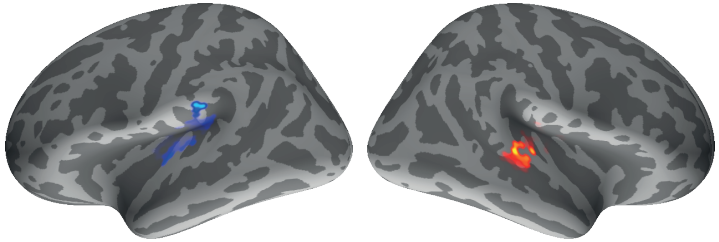
(long > short)

Permutation Clusters

176-256 ms

408-484 ms

Stimulus-Locked

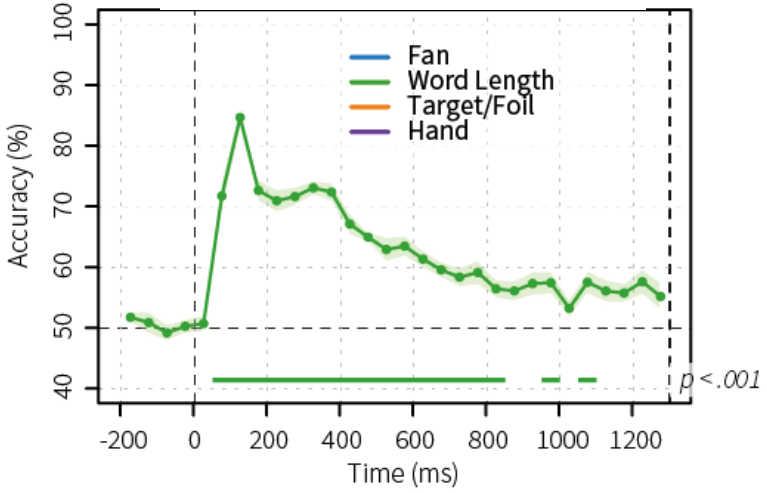


212 ms

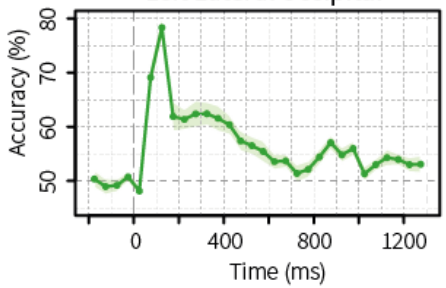
440 ms

Classifier

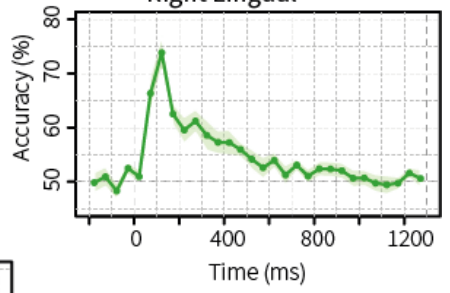
Sensors

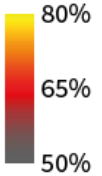


Left Lateral Occipital

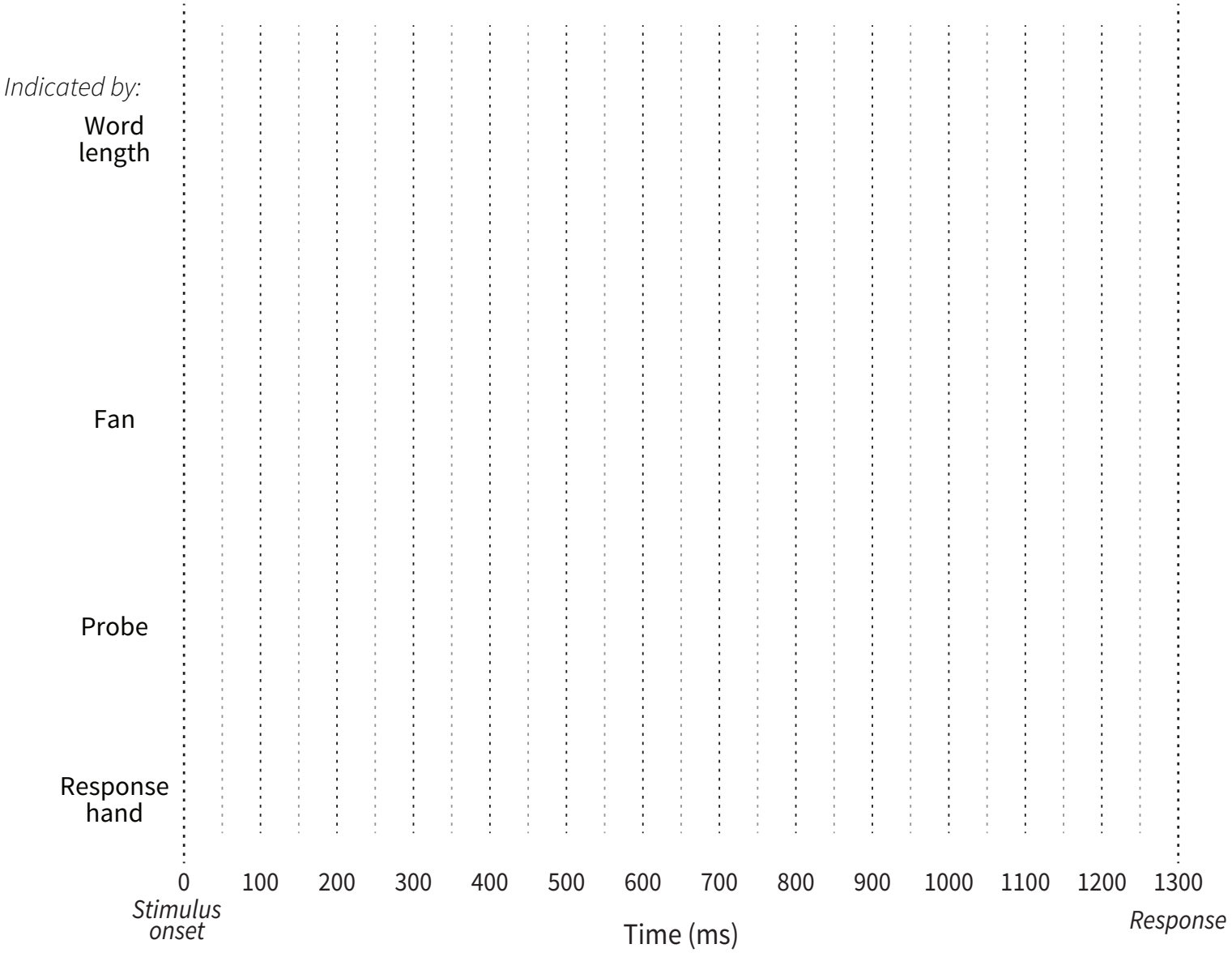


Right Lingual

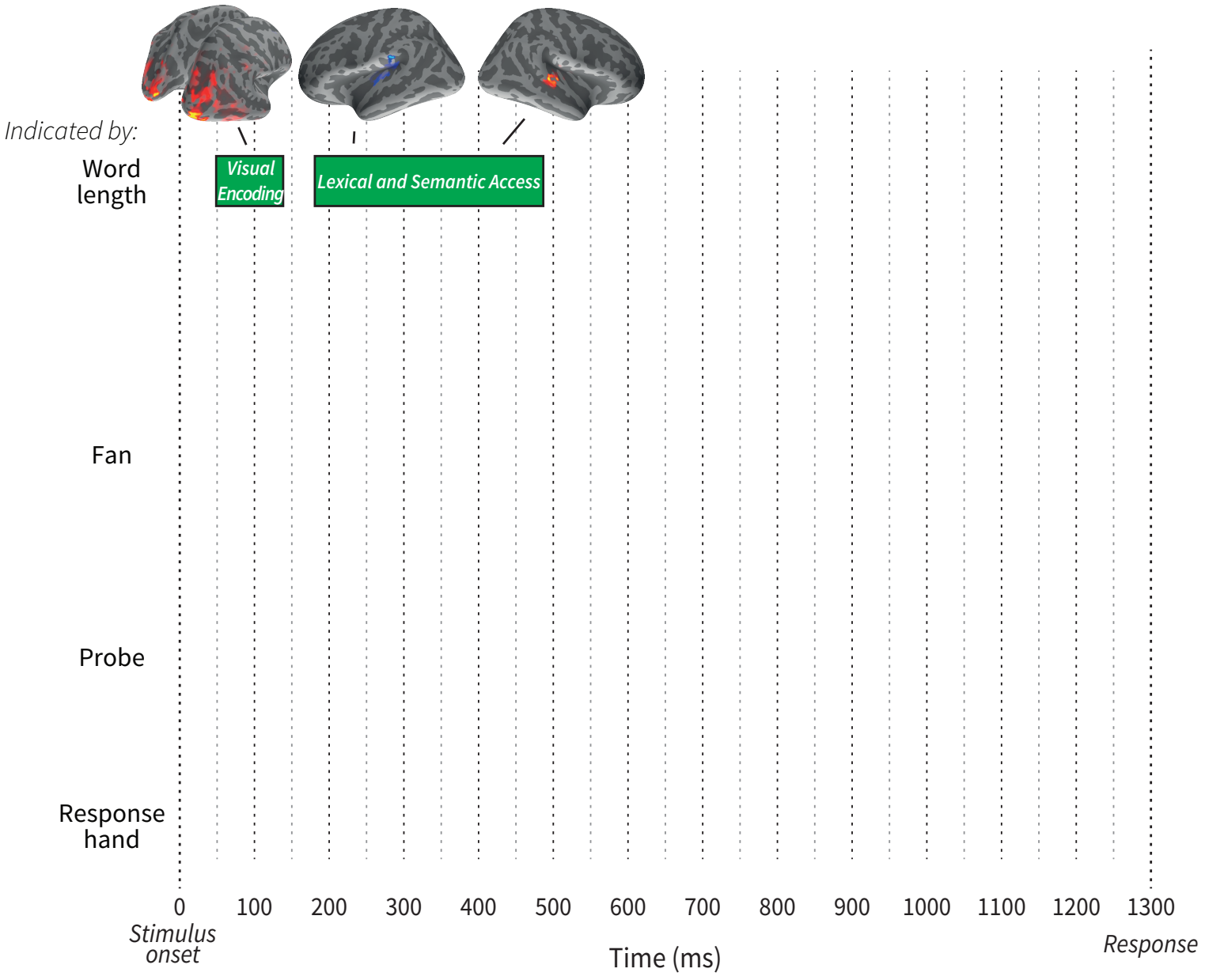




MEG Model


Indicated by:
Word length
Fan
Probe
Response hand
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

