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Do you remember the time?

Auditory Cognition Group
Wellcome Trust Centre for Neuroimaging

Outline

I Timing and Time perception

II Memory for Time

III Psychophysics

IV fMRI experiment

V Summary

I. Timing and Time Perception

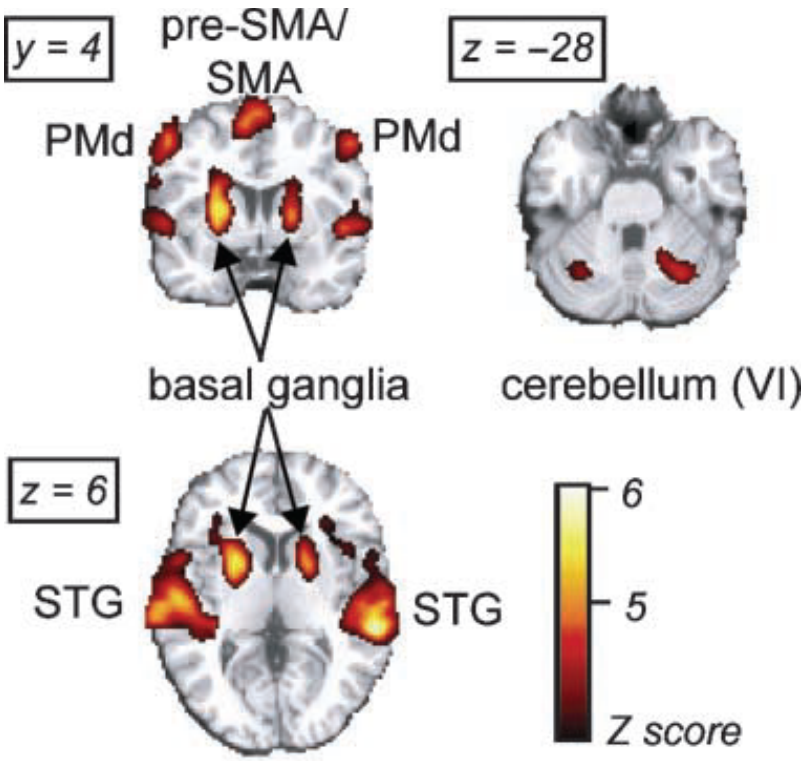
- **Types of timing classifications/mechanisms?**
  - Implicit vs. Explicit
  - Sub-second vs. Supra-second
  - Automatic vs. Cognitive
  - Duration-based vs. Beat-based
- **Areas involved in perception of time?**
  - Basal ganglia
  - Cerebellum
  - Supplementary Motor Area (SMA)
  - Pre-motor cortex (PMC)
  - Prefrontal cortex
  - Parietal cortex

