

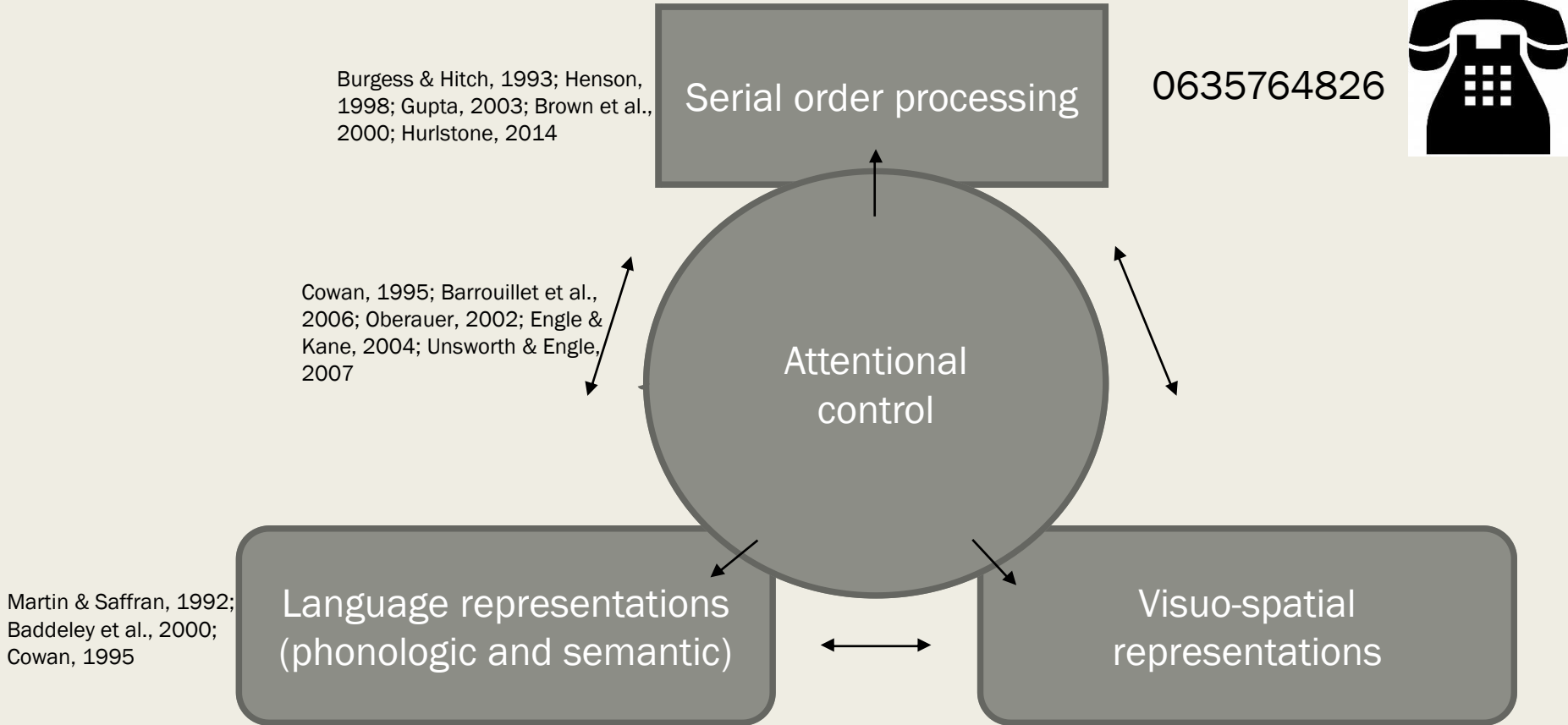
SERIAL ORDER IN WM :

FUNCTION AND NATURE OF THIS CODING

Lucie Attout, University of Liège, Belgium

Theoretical framework

Working memory = capacity to temporarily maintain information in mind and to mentally manipulate them during a short period when we want to reach a specific goal (Cowan & Alloway, 2009).



THE FUNCTION OF ORDER WM CODING

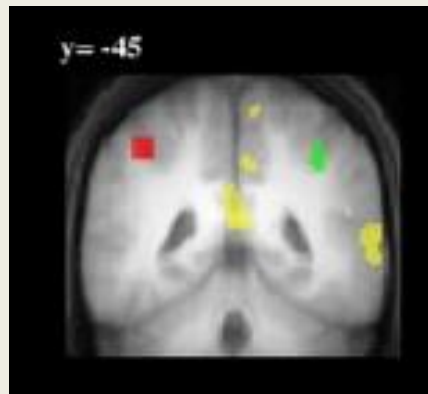


Why is serial order important?



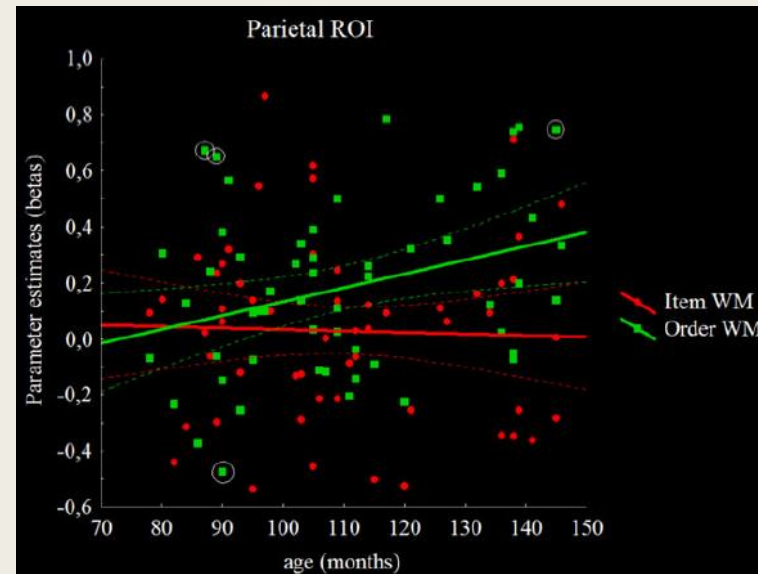
Why is serial order important?

- Serial order is a specific and independent component
 - *Distinct impairment in brain-damaged patients or atypical developmental disorders*
 - *Distinct cerebral networks in adults and children*



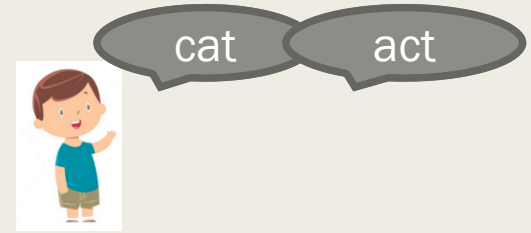
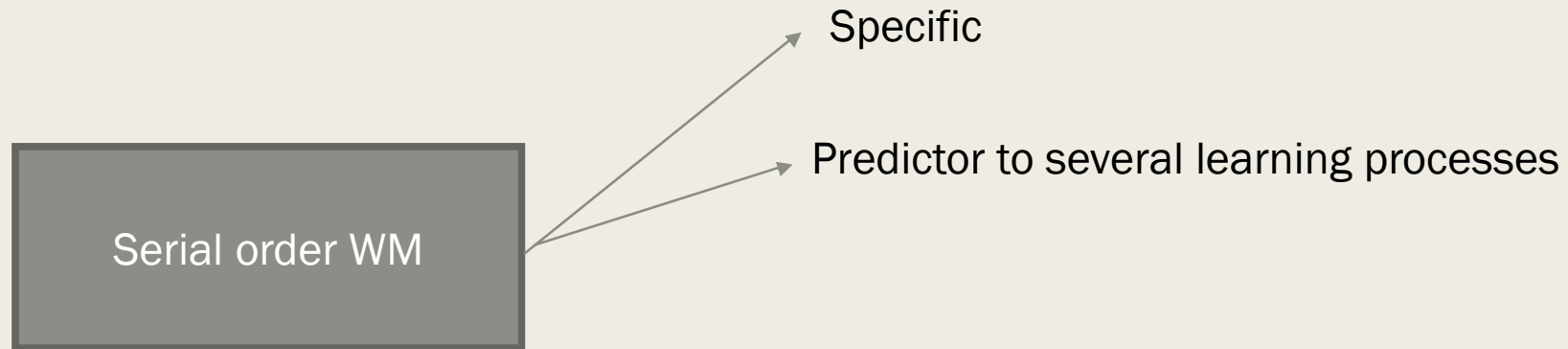
Majerus et al. (2006), NI

- Order WM
- Item WM



Attout et al. (2018), HBM

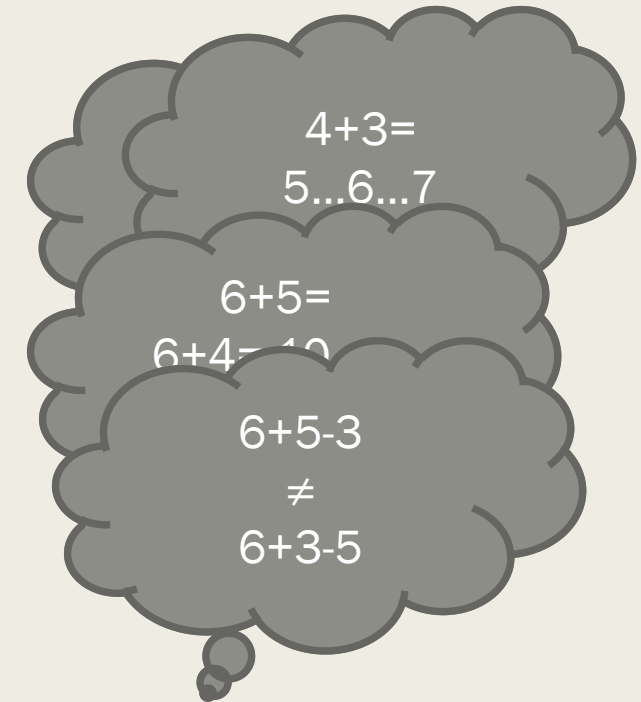
Why is serial order important?



Involvement in mathematical abilities



- *Verbal counting / first additions*
To know which number has already been counted
- *To solve a more complex calculation*
To recall an interim result
- *To maintain the order of events*



Involvement in mathematical abilities

preschool

1st grade

2nd grade



Order WM



Calculation
(simple additions)