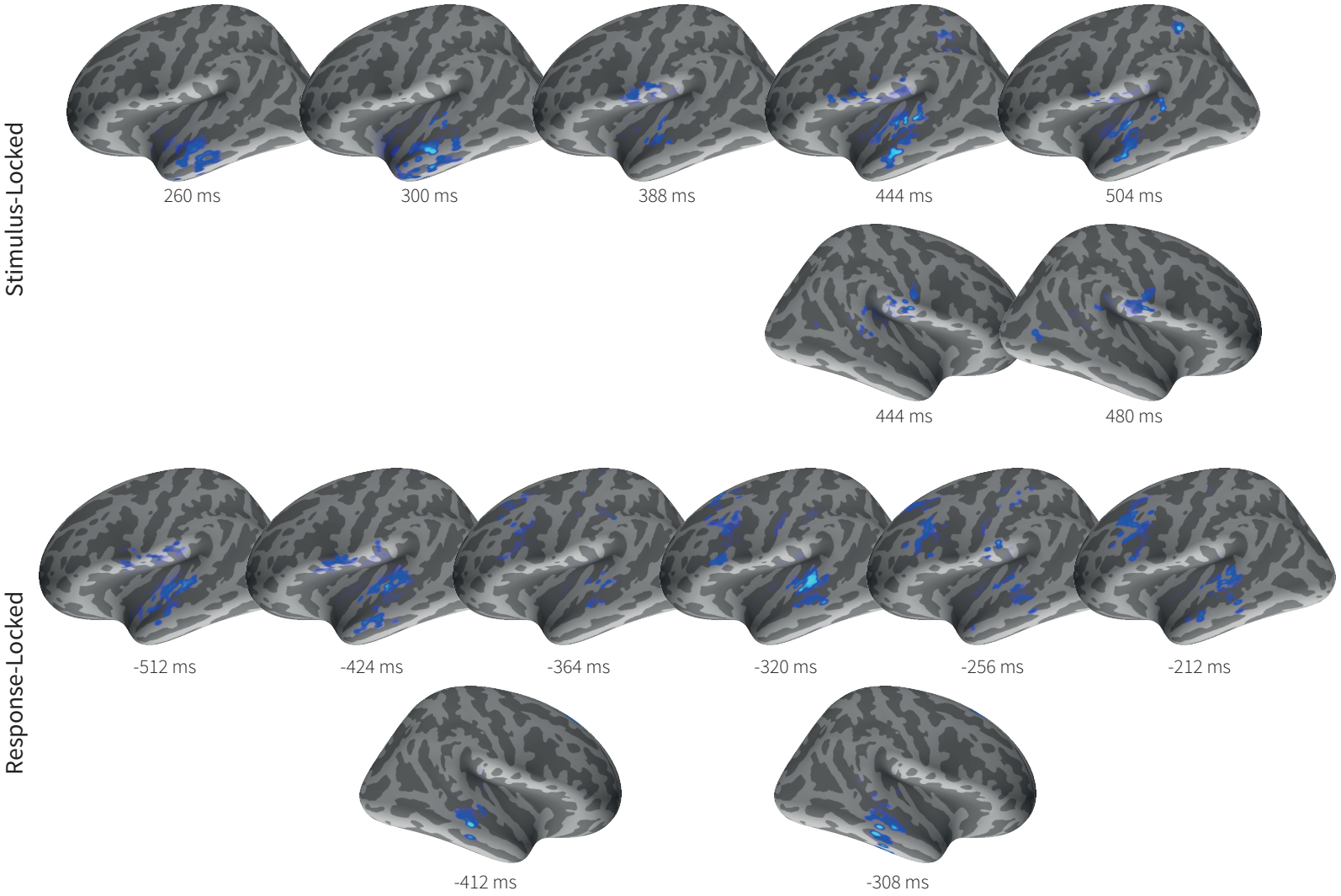
MEG Model


Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