Buhusi and Meck, 2005;
Merchant et al., 2013; Allman et al., 2014

I. Beat-Based timing

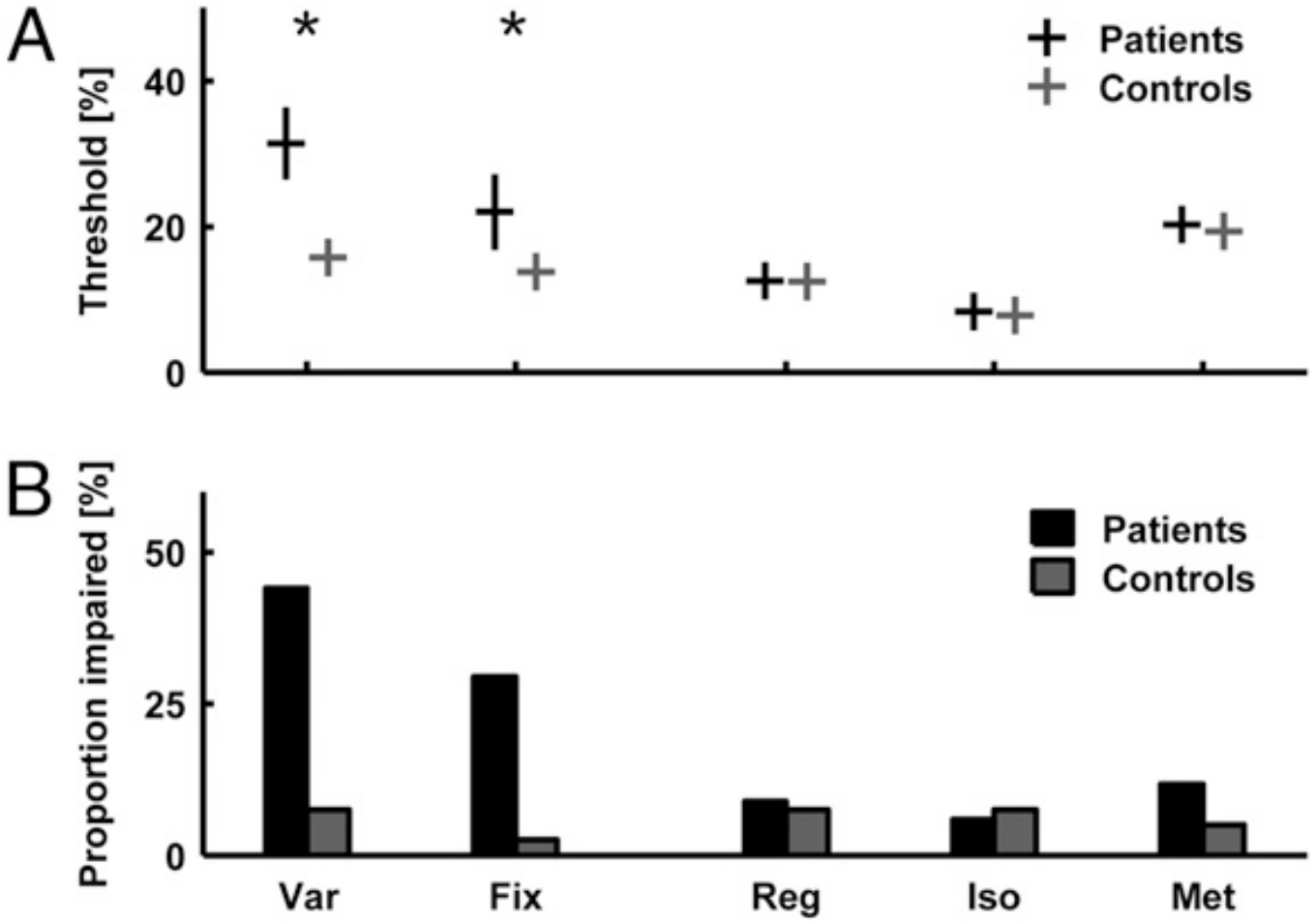
- Natural sound sequences have variable temporal structure and rhythmic context.