$$2+2$$

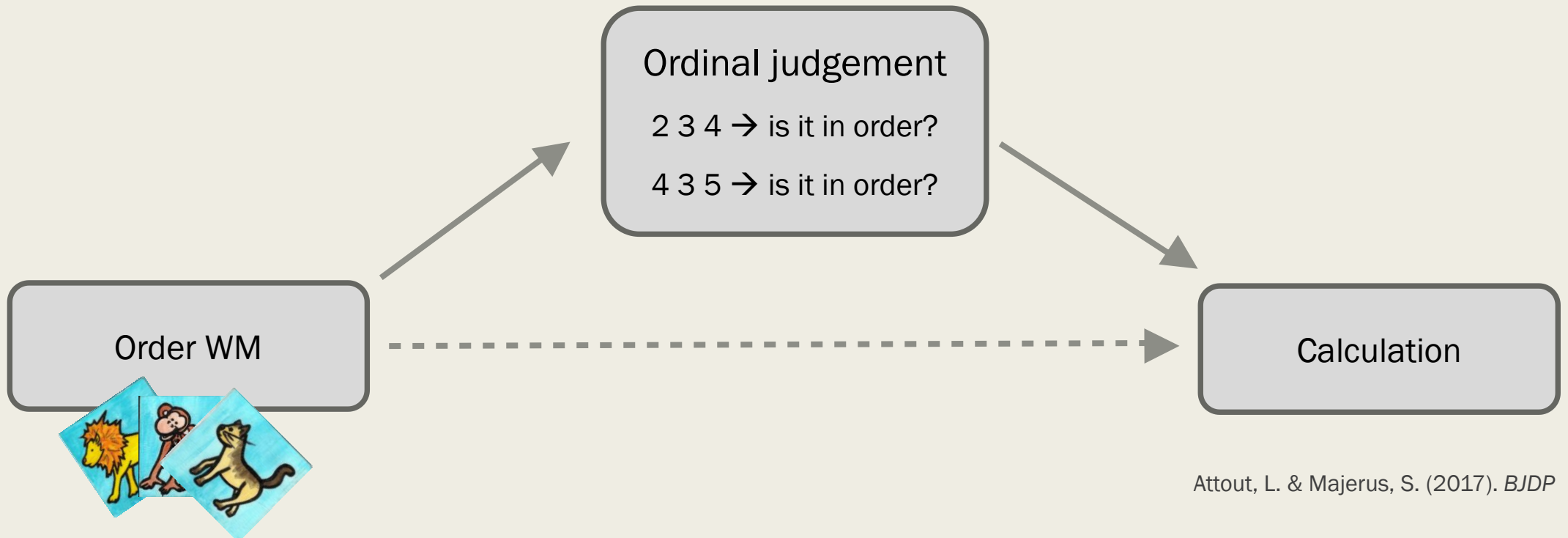
Complex
calculation

$$8+5$$

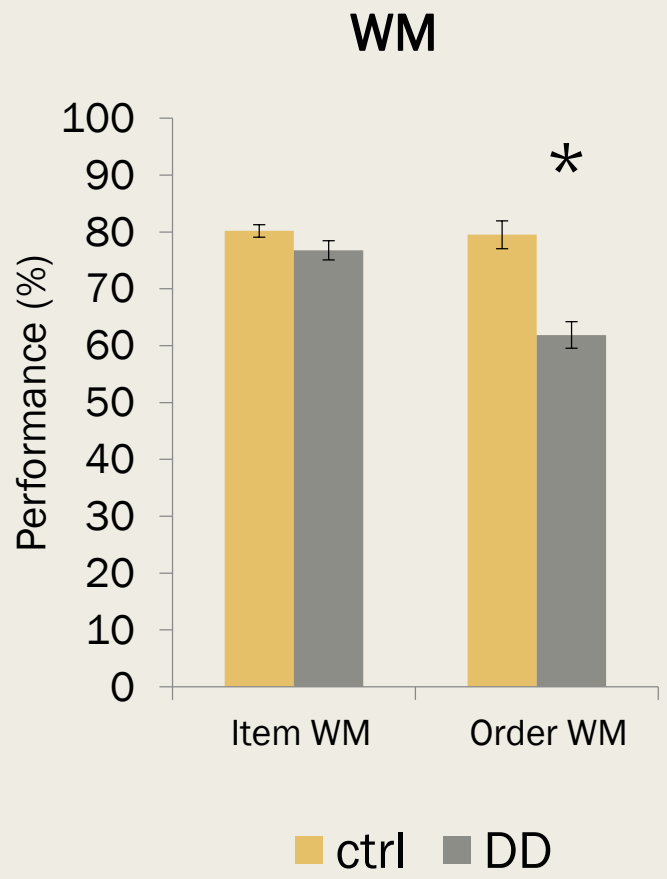
Involvement in mathematical abilities



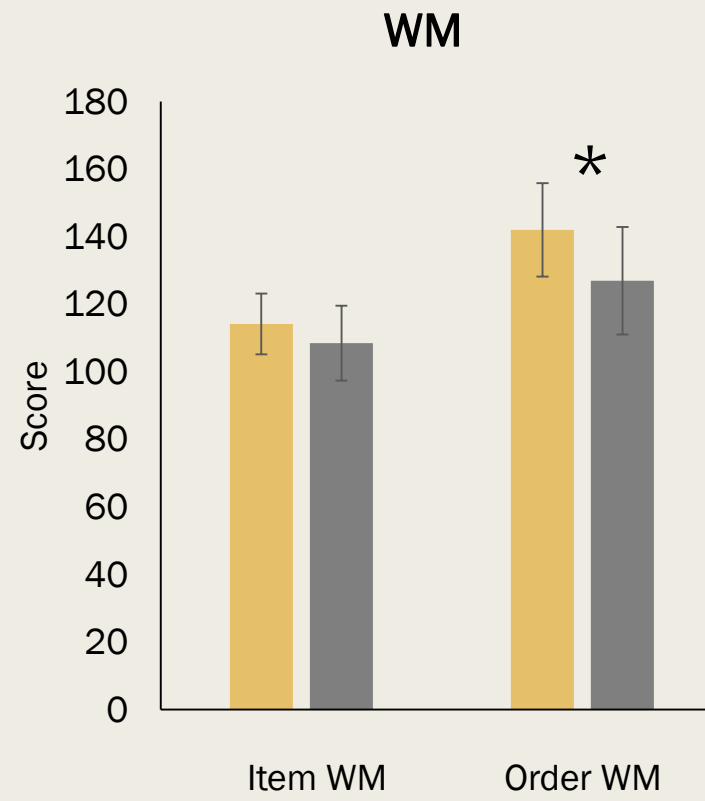
- N=108 8 year-old children



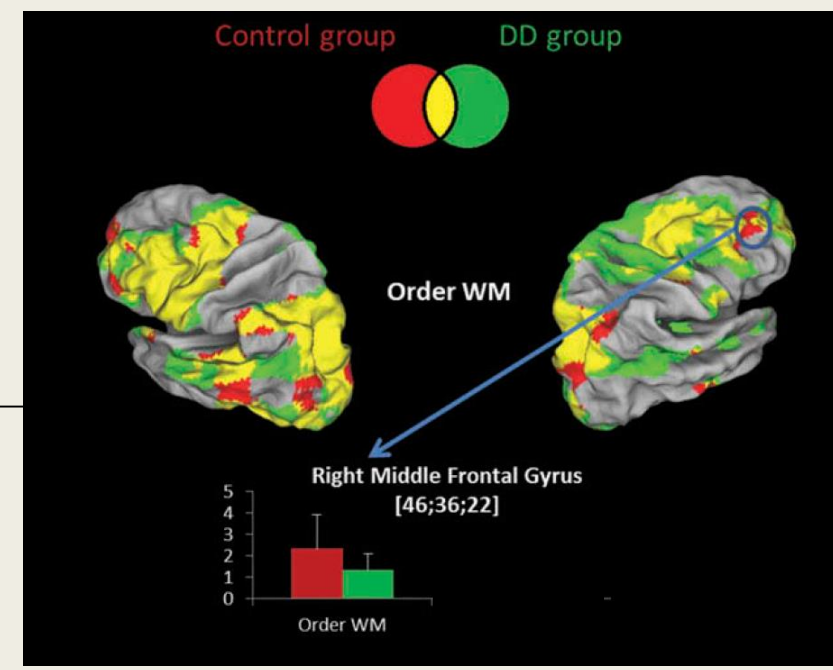
Involvement in mathematical abilities



Attout & Majerus (2014). *Child Neuropsychology*.



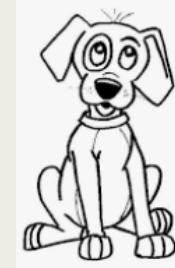
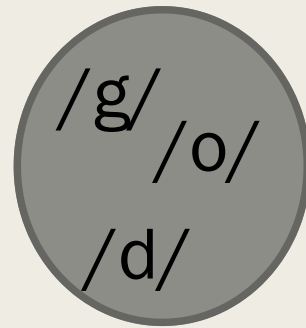
Attout, Salmon & Majerus (2015). *Developmental neuropsychology*



Involvement in oral language



Language = letters → words



/dog/



/god/

→ Importance of serial order processes

Involvement in oral language



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Cognitive Development

journal homepage: www.elsevier.com/locate/cogdev

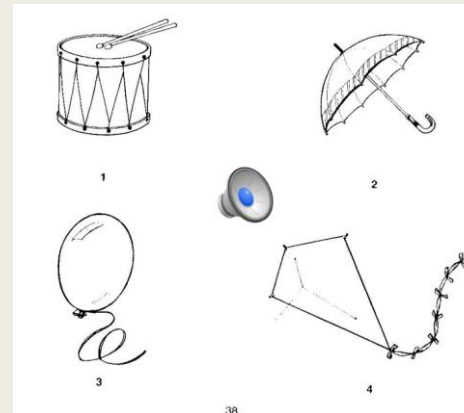
How robust is the link between working memory for serial order and lexical skills in children?

Lucie Attout^{a,*}, Coline Grégoire^a, Steve Majerus^{a,b}

^a Psychology and Neuroscience of Cognition Research Unit, University of Liège, Belgium

^b Fund for Scientific Research FNRS, Brussels, Belgium

Receptive vocabulary



Productive vocabulary



Table 2

Bayesian correlation (Pearson r) between the WM tasks and the different vocabulary measures and Raven's CPM.

	Item WM	Order WM
Receptive vocabulary	.09 (BF ₁₀ = 0.18)	.34 (BF ₁₀ = 28.12)
Productive vocabulary (total)	-.03 (BF ₁₀ = 0.14)	.33 (BF ₁₀ = 24.02)
Productive vocabulary (frequent words)	-.08 (BF ₁₀ = 0.18)	.29 (BF ₁₀ = 5.86)
Productive vocabulary (rare words)	-.01 (BF ₁₀ = 0.13)	.35 (BF ₁₀ = 45.45)
Productive vocabulary (verbs)	.04 (BF ₁₀ = 0.14)	.21 (BF ₁₀ = 0.93)
Raven's CPM	.19 (BF ₁₀ = 0.61)	.18 (BF ₁₀ = 0.53)

Involvement in oral language



Cognitive Development 47 (2018) 146–157

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Cognitive Development

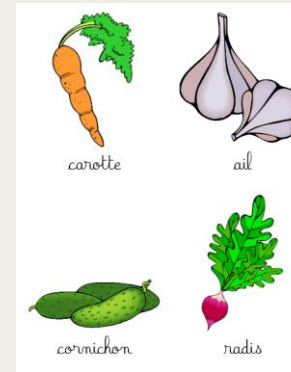
journal homepage: www.elsevier.com/locate/cogdev

ELSEVIER

Short-and long-term memory determinants of novel word form learning

Laura Ordonez Magro^{a,*}, Lucie Attout^c, Steve Majerus^c, Arnaud Szmalec^{a,b,d}

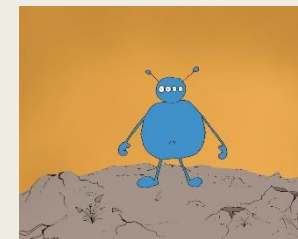
Check for updates



Order WM



Learning of new words



/bam/

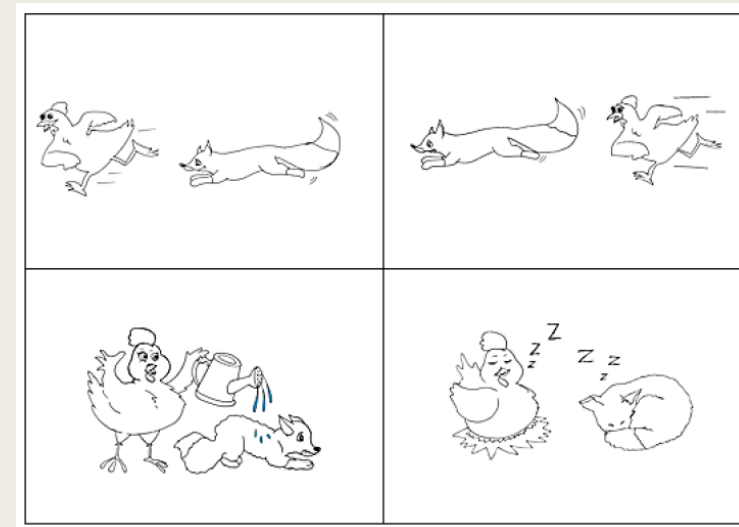
Involvement in oral language



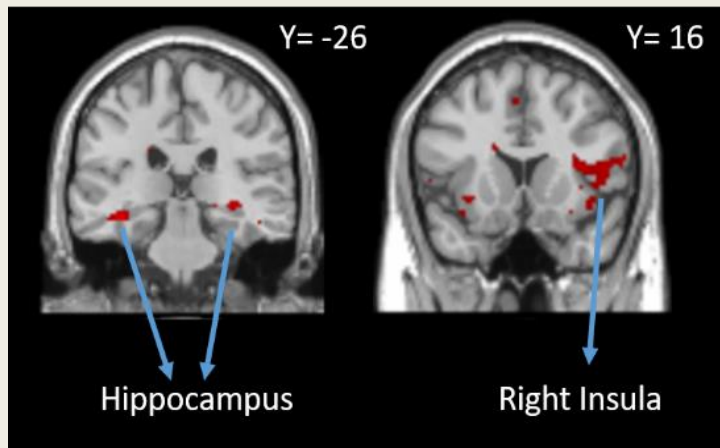
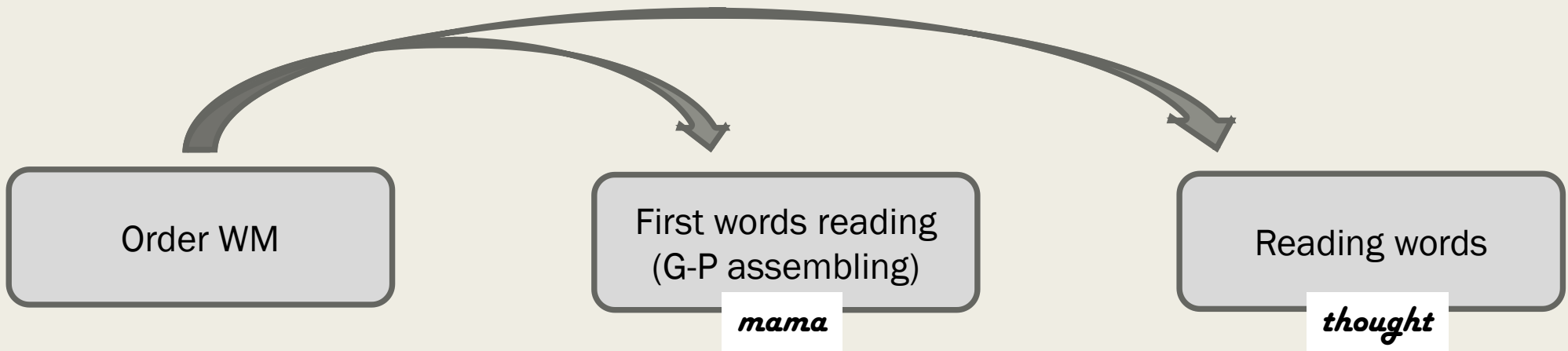
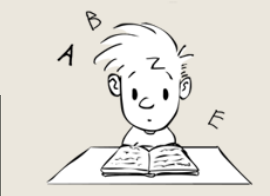
Syntactic skills