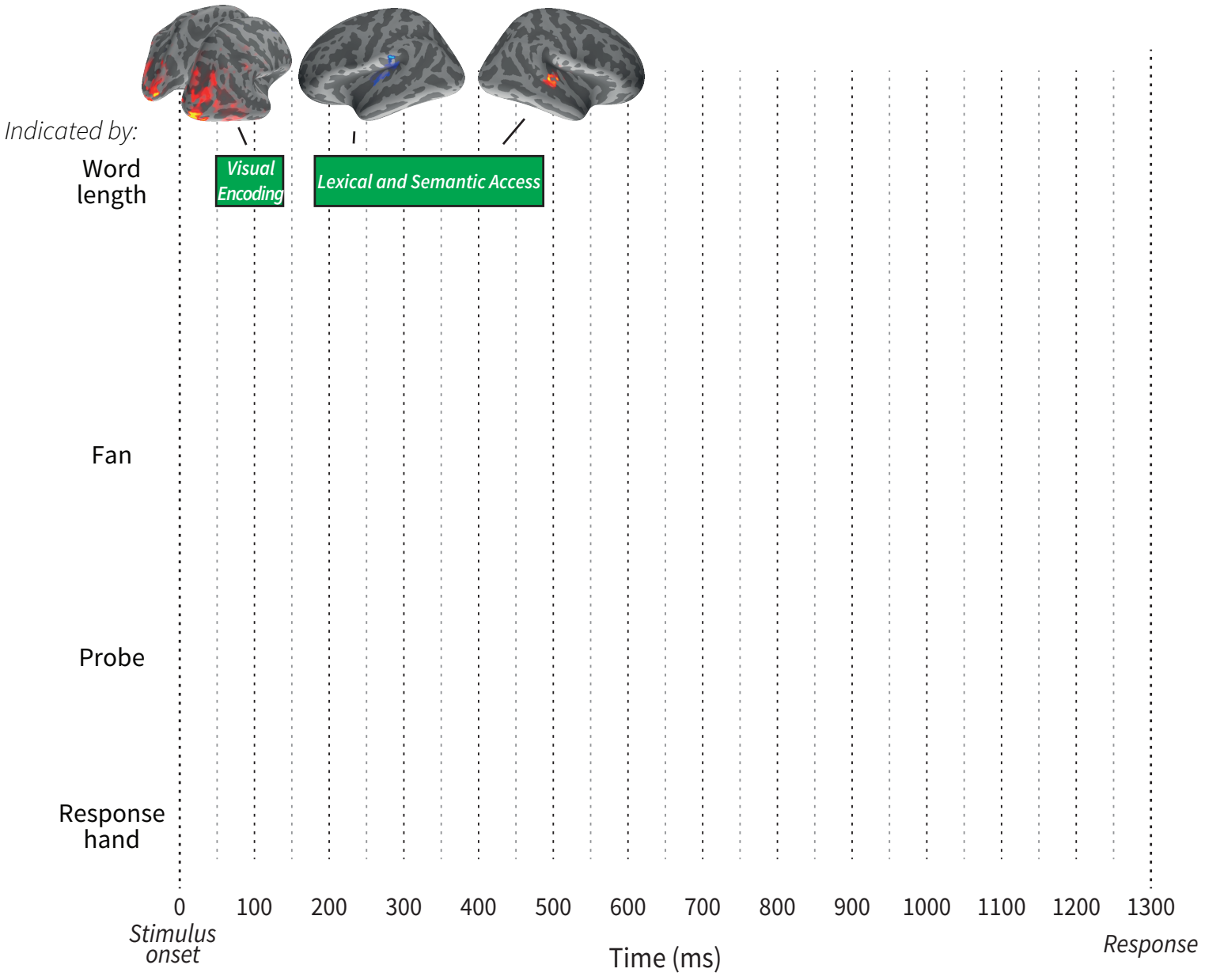
Permutation Clusters

Associative Strength

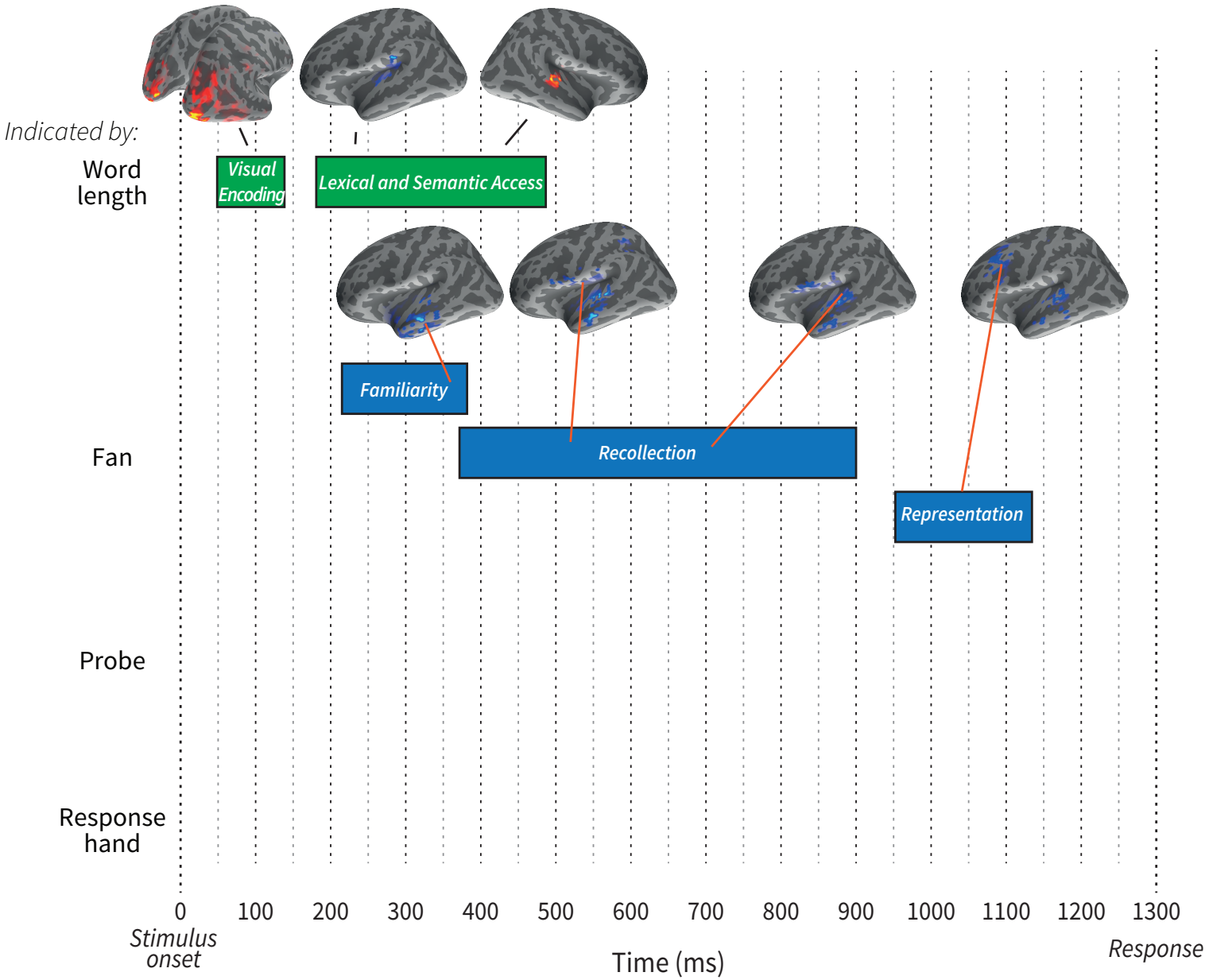
(fan 2 > fan 1)