« A chicken that is hunting the fox »

Order WM →

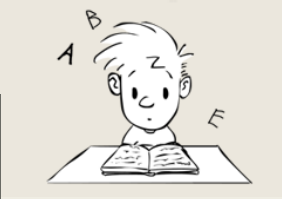


Involvement in written language

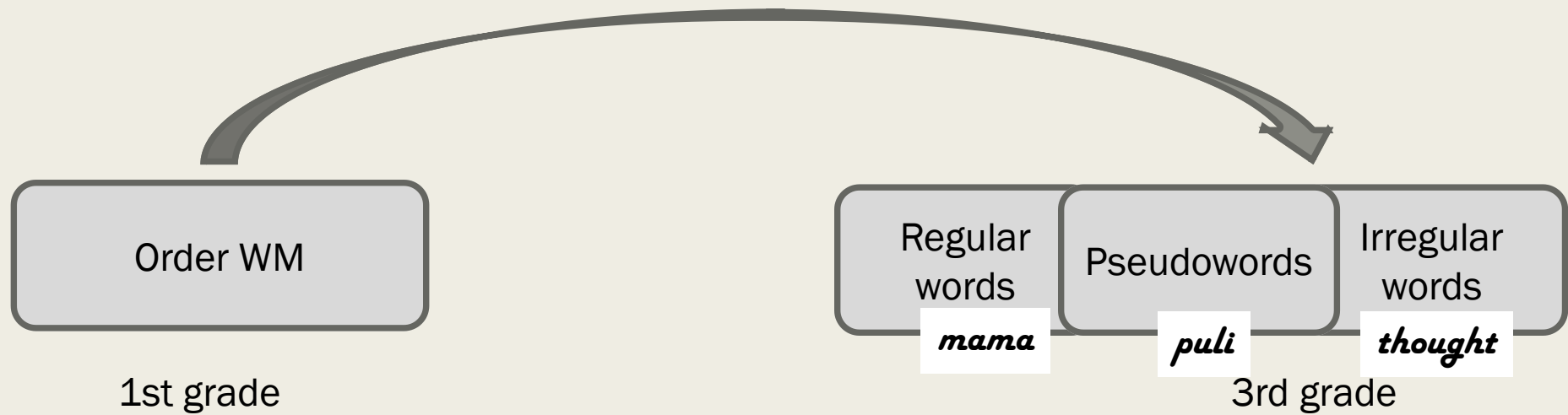


Attout et al., 2020, HBM
Ordonez et al., 2020,
Developmental psychology

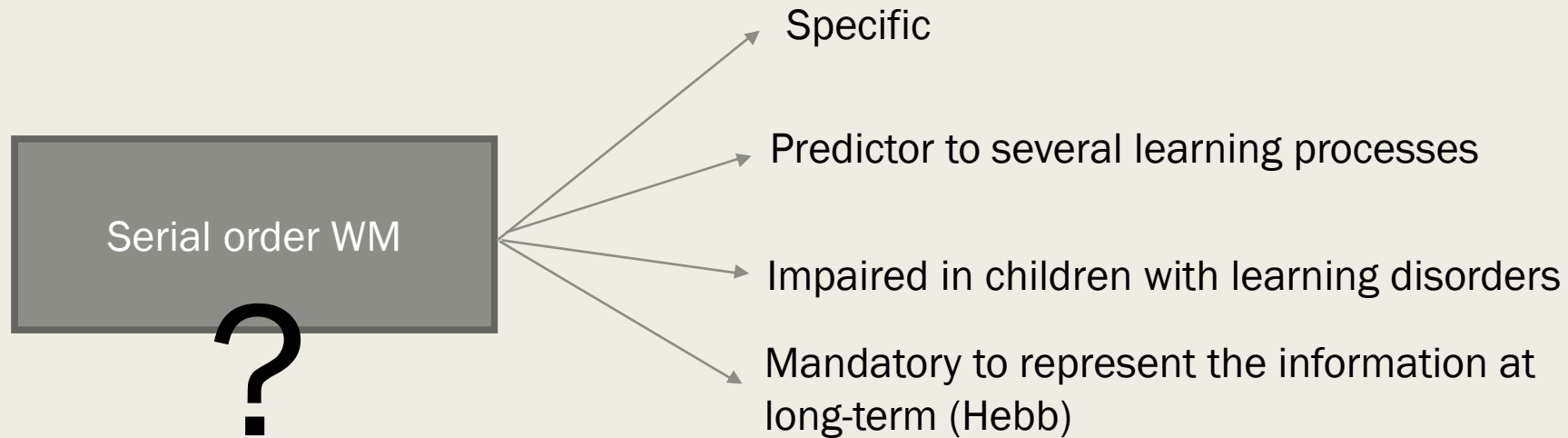
Involvement in written language



- Spelling abilities



Why is serial order important?

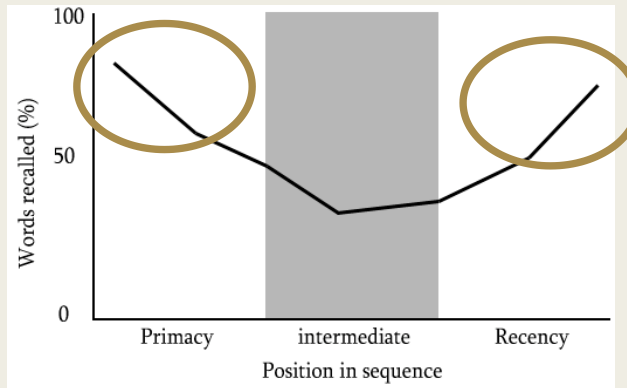


THE NATURE OF ORDER WM CODING



Nature of order WM


0 4 9 4 4 9 6 8 2 4



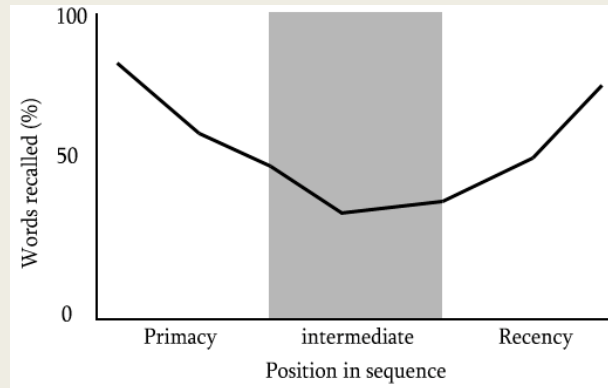
Ebbinghaus, 1885; Avons, 1998;
Guérard & Tremblay, 2008;
Johnson et al., 2016; Lee & Estes,
1981; Smyth et al., 2005; Ward et
al., 2005

Nature of order WM

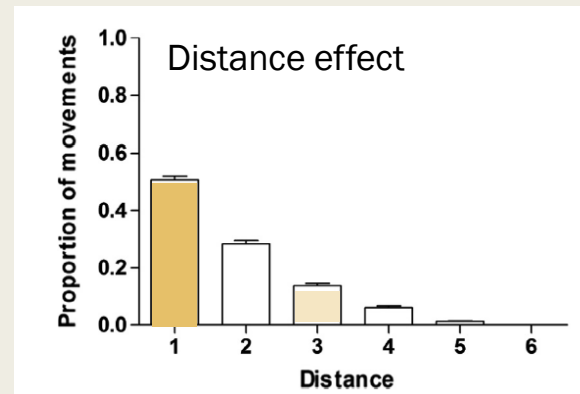
0 4 9 4 4 9 6 8 2 4



A diagram showing a sequence of numbers: 0, 4, 9, 4, 4, 9, 6, 8, 2, 4. Below the numbers, there are three curved arrows pointing from left to right, indicating movement or transitions between the numbers. The first arrow starts under the first '4' and points to the second '4'. The second arrow starts under the second '4' and points to the '6'. The third arrow starts under the '6' and points to the '8'.



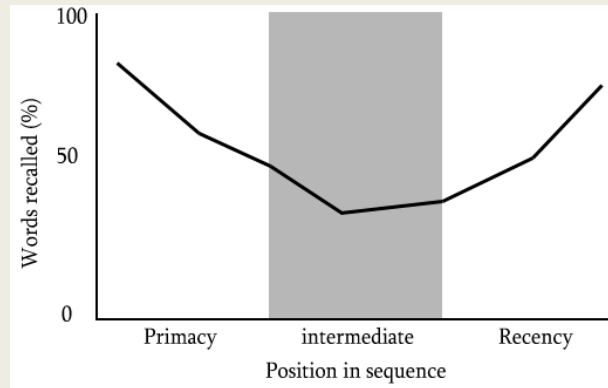
Ebbinghaus, 1885; Avons, 1998;
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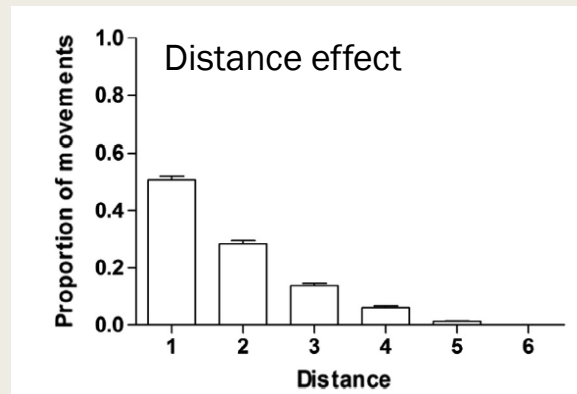
Burgess & Hitch, 1999; Henson;
1996; Hurlstone & Hitch, 2015;
Parmentier et al., 2006

Nature of order WM

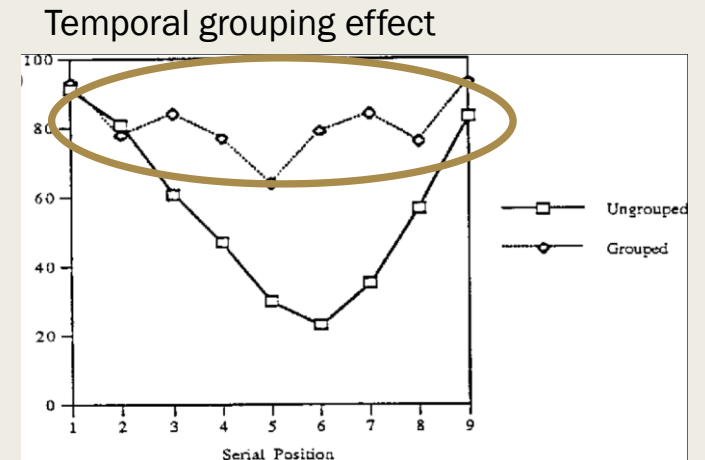
0 4 9 4 / 4 9 6 / 8 2 4



Ebbinghaus, 1885; Avons, 1998; Guérard & Tremblay, 2008; Johnson et al., 2016; Lee & Estes, 1981; Smyth et al., 2005; Ward et al., 2005



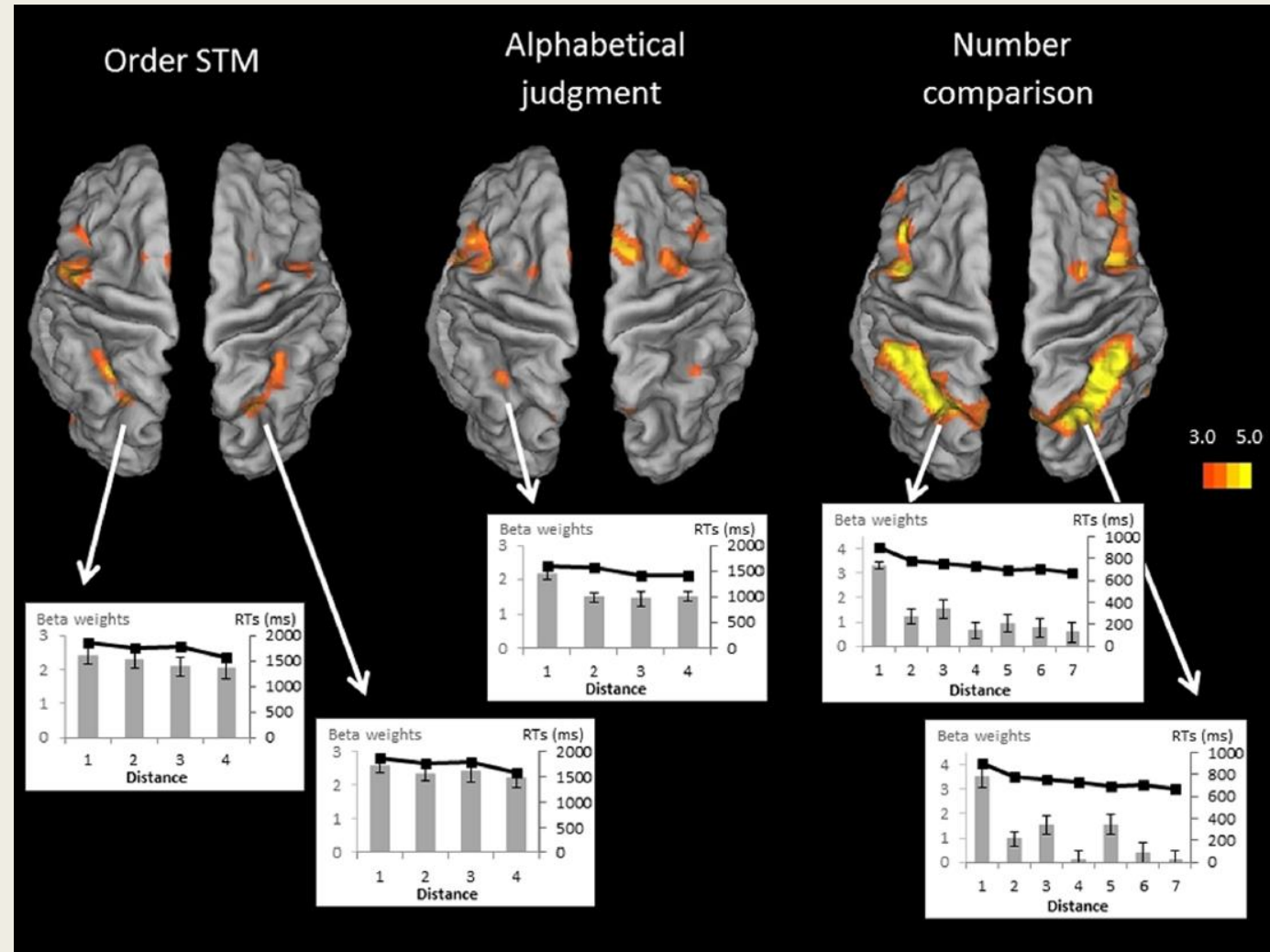
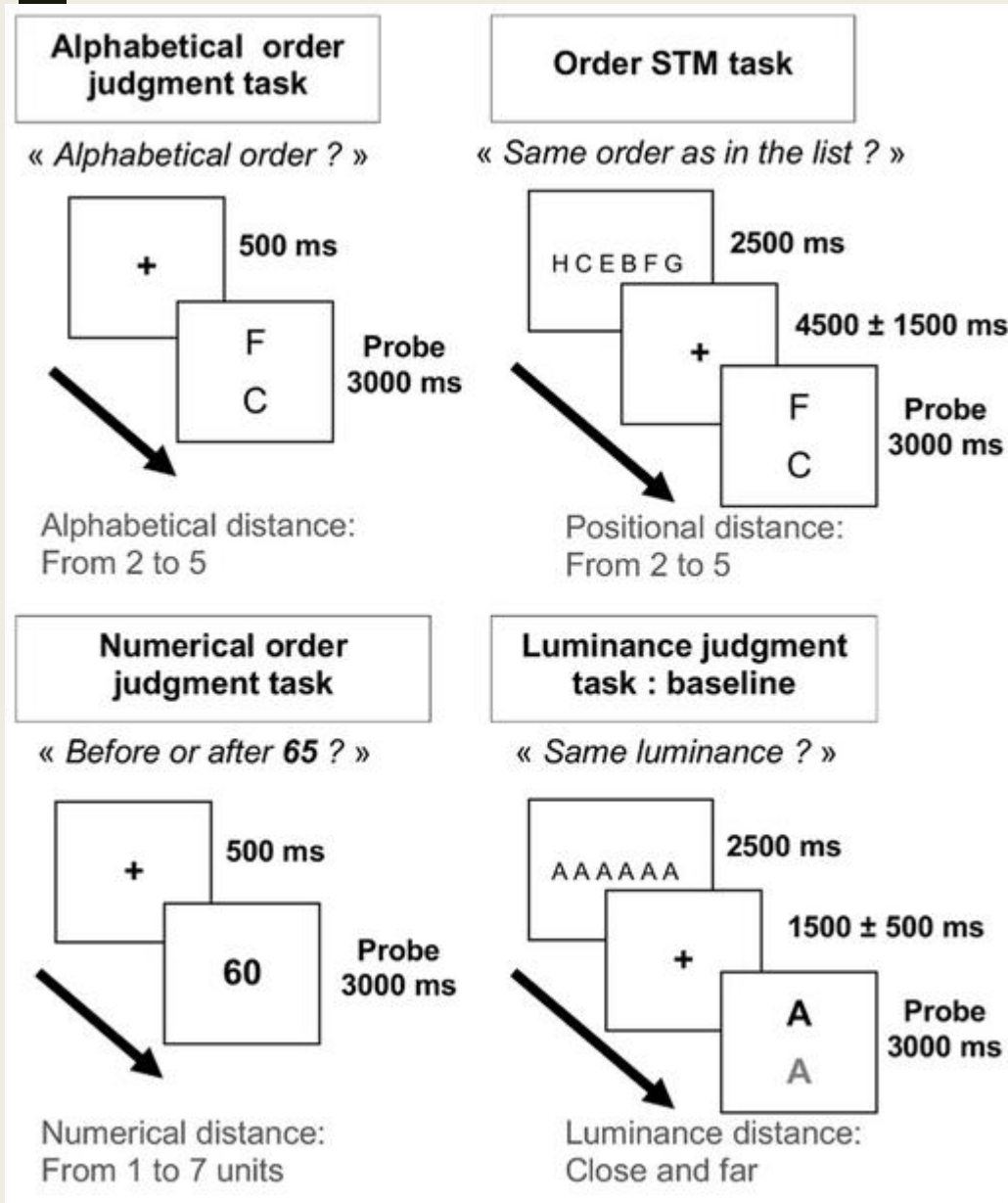
Burgess & Hitch, 1999; Henson, 1996; Hurlstone & Hitch, 2015; Parmentier et al., 2006



Deutsh, 1980; Frankish, 1985, Henson, 1996; Hitch et al., 1996; Parmentier et al., 2004; 2006

Several theoretical models exist but no one can reproduce the entire behavioral effects usually seen in order WM processing

Common distance effect



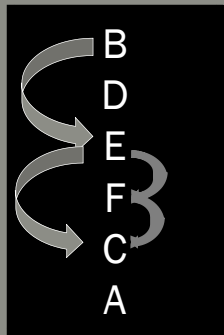
Common ordinal representation ?



Participants: 34 young adults (22 women) aged from 19 – 33
(23.30 ± 2.80 years old)

Order WM judgment

Are they in the same order or not as in the memory list?



Encoding
2500 ms

Maintenance
6000 ± 2000
ms

4000 ms
max.

E F C

B E C

B C E

Distance 1

Distance 2

Negative trials

Alphabetical order judgment

Are they in the correct alphabetical order or not?

B
C
D

B
D
E

B
E
D

Numerical order judgment

Are they in the correct numerical order or not?

2
3
4

2
4
6

2
6
4

Luminance judgment

Are they different or not?

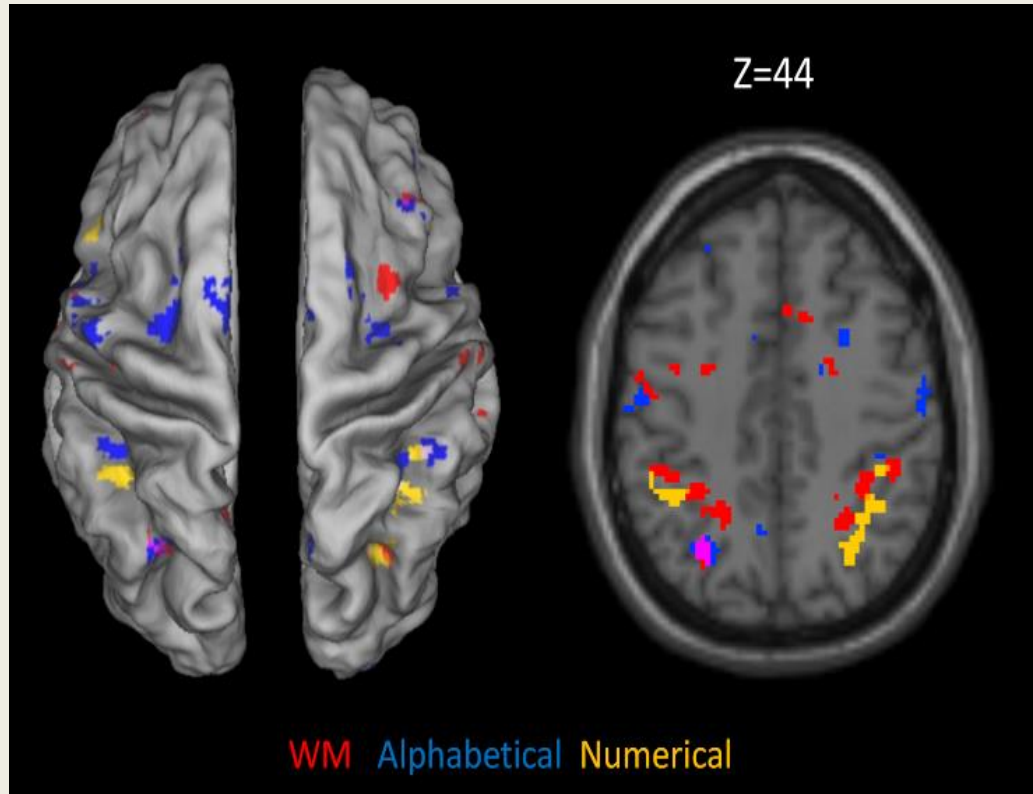
■ ■ ■

■ ■ ■

■ ■ ■

Common ordinal representation ?