MEG Model

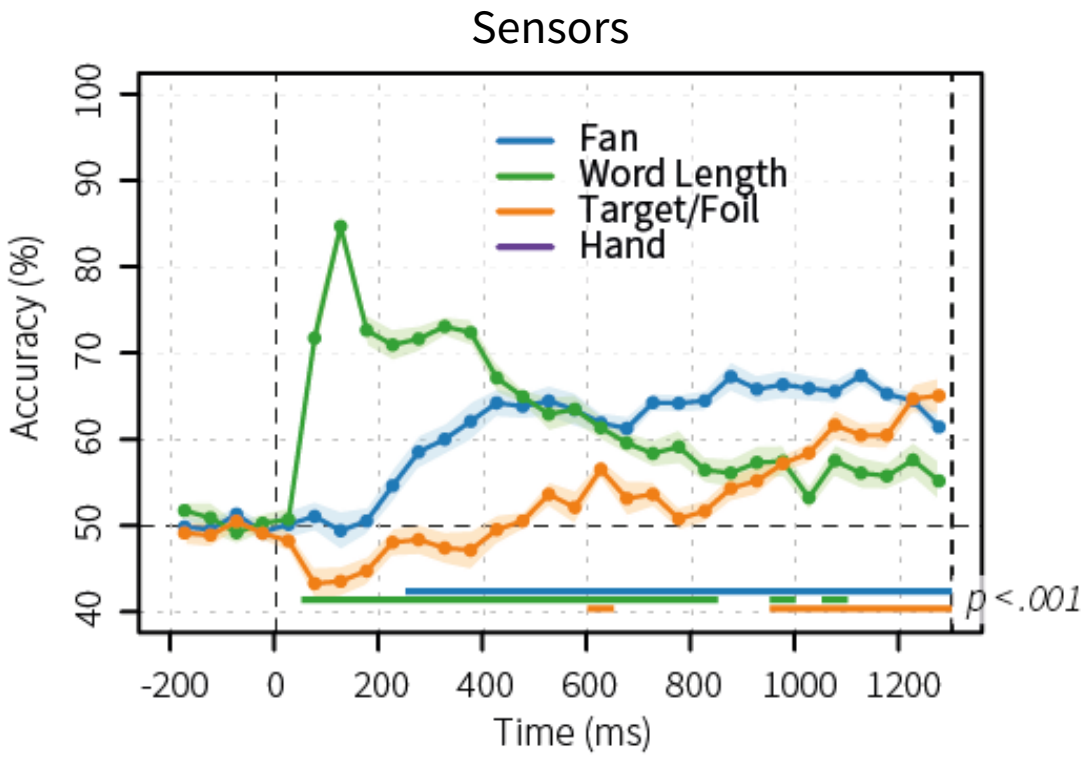

Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

MEG Model

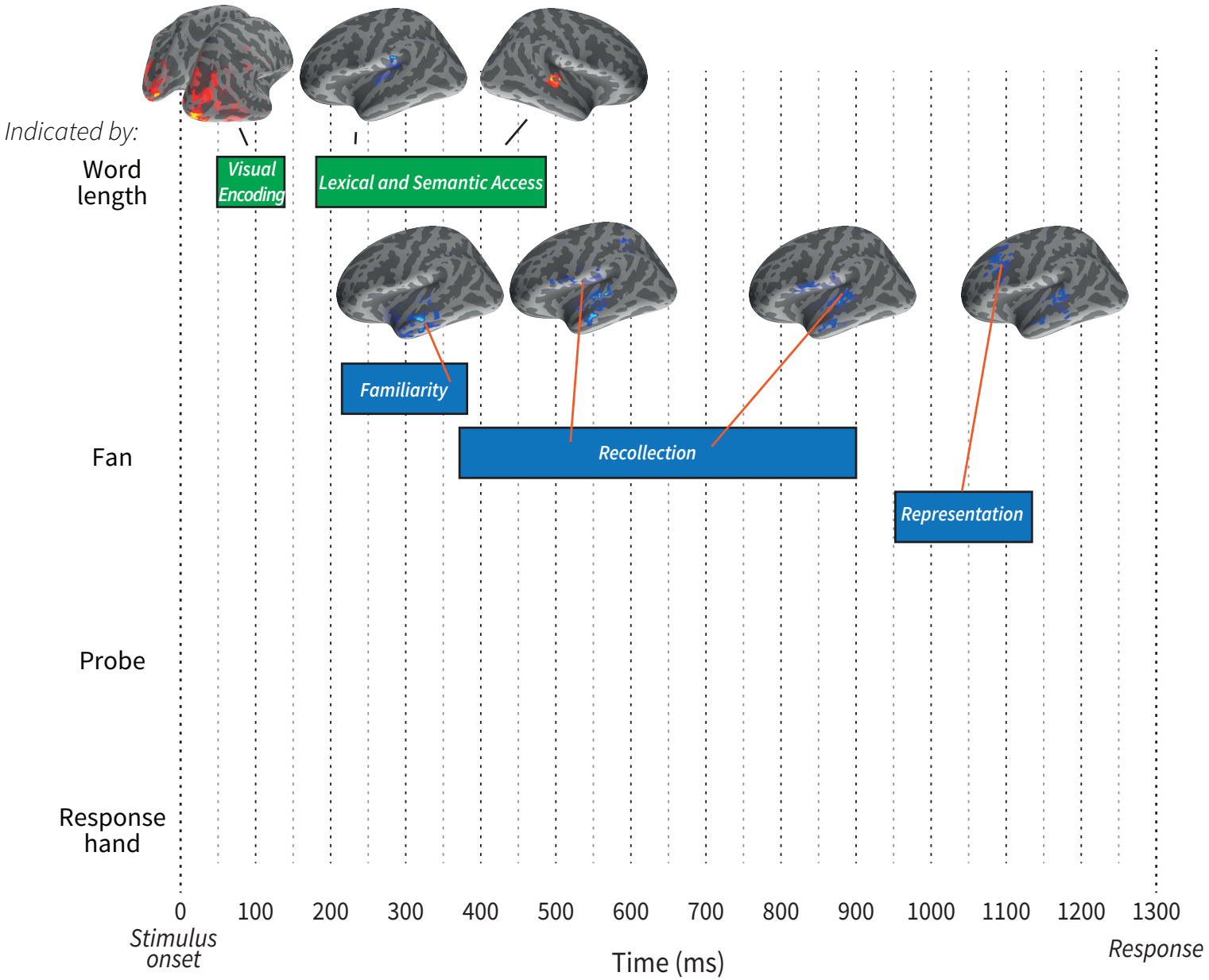

Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
Familiarity
Recollection
Representation
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

Probe Type

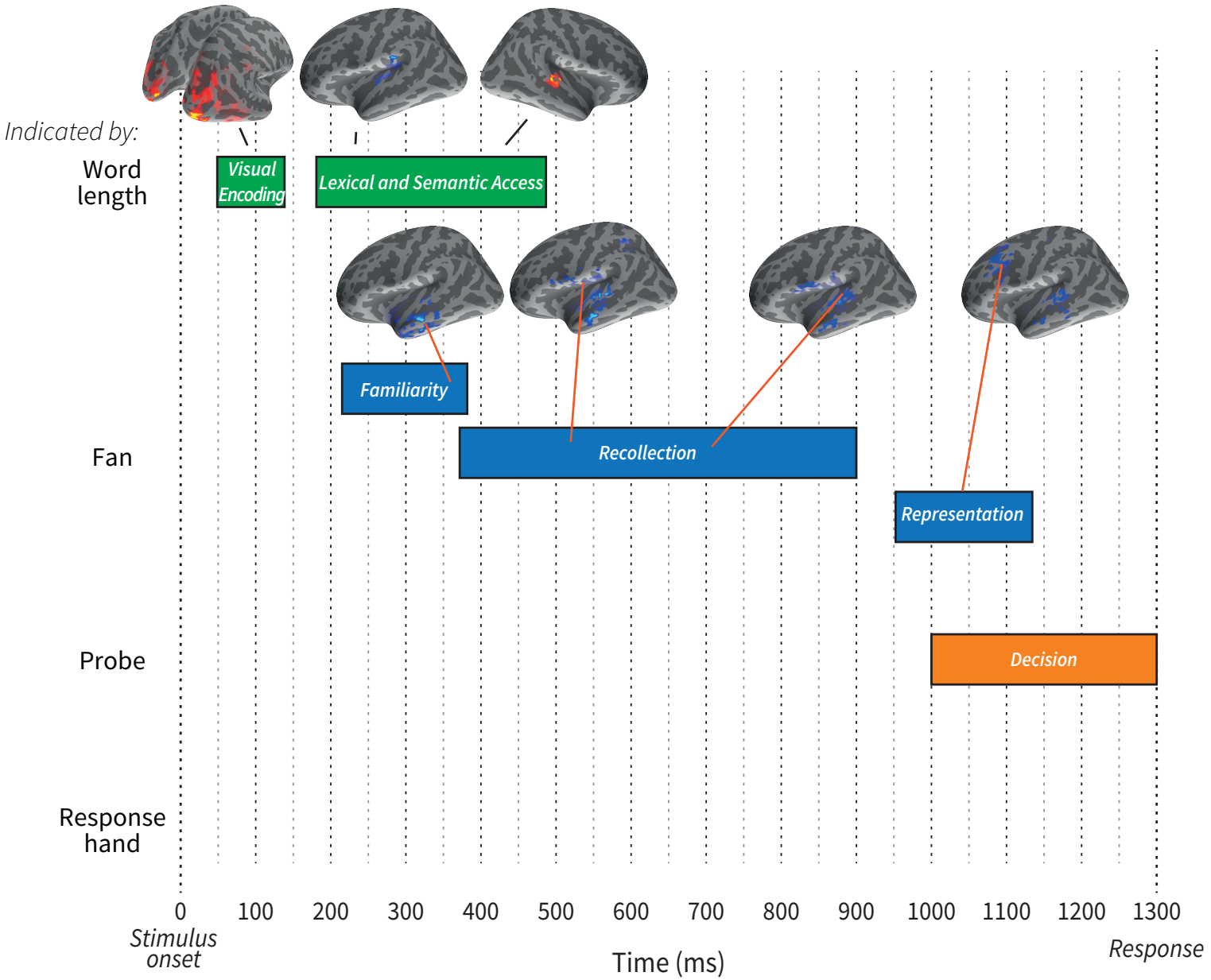
(target > foil)



MEG Model


Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
Familiarity
Recollection
Representation
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

MEG Model

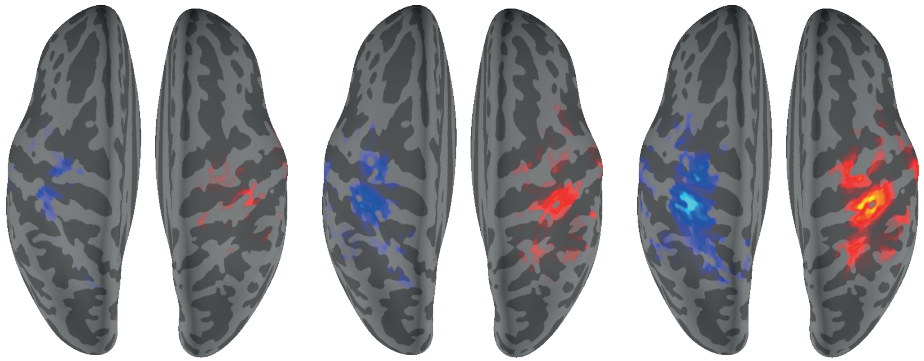

Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
Familiarity
Recollection
Representation
Decision
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

Response Hand

(left > right)