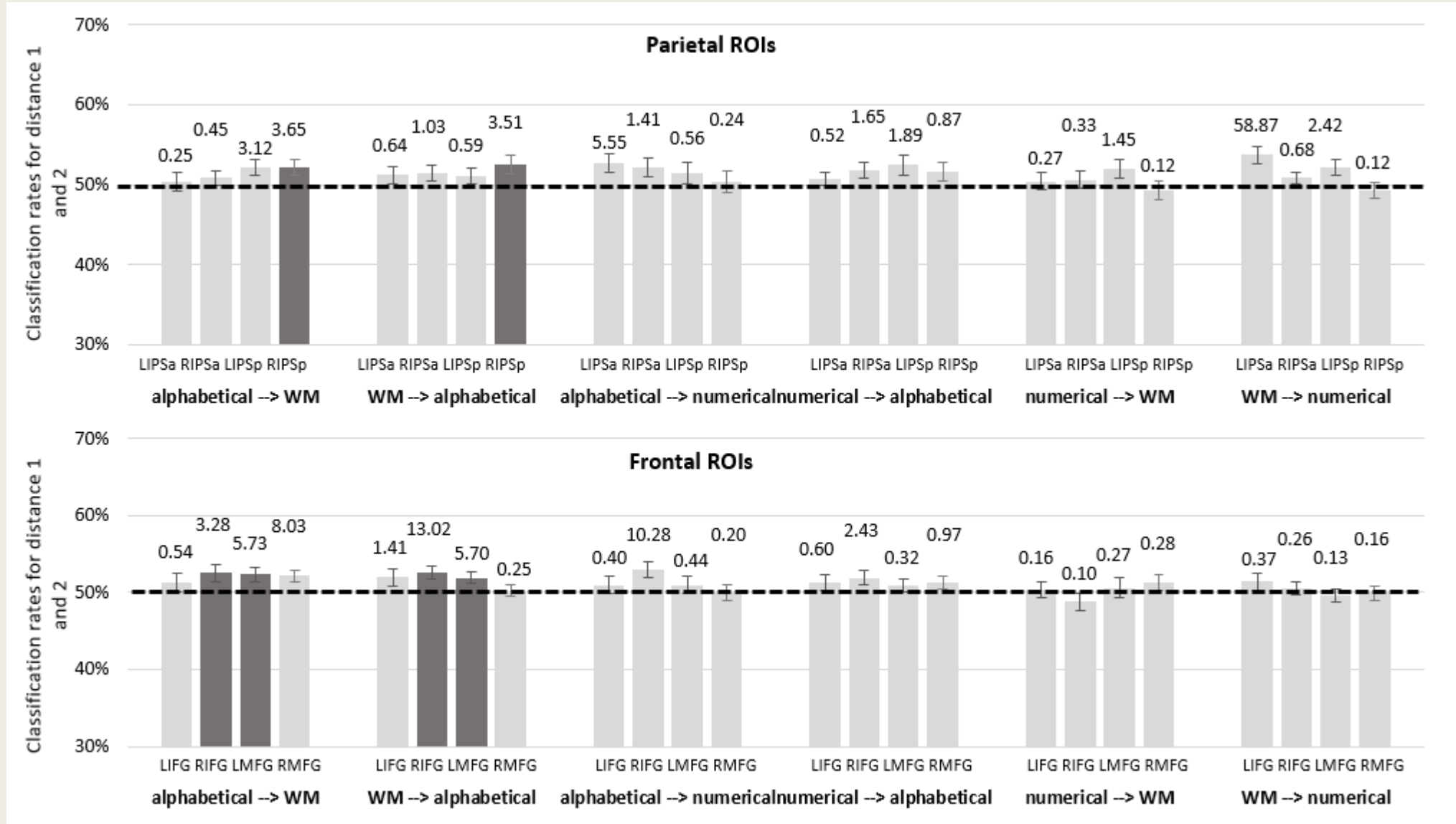
- Univariate



	No. voxels	Left/ right	x	y	z	SPM Z - value
Ordinal distance effect for order WM (D2<D1)						
IPSa	26	L	-30	-44	44	3.79*
	50	R	46	-36	40	4.25*
IPSp	96	L	-28	-64	44	4.26*
Ordinal distance effect for ordinal alphabetical judgment (D2<D1)						
IPSp	43	L	-28	-64	44	4.24*
	11	R	30	-62	38	3.50*
Ordinal distance effect for ordinal numerical judgment (D2<D1)						
IPSa	69	L	-38	-44	40	3.81*
	28	R	38	-38	40	3.73*
IPSp	71	R	32	-60	46	4.00*
MFG	57	L	-48	22	22	3.98*
	18	R	46	40	22	3.89*
IFG	34	L	-36	28	20	4.06*
Standard distance effect for luminance judgment (D1<D2)						
BA17	6	R	16	-94	-4	3.57 ^a

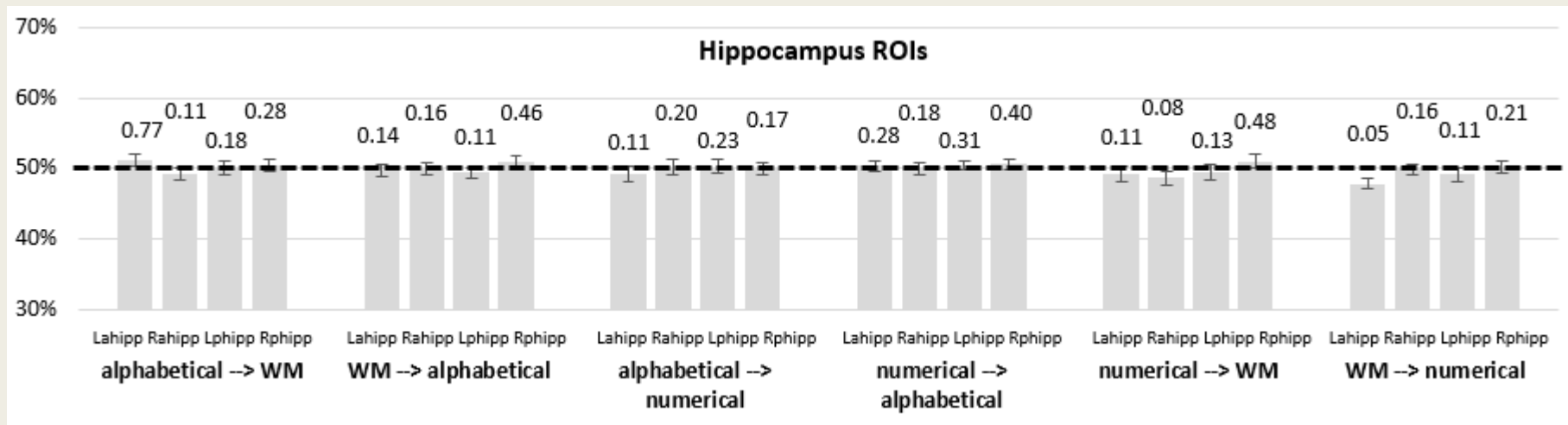
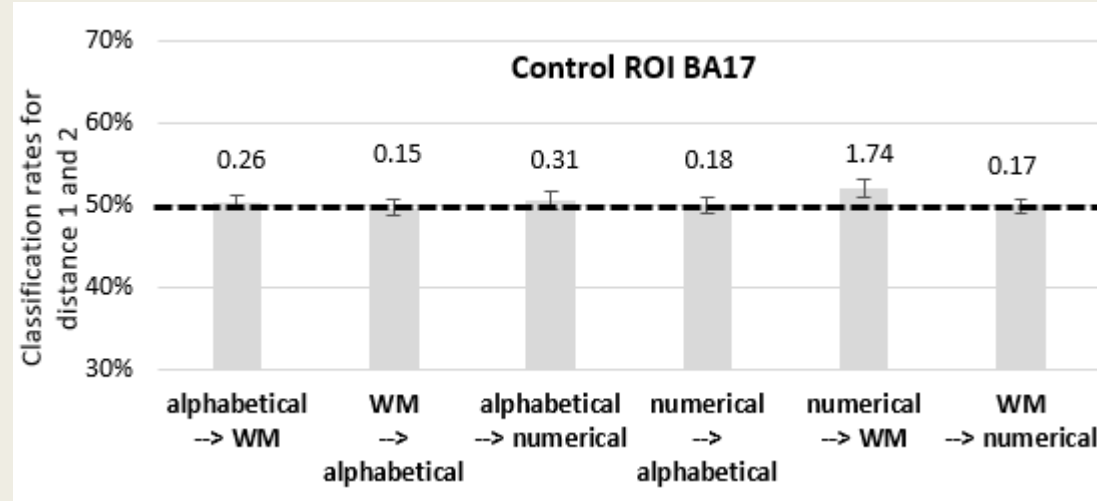
Common ordinal representation ?

MVPA
Prediction
between
tasks



Common ordinal representation ?

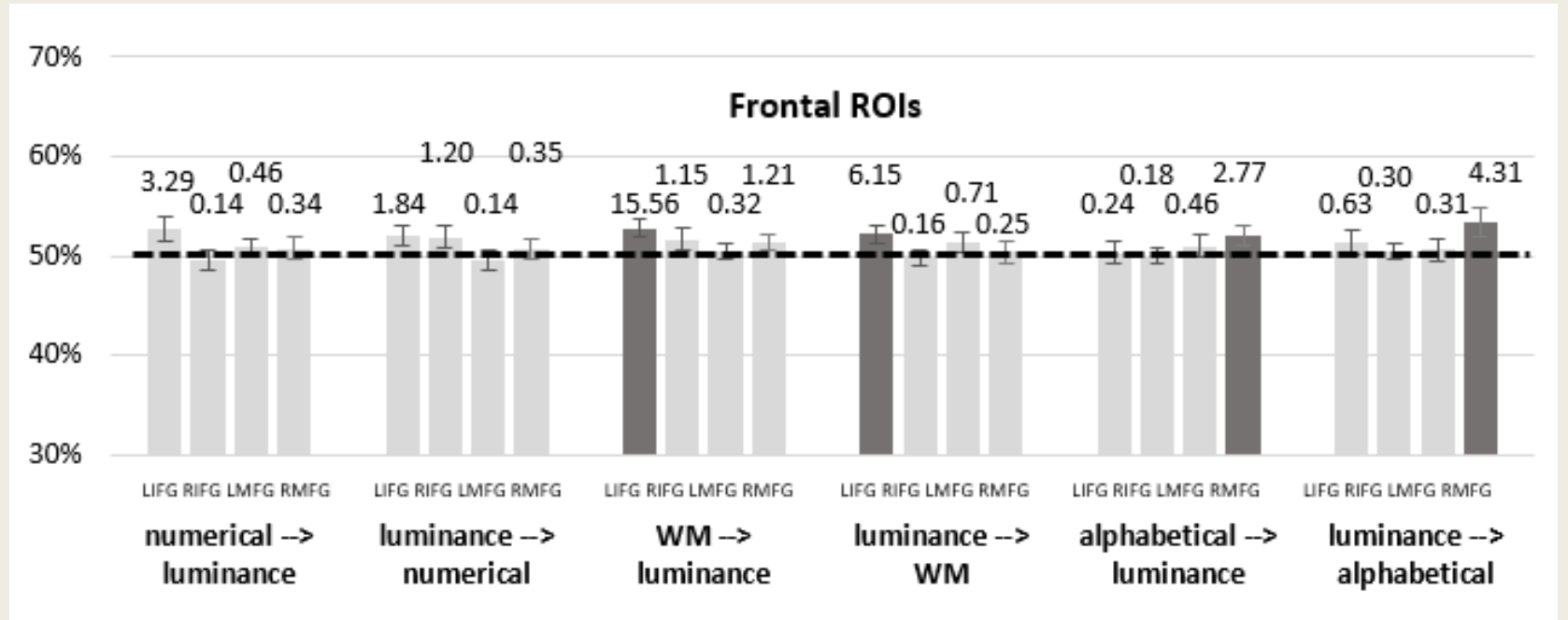
MVPA
Prediction
between
tasks



Common ordinal representation ?

Prediction between tasks

With luminance judgment




Common distance effect ?

- Domain-general implication of fronto-parietal cortices BUT not support the hypothesis of domain-general ordinal codes per se
 - *prediction of ordinal distance only for the order WM and alphabetical tasks, but not for the numerical domain*
 - *prediction not specific to ordinal distance → luminance distance*

‘hard-vs-easy’ dimension → different levels of attentional control

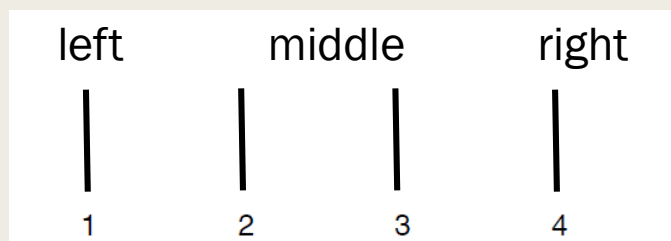
- More specific role of the posterior IPS for ordinal processing ?
- A spatial-attentional role of the posterior IPS
 - *Differentiated neural signals for leftward versus rightward orientation of attention (Yantis et al. 2002; Silver and Kastner 2009; Vandenberghe and Gillebert 2009; Bressler and Silver 2010; Gillebert et al. 2011).*
 - *Mental whiteboard hypothesis : attentional spatial frame could allow to temporarily organize memoranda and letters on a horizontal line, ordered from left to right (Abrahamse et al. 2014, 2017)*

Role of spatial or temporal in order WM representation



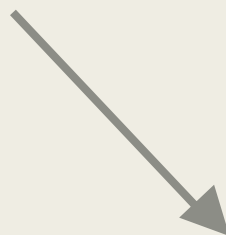
Spatial codes

Henson, 2000; Abrahamse et al., 2017; Van Dijck et al., 2011; Guida



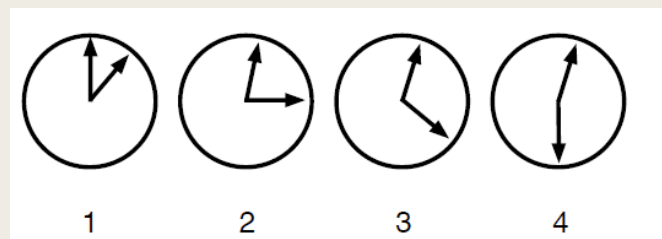
Role of spatial or temporal in order WM representation