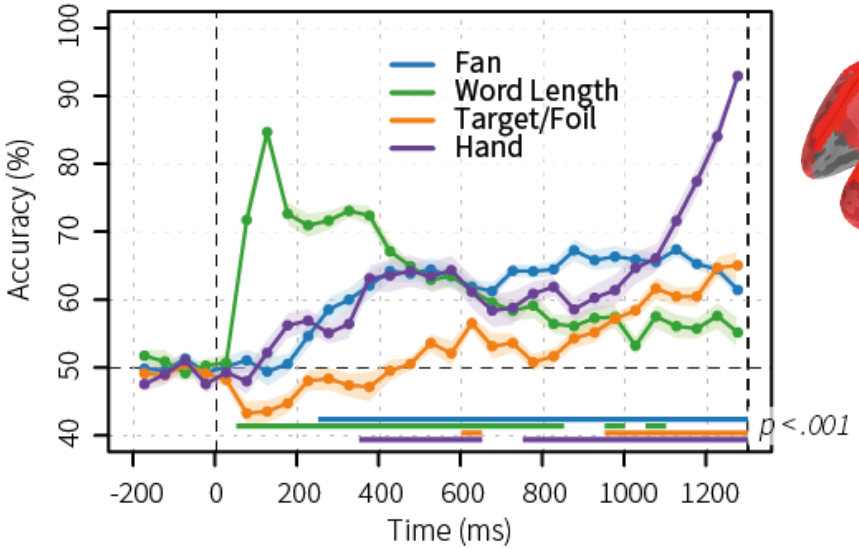
Permutation Clusters

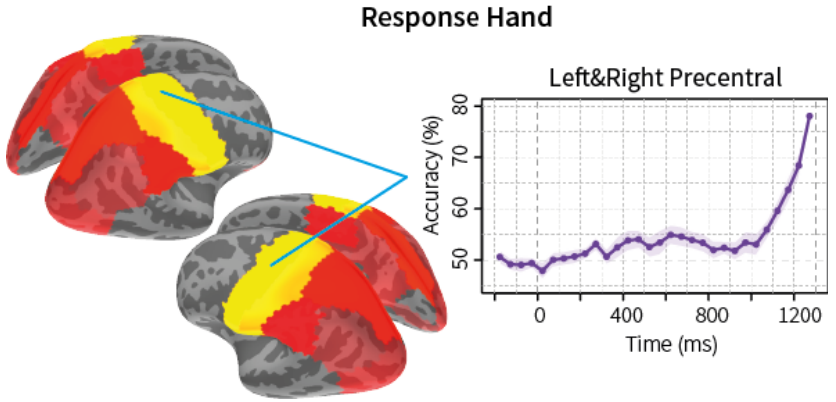
Response-Locked



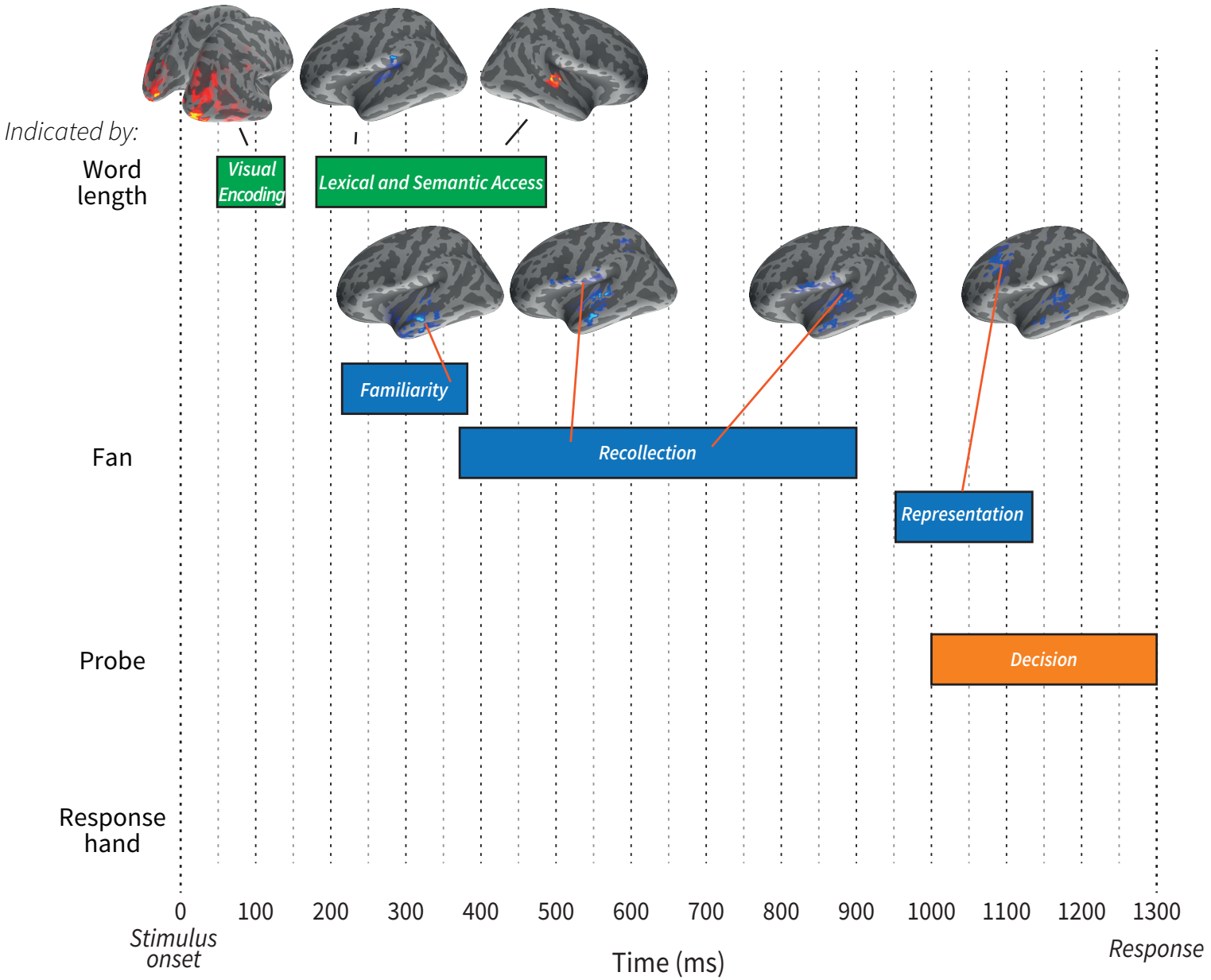
Classifier

Sensors

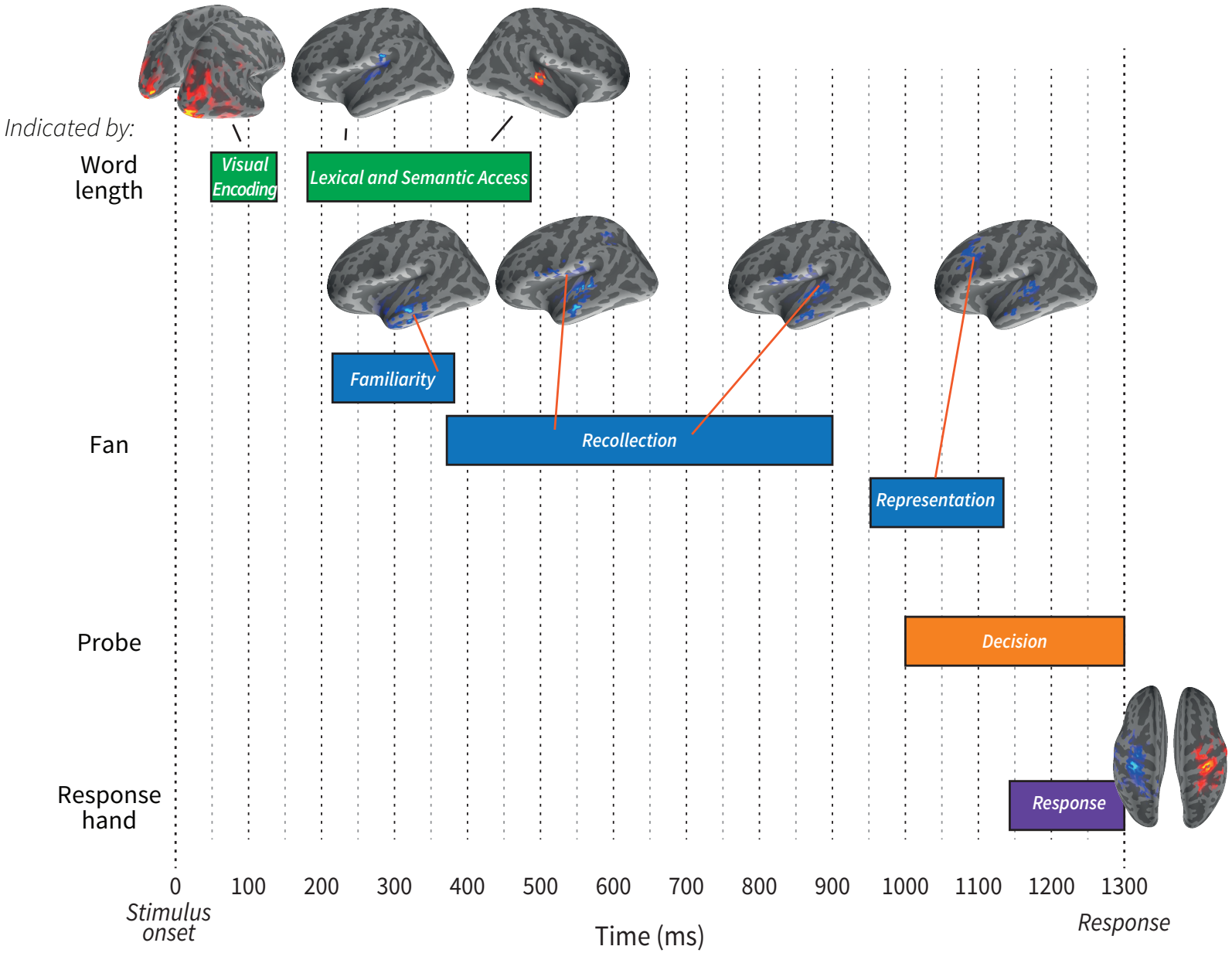




MEG Model


Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
Familiarity
Recollection
Representation
Decision
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

MEG Model


Indicated by:
Word length
Fan
Probe
Response hand
Visual Encoding
Lexical and Semantic Access
Familiarity
Recollection
Representation
Decision
Response
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Stimulus onset