Positional models



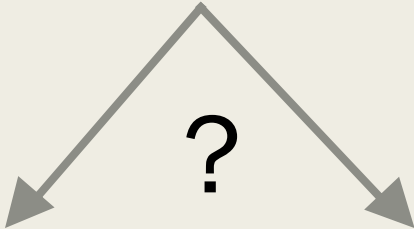
Temporal codes

Hartley, Hurlstone and Hitch, 2016; Brown et al. 2000



Role of spatial or temporal in order WM representation

Positional models

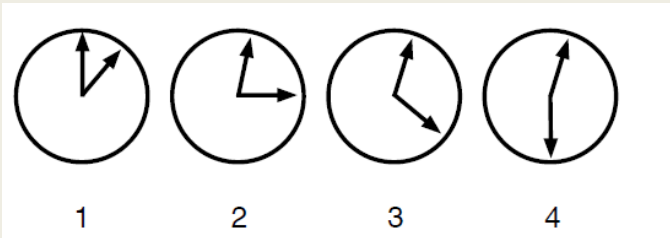
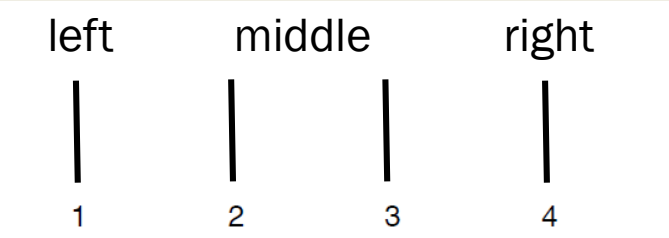


Spatial codes

Temporal codes

Henson, 2000; Abrahamse et al., 2017; Van Dijck et al., 2011; Guida

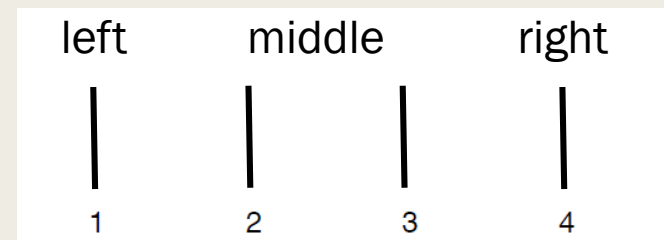
Hartley, Hurlstone and Hitch, 2016; Brown et al. 2000



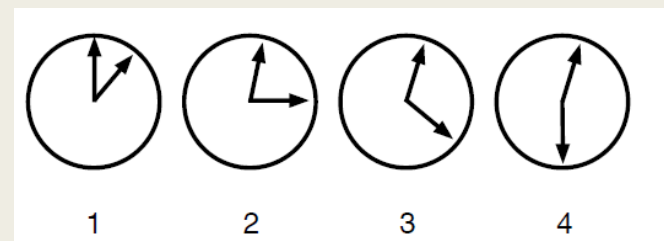
Role of spatial or temporal in order WM representation

Understand the interactions between time, space and serial order in WM

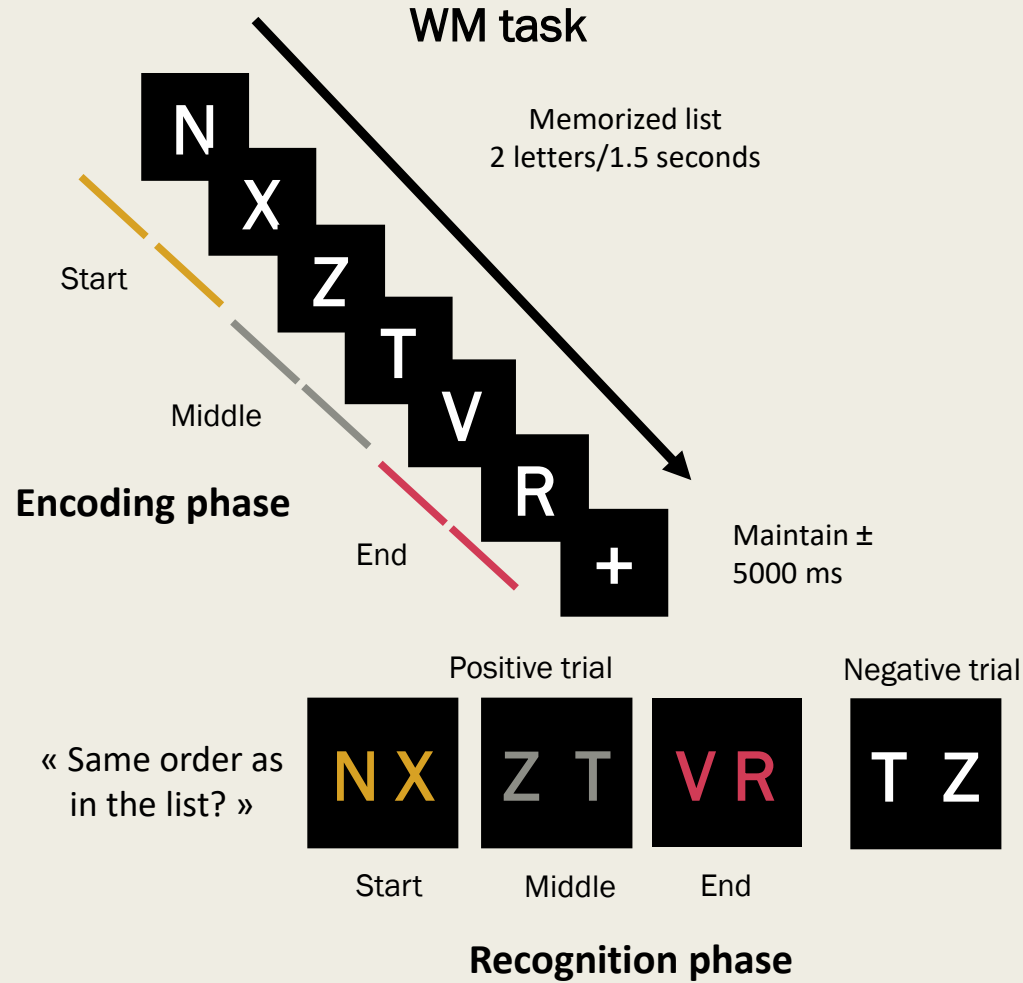
- commonality of the spatial attention and WM representations



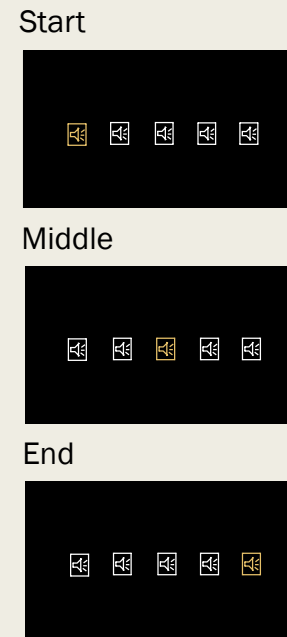
- commonality of the temporal attention and WM representations



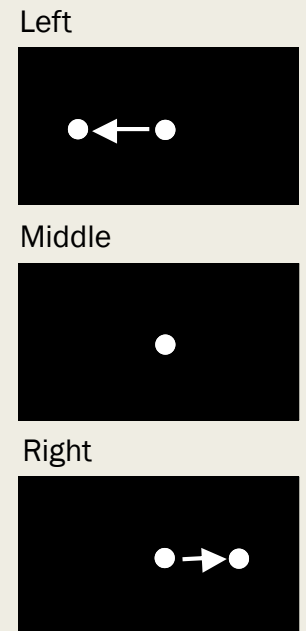
Role of spatial or temporal in order WM representation



Implicit Temporal task
«Press as soon as you hear the high-pitched sound among the low-pitched sounds in the sound sequence»



Implicit Spatial task
«Press as soon as the dot stops»

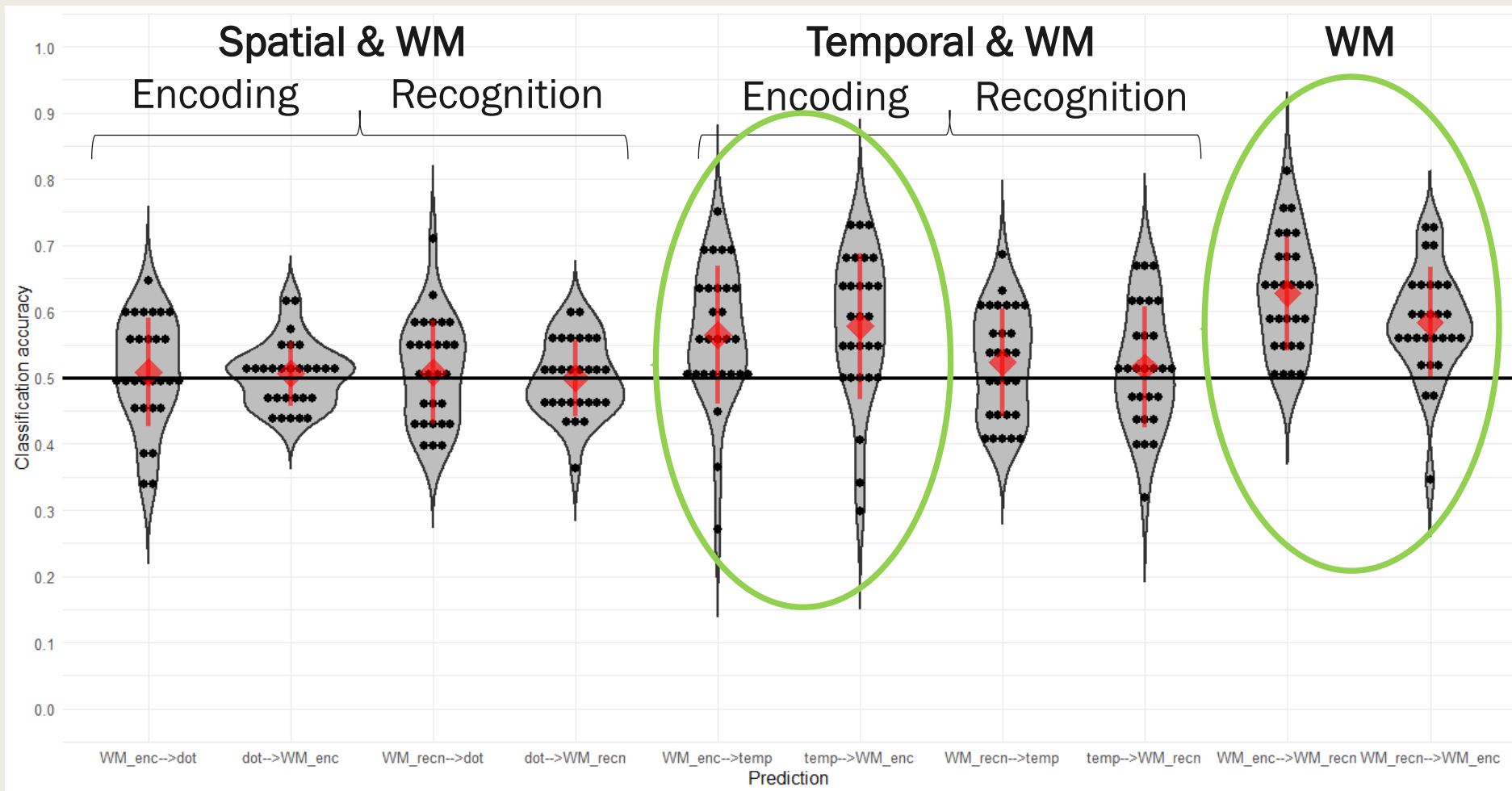


Max. 4000 ms

For all Tasks : Start/Left vs. End/Right

Role of spatial or temporal in order WM representation

Prediction between spatial/temporal tasks & the WM task (for encoding and recognition) for the classification between start-of-list/left VS end-of-list/right