Time (ms)
Response

EEG & MEG conclusions

- Encoding (occipital)
- Three memory stages:
  - familiarity (perirhinal cortex)
  - associative retrieval (hippocampus)
  - representation (prefrontal, neural activation depends on activation of facts)
- More involved decision process in parietal cortex, input from prefrontal representation
- Motor (precentral)

EEG 2: Complex Fan

Zhang, Walsh, & Anderson, *submitted*

EEG 2: Complex Fan

Study

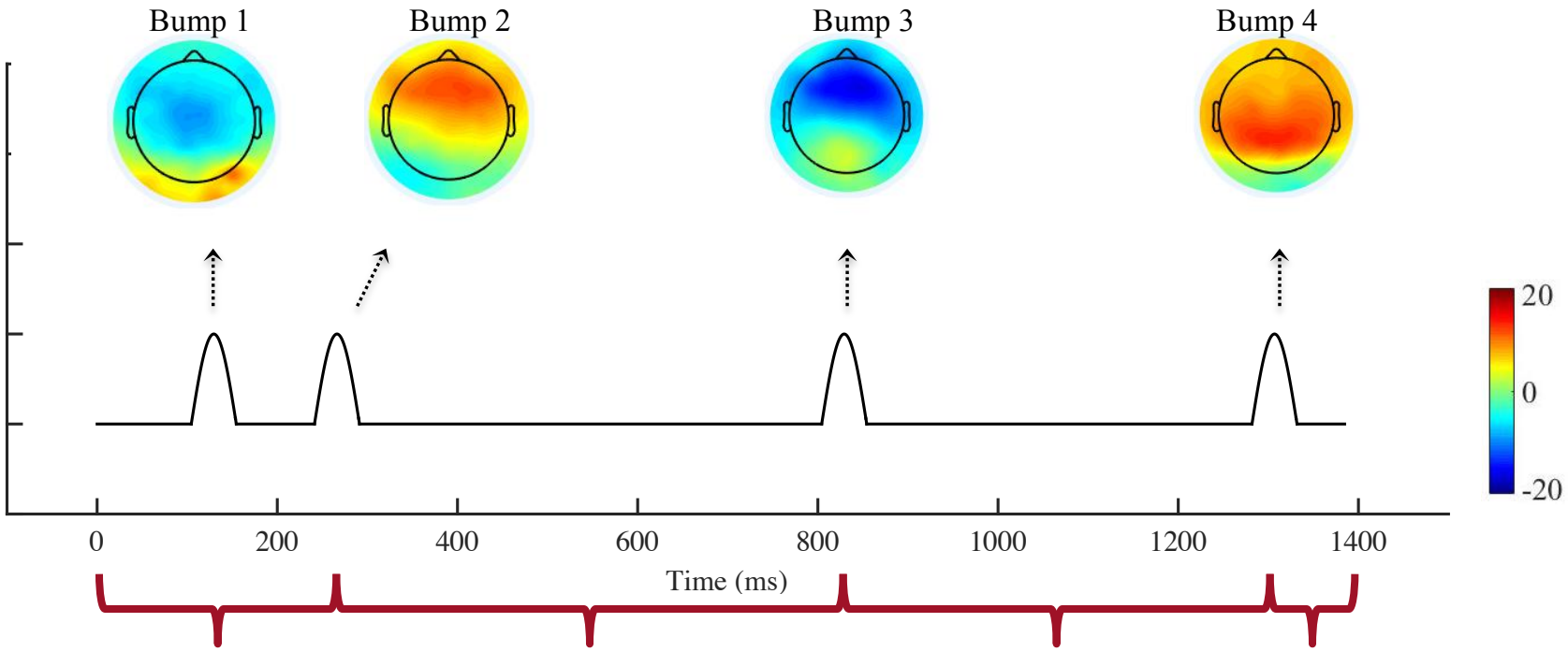
Actor	Verb	Location
Queen	Sing	Office
Sheriff	Laugh	Kitchen
Musician	Sing	Kitchen

Test

Target (similar 3)	Musician	Sing	Kitchen
Dissimilar (similar 0)	Musician	Sleep	Studio
Similar 1	Queen	Laugh	Kitchen
Similar 2	Musician	Sing	Office

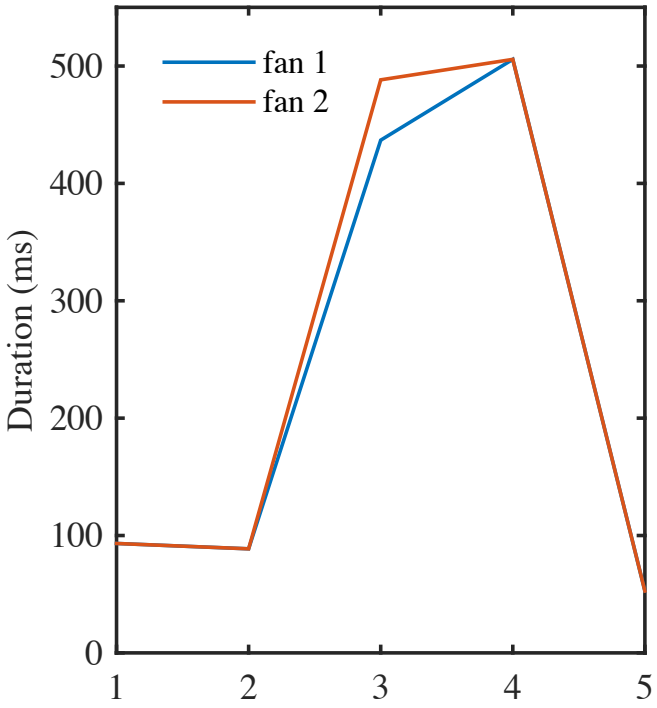
Zhang, Walsh, & Anderson, *submitted*

HSMM Model



1+2: Encoding 3: Retrieval 4: Decision 5: Response

HSMM-MVPA



Retrieval Decision

Retrieval Decision

EEG 2: Conclusions

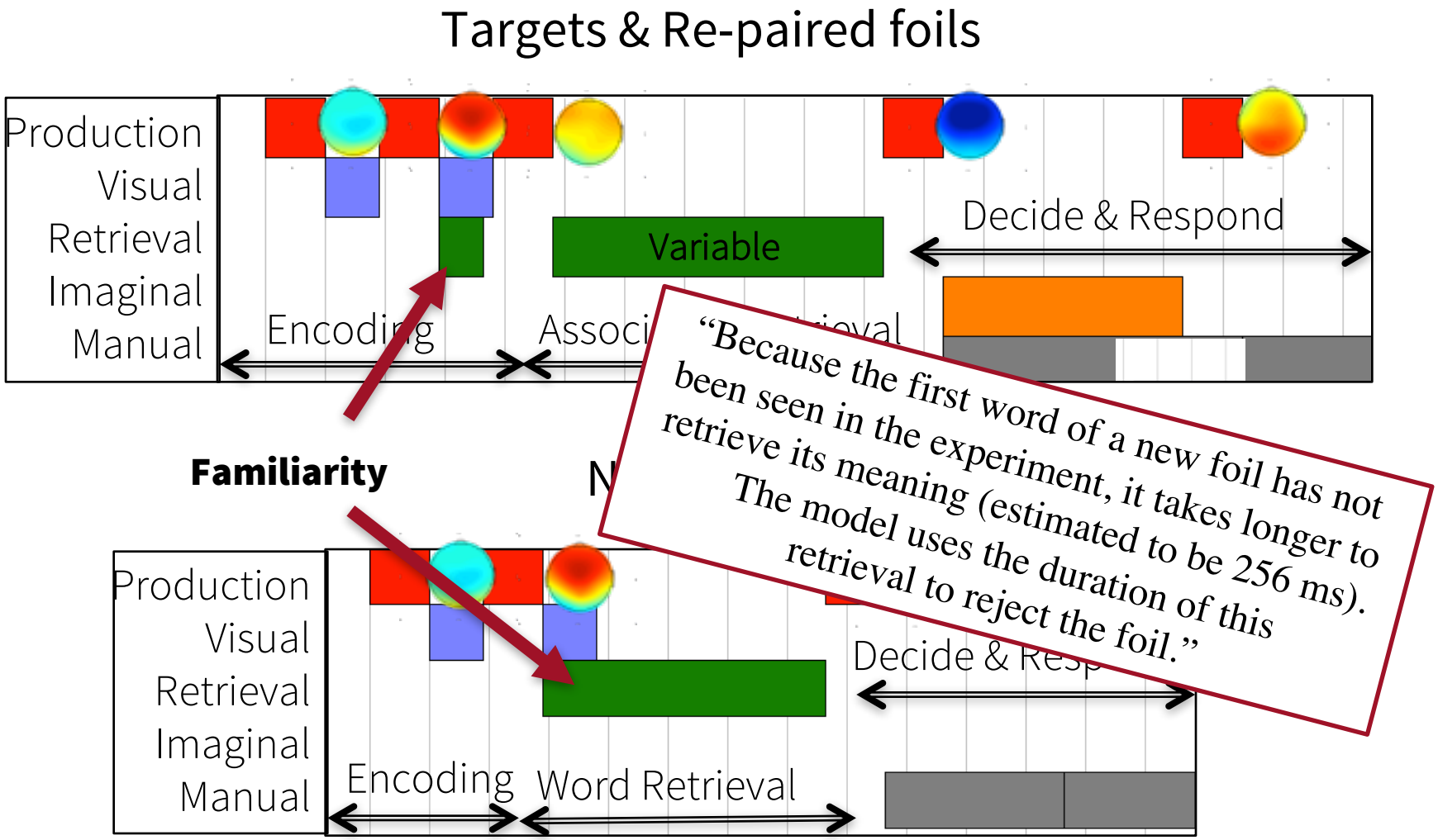
- Associative retrieval followed by separate decision
- Decision process is serial, not evidence accumulation

Summary

- Encoding (occipital)
- Three memory stages:
  - familiarity (perirhinal cortex)
  - associative retrieval (hippocampus)
  - representation (prefrontal, neural activation depends on activation of facts)
- Serial decision process in parietal cortex, input from prefrontal representation
- Motor (precentral)

Not standard ACT-R

Psych Review Model



Anderson, Zhang, Borst, & Walsh, *Psych Review,* 2016

Discussion

- Familiarity process:
  - Psych Review Model: slower retrieval. How to measure this? Temporal module? (cf. Fechner et al., in revision)
  - Other theories: summed similarity to all items in memory (no recollection of content)
  - **Do we need a separate familiarity process, i.e. estimate of memory activation without retrieval?**

- Prefrontal representation of retrieved facts, maintaining their activation
  - Activation can be used as a proxy for retrieval time
  - **Is this useful for other models? Arguments in favor, against?**

Thank you!

Jelmer Borst

j.p.borst@rug.nl
www.jelmerborst.nl

university of groningen