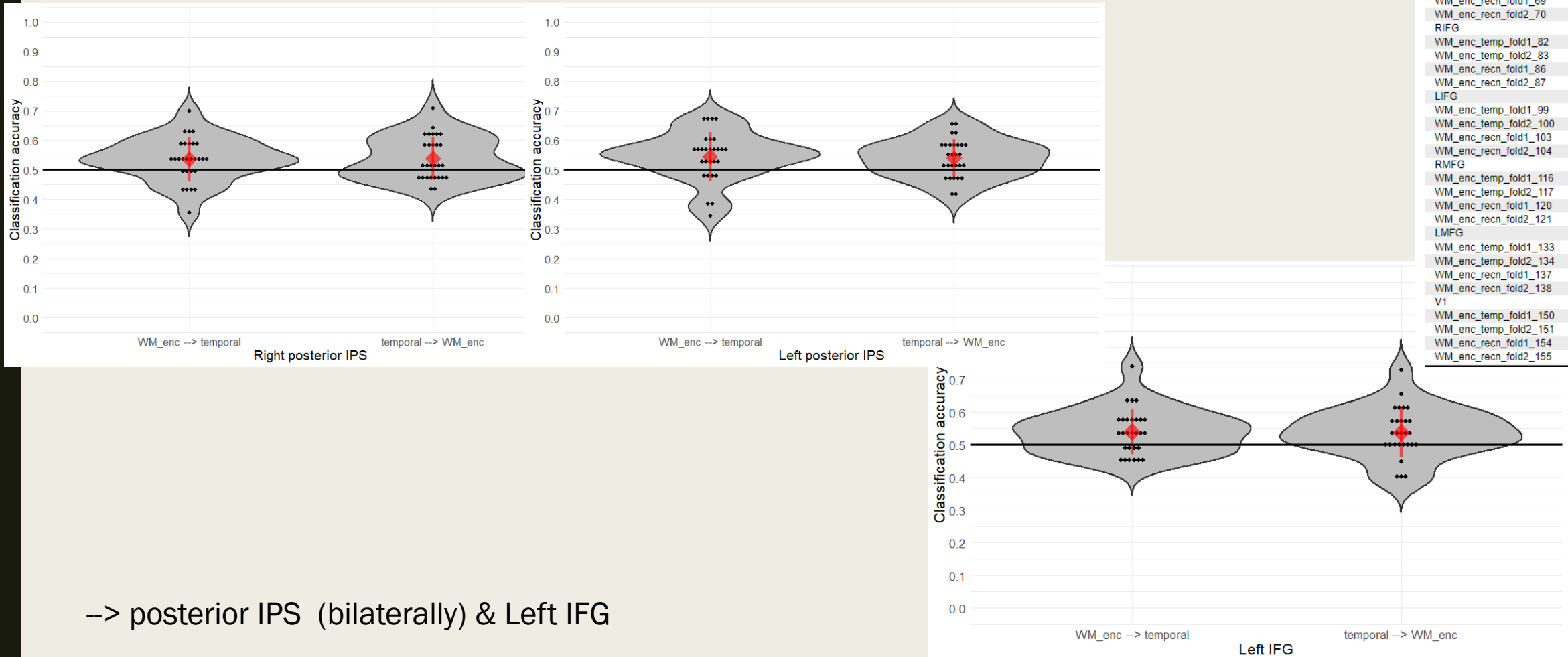


Bayesian One Sample T-Test	
	BF _∞
dot_temp_fold1_37	0.217
dot_temp_fold2_38	0.361
WM_enc_dot_fold1_39	0.317
WM_enc_dot_fold2_40	0.358
WM_recn_dot_fold1_41	0.332
WM_recn_dot_fold2_42	0.191
WM_enc_temp_fold1_43	25.890
WM_enc_temp_fold2_44	76.568
WM_recn_temp_fold1_45	1.009
WM_recn_temp_fold2_46	0.478
WM_enc_recn_fold1_47	1.381e +6
WM_enc_recn_fold2_48	3957.313

Bayesian One Sample T-Test	
	BF ₊
RISPA	NaN ^a
WM_enc_temp_fold1	0.461
WM_enc_temp_fold2	1.048
WM_enc_recn_fold1	60.715
WM_enc_recn_fold2	18.925
LIPSA	NaN ^b
WM_enc_temp_fold1_31	0.825
WM_enc_temp_fold2_32	15.558
WM_enc_recn_fold1_35	495.677
WM_enc_recn_fold2_36	2.029
RIPSP	NaN ^c
WM_enc_temp_fold1_48	5.699
WM_enc_temp_fold2_49	10.625
WM_enc_recn_fold1_52	13.039
WM_enc_recn_fold2_53	77.031
LIPSP	NaN ^e
WM_enc_temp_fold1_65	10.290
WM_enc_temp_fold2_66	23.272
WM_enc_recn_fold1_69	28.511
WM_enc_recn_fold2_70	33.919
RIFG	NaN ^f
WM_enc_temp_fold1_82	0.201
WM_enc_temp_fold2_83	2.180
WM_enc_recn_fold1_86	475.948
WM_enc_recn_fold2_87	45.646
LIFG	NaN ^g
WM_enc_temp_fold1_99	18.358
WM_enc_temp_fold2_100	6.472
WM_enc_recn_fold1_103	18.335
WM_enc_recn_fold2_104	60.183
RMFG	NaN ^h
WM_enc_temp_fold1_116	0.304
WM_enc_temp_fold2_117	2.874
WM_enc_recn_fold1_120	2.194
WM_enc_recn_fold2_121	36.834
LMFG	NaN ⁱ
WM_enc_temp_fold1_133	1.611
WM_enc_temp_fold2_134	24.011
WM_enc_recn_fold1_137	5.782
WM_enc_recn_fold2_138	84.602
V1	NaN ^j
WM_enc_temp_fold1_150	0.193
WM_enc_temp_fold2_151	0.226
WM_enc_recn_fold1_154	28.411
WM_enc_recn_fold2_155	122.756

Role of spatial or temporal in order WM representation

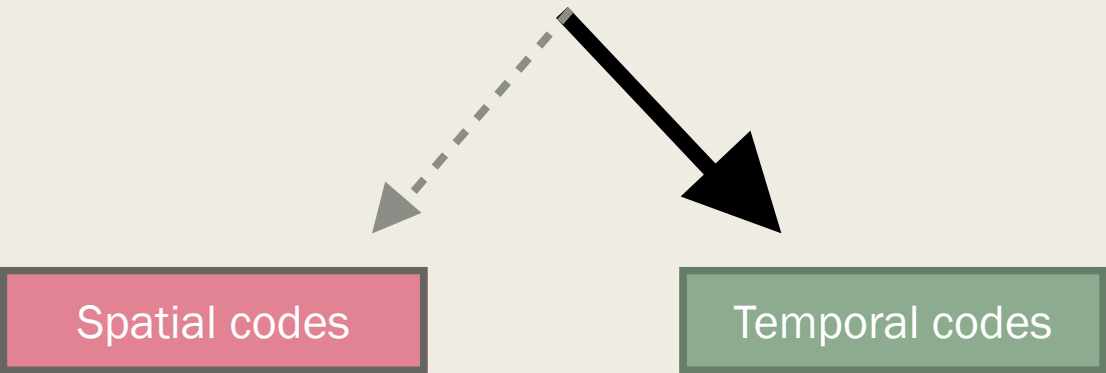
Prediction between temporal tasks and the WM task (for encoding) for ROIs (IPSa; IPSp; IFG; MFG; V1)



--> posterior IPS (bilaterally) & Left IFG

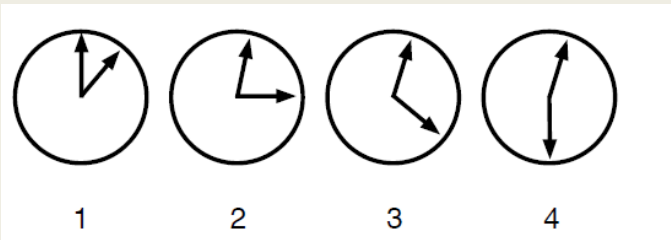
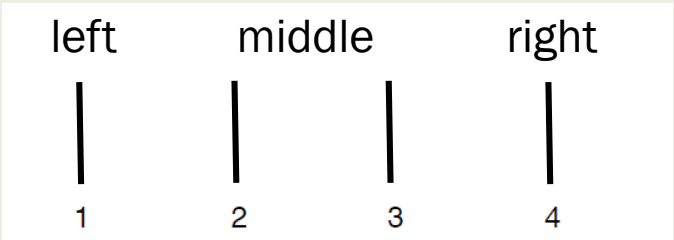
Role of spatial or temporal in order WM representation

Positional models



Henson, 2000; Abrahamse et al., 2017; Van Dijck et al., 2011; Guida

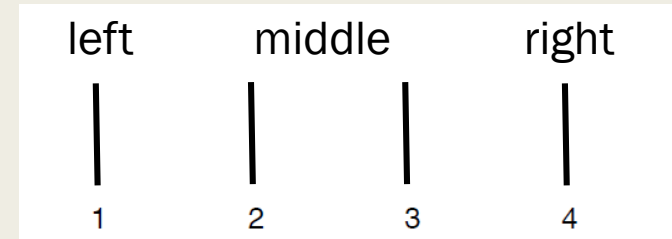
Hartley, Hurlstone and Hitch, 2016; Brown et al. 2000



Spatial codes

Discussion

Henson, 2000; Abrahamse et al., 2017; Van Dijck et al., 2011; Guida



- “serial order in verbal WM is coded within a spatial coordinate system with spatial attention being involved when searching through WM”

- Spatialization is flexible → more like a strategy than a coding per se

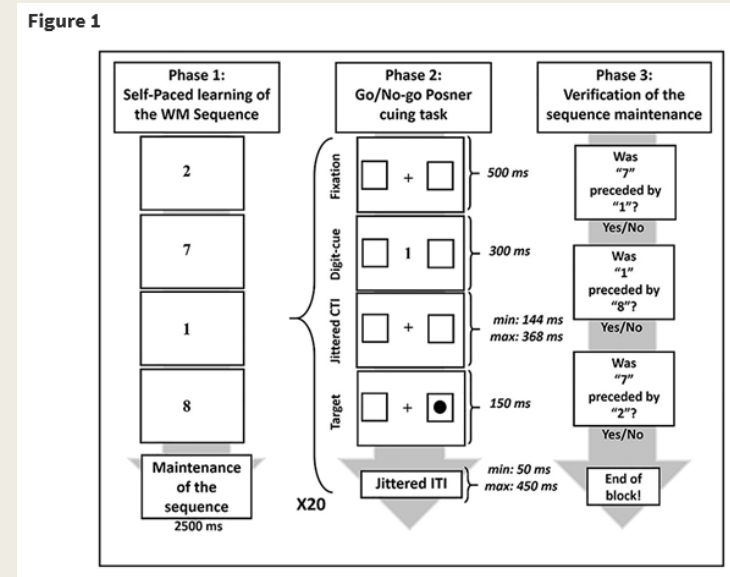
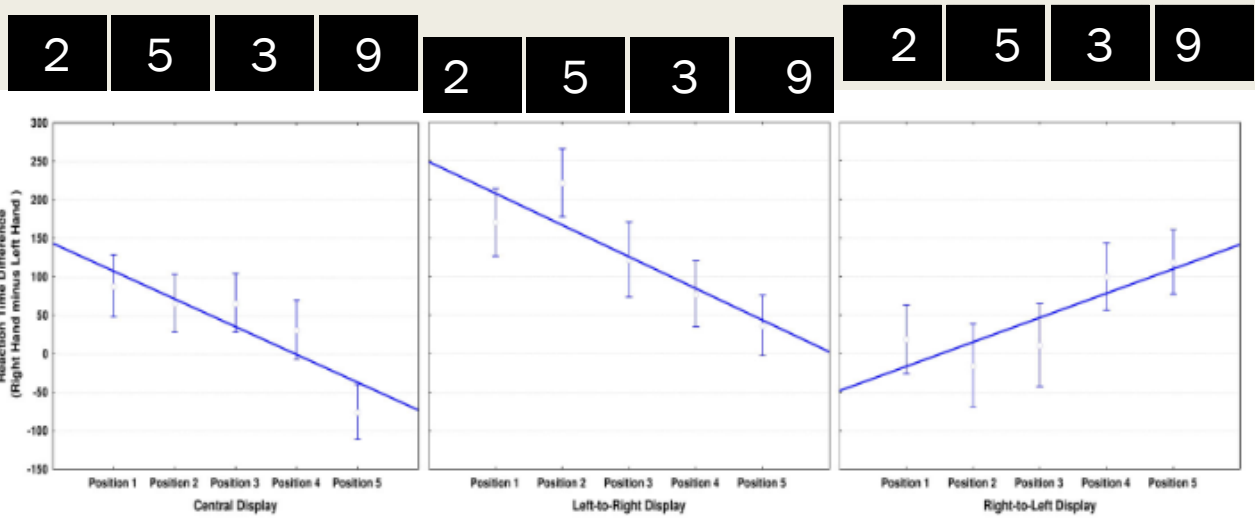


Figure 2. Observed data and regression line representing right-hand reaction times minus left-hand reaction times as a function of position in the sequence that was probed (five positions) and items presentation. Guida et al., 2020

Spatial Attention in Serial Order Working Memory: An EEG Study
 Vesal Rasoulzadeh ✉, Muhammet Ikbal Sahan, Jean-Philippe van Dijck, Elger Abrahamse, Anna Marzecova, Tom Verguts, Wim Fias
 Cerebral Cortex, Volume 31, Issue 5, May 2021, Pages 2482–2493, <https://doi.org/10.1093/cercor/bhaa368>

Conclusion

- Serial order WM required **domain-general coding** but not necessarily a more general ordinal representation per se
- This domain-general coding could be **sustained by a temporal coding** engrained in the posterior IPS and the IFG.
- However, to maintain and recall the information, this one could be represented spatially to be manipulated and recalled more easily.

→ Further research needs to be done to understand this specificity of spontaneous vs. strategic coding of information.

Conclusion

- Show the importance to take into account the serial order level in WM and to understand the nature of this coding
- Important to identify precisely the WM deficits to accurately deal with them
- Required to consider the treatment/training of order WM in children with learning disabilities

$$\begin{array}{r} 299 \\ 31015 \\ -1538 \\ \hline 1467 \end{array}$$

Çon ou sont

Il ne faut pas confondre le mot **son** et le mot **sont**.
Son est un adjectif possessif. Son travail quand il fait œuvre son ; il faut le remplacer par son pluriel : **ses**.
Exemple :
Le monsieur **son** chien → Le monsieur **ses** chiens.

Sont est le verbe être au présent à la troisième personne du pluriel. Son travail quand il fait œuvre sont ; il faut le remplacer par **sont**.
Exemple :
Les enfants **sont** cachés → Les enfants **sont** cachés.



THANK YOU FOR YOUR ATTENTION



Steve Majerus

Robin Remouchamps

Nathan Leroy

David Stawarczyk

Coline Grégoire

Pauline Querella



Memory benefited from temporal regularities

- When implemented at **encoding**

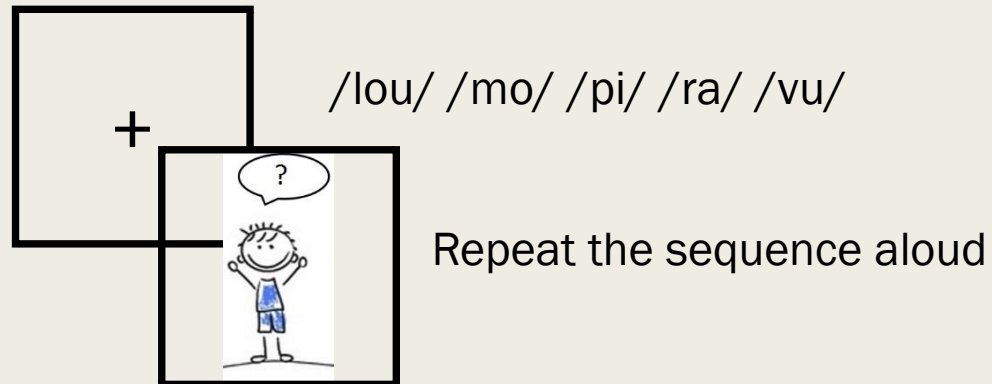
Povel & Essens, 1985 ; Silverman & Schwartzberg, 2014 ; Tillmann & Dowling, 2007

- **Bottom-Up Multi-scale Population oscillators model**

Hartley, Hurlstone & Hitch, 2016

fMRI tasks

- *Hebb learning task*



5-syllable lists

→ Closed pool → overlap sequences

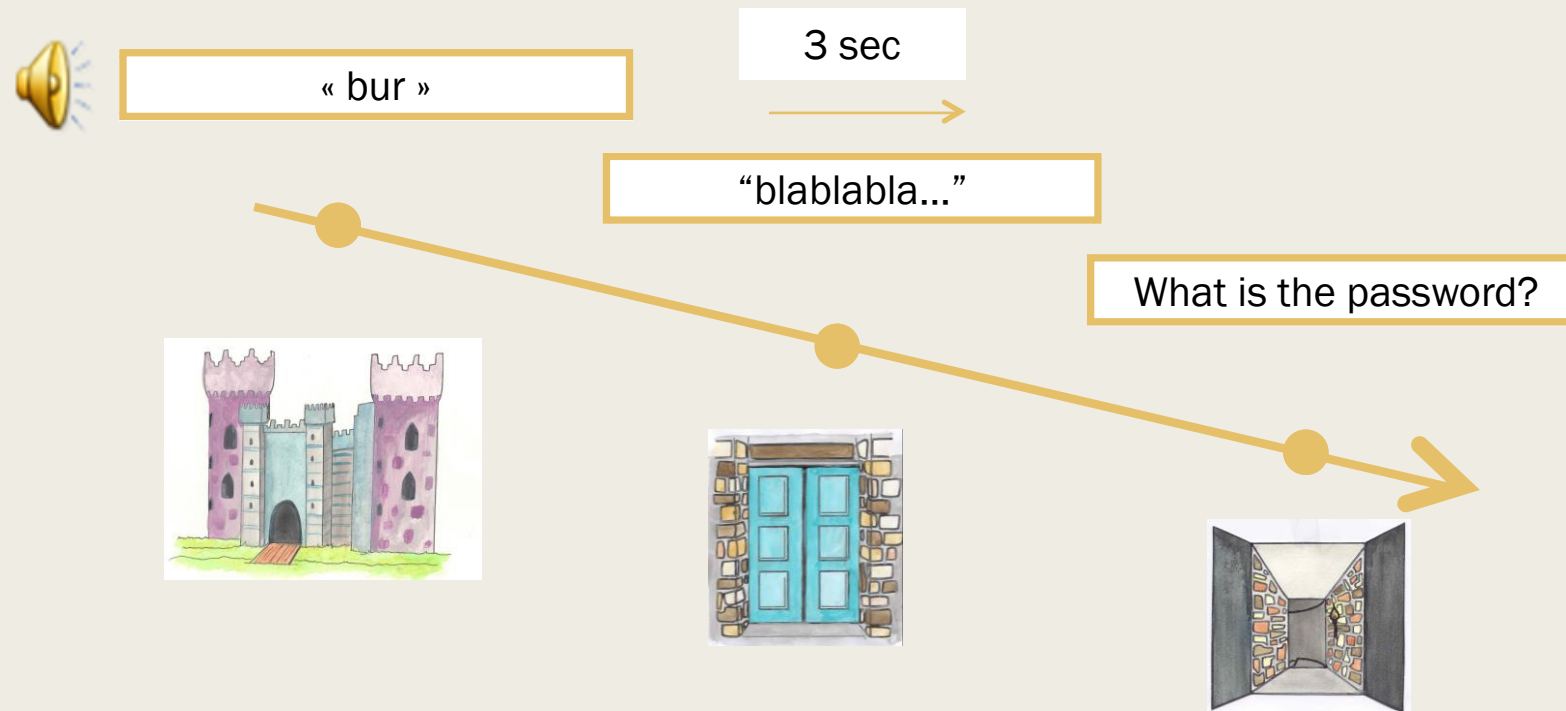
Hebb 1
Filler
Hebb 1
Filler
Hebb 1
Filler
Hebb 1
Filler
...

3 blocks each including :

- 1 hebb list repeated 8 times
- 8 fillers

Methodology

Item STM task (Majerus et al., 2006; Leclercq & Majerus, 2010)



- Single nonword delayed repetition
- 30 monosyllabic nonwords
- Number of phonemes repeated correctly.

Methodology

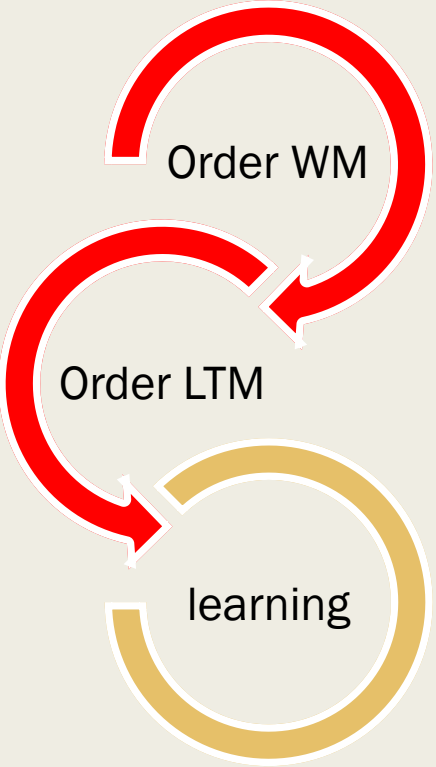
Order STM task (Majerus et al., 2006; Leclercq & Majerus, 2010)



/lion/, /monkey/, /cat/

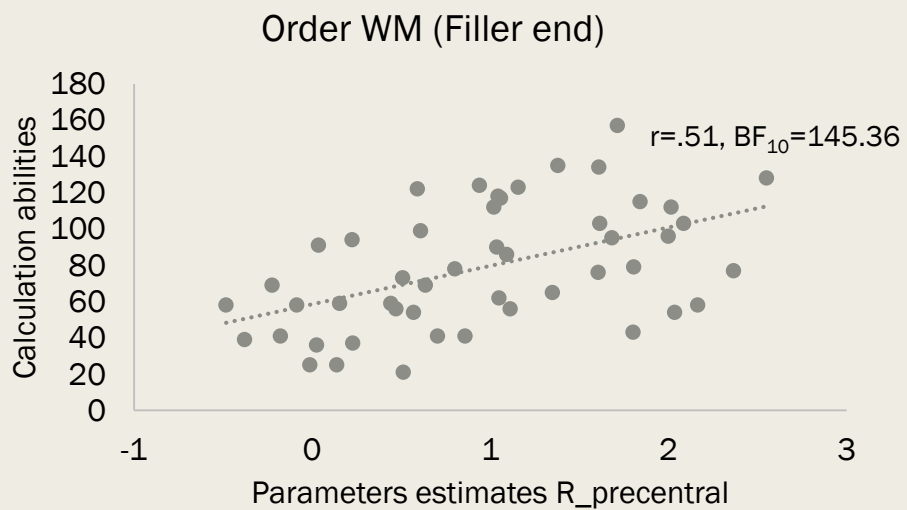


- Serial order reconstruction
- 7 animals
- 4 lists by length (from 2 to 7)

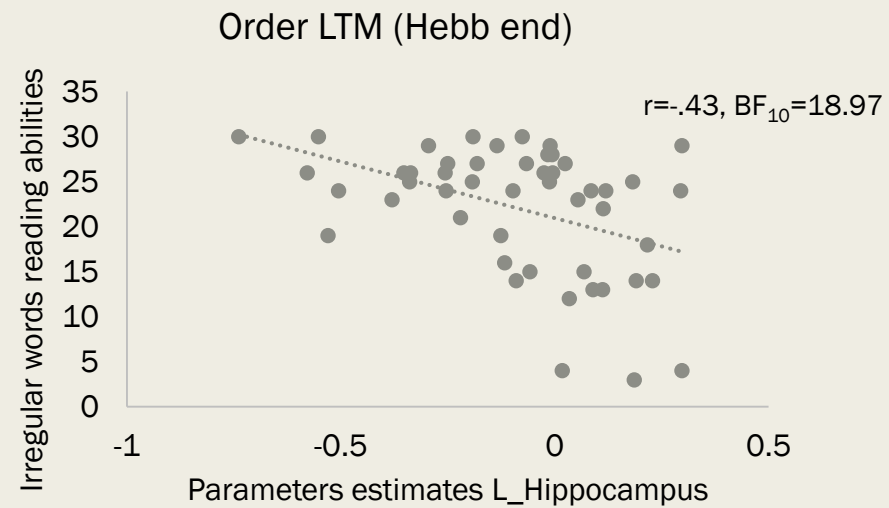


Encoding

Consolidation



→ Better performance in math were related to more activation at the right precentral level for the order WM contrast



→ Better performance in IRR words reading were linked to lower activation at the left hippocampus level during the order LTM

Order WM – Nature of representation

Spatial codes

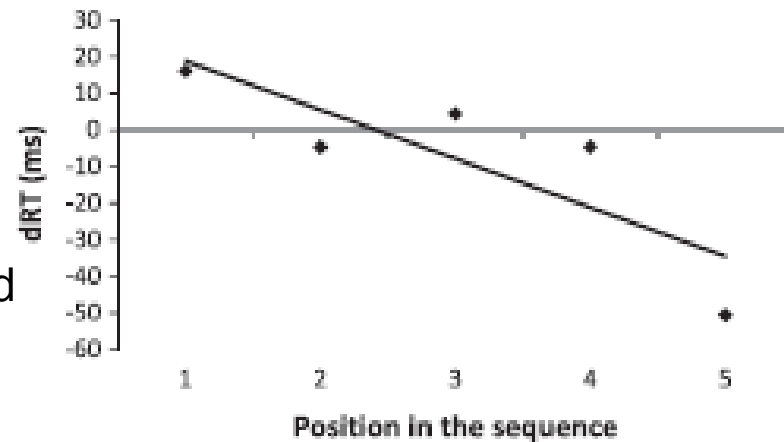
Phase 1
Maintenance
3-7-1-4-9

Phase 2 : Go/no go task:
Parity judgment task
2? 3? 8? 9?

Phase 3
Recall

Left hand

Right hand



interaction between serial order retrieval
from verbal WM and spatially defined
response options

Order WM – Nature of representation

Temporal codes

Plancher et al., 2017; Henson et al., 2003