Grahn et al.: role of basal ganglia in beat perception

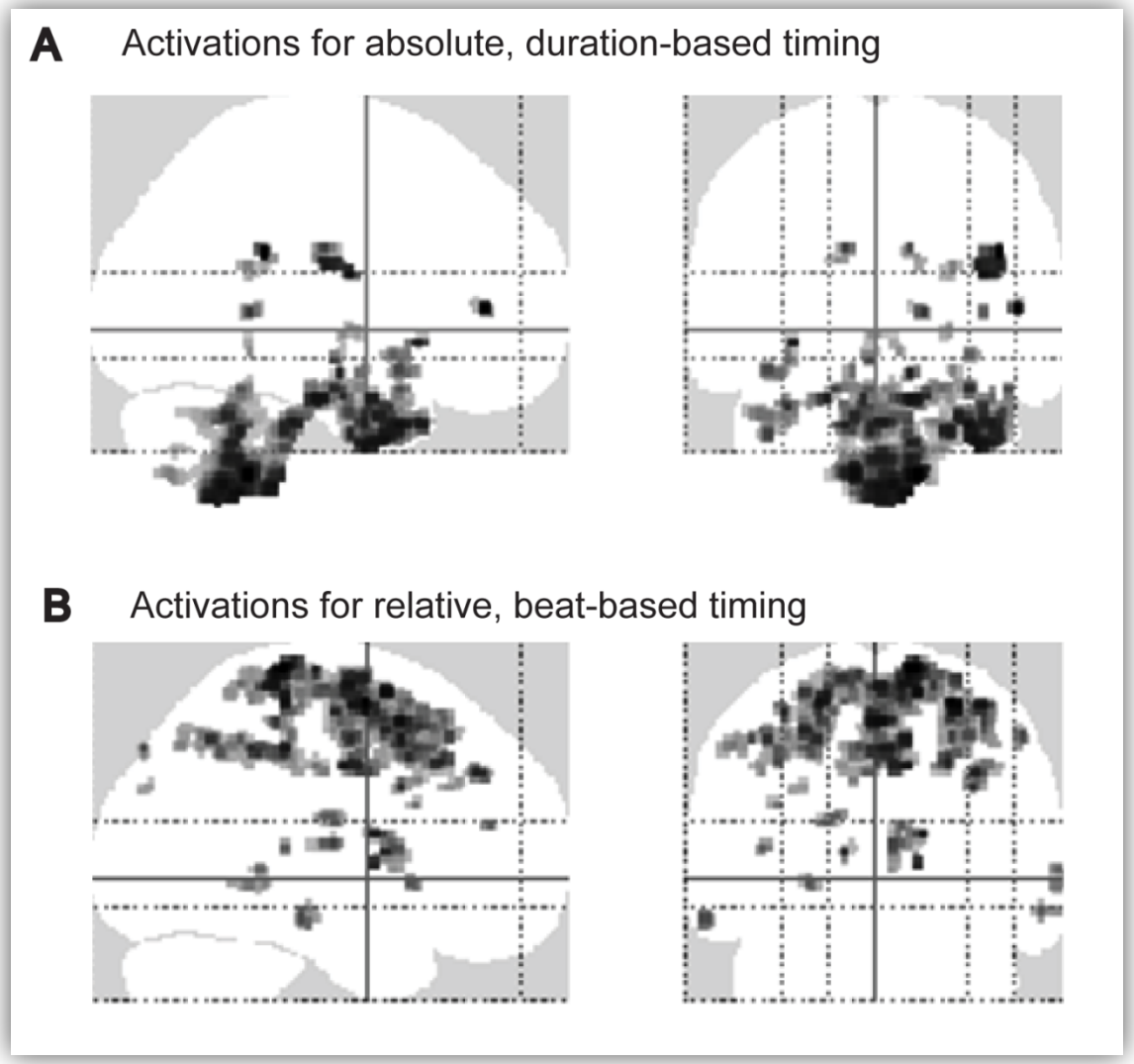


I. Duration-based timing

Grube et al.: implicate cerebellum in duration-based timing

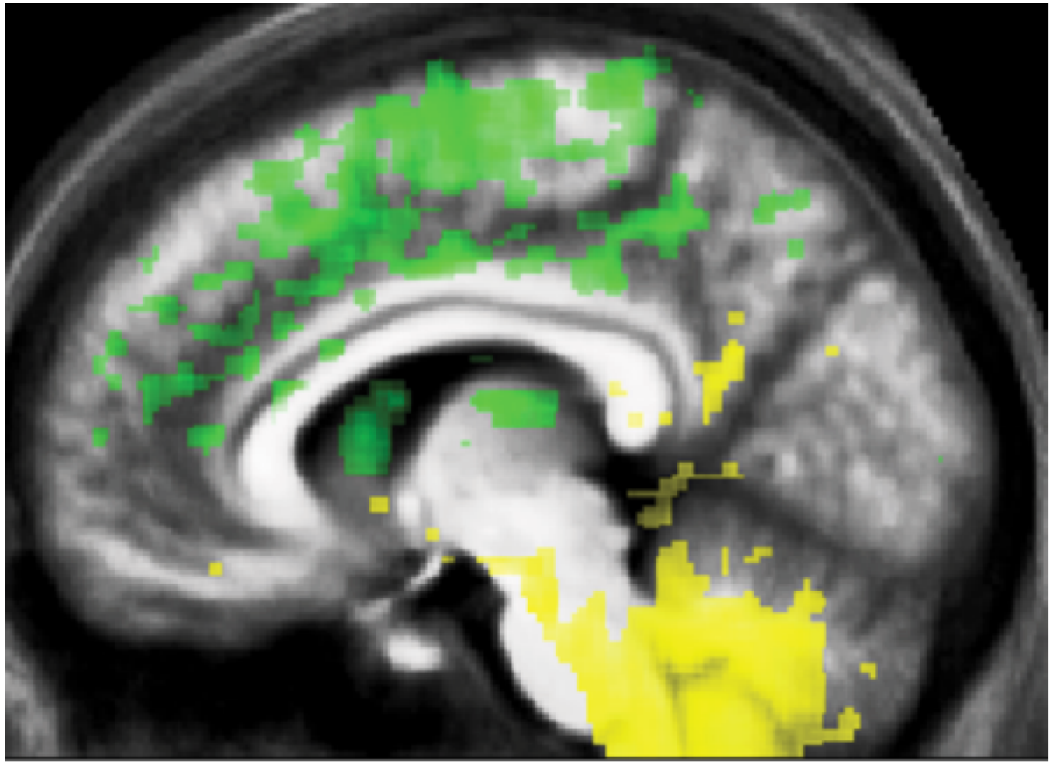


I. Duration-based vs. Beat-Based



Teki et al., 2011

I. Duration-based vs. Beat-Based

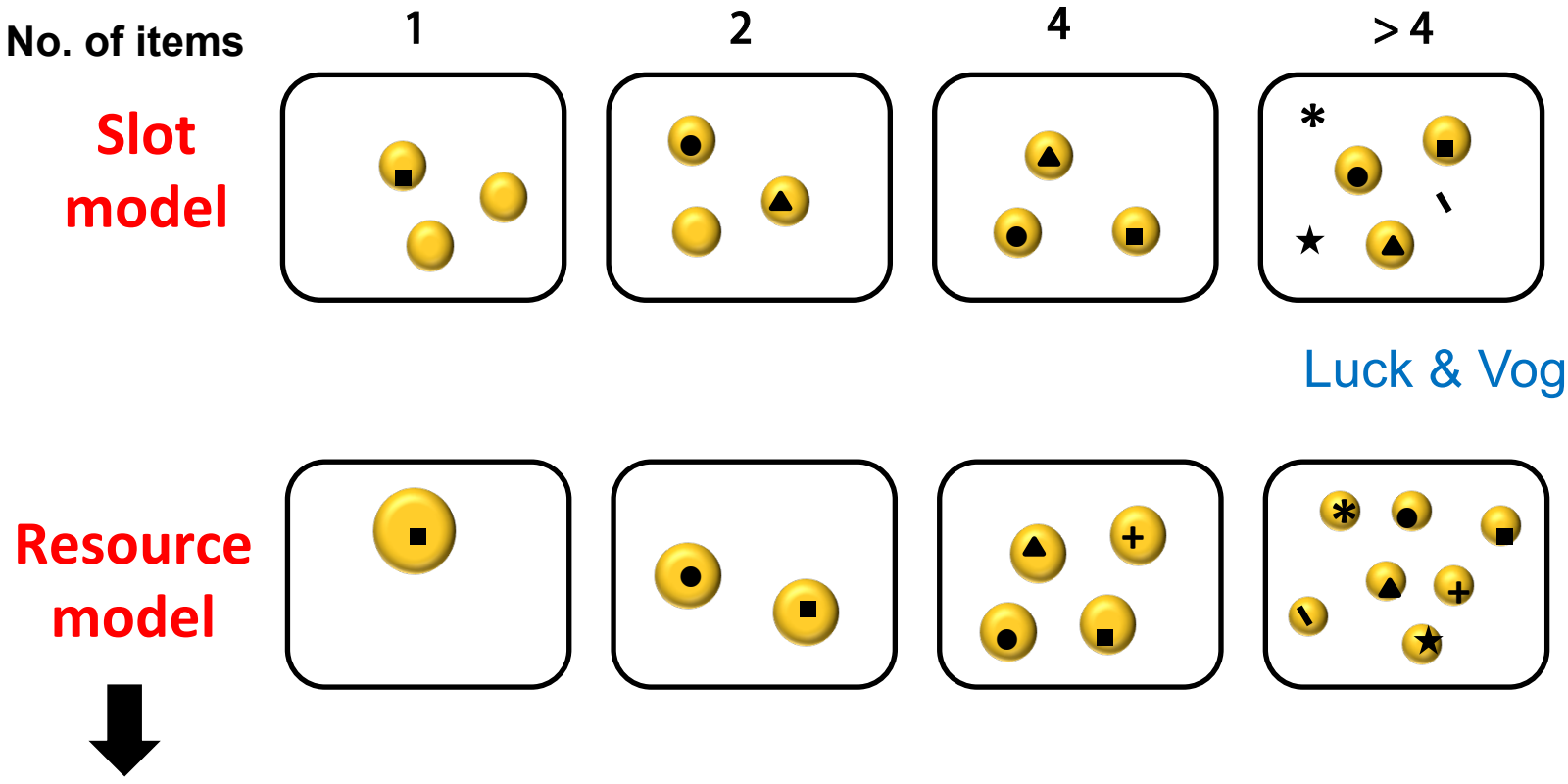


Cerebellar network more involved in duration-based timing

Striato-thalamo-cortical network more involved in beat-based timing

Teki et al., 2011

II. Models of Working Memory

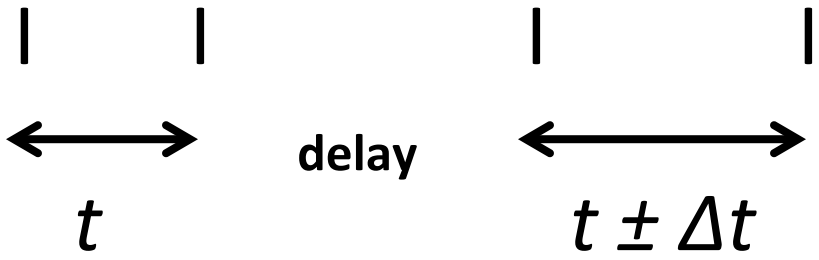


Luck & Vogel (1997)

Bays & Husain (2008)
Bays et al (2009)
Kumar et al (2013)

Shown for colour, orientation, pitch.
Similar model for time intervals?

II. Memory for Time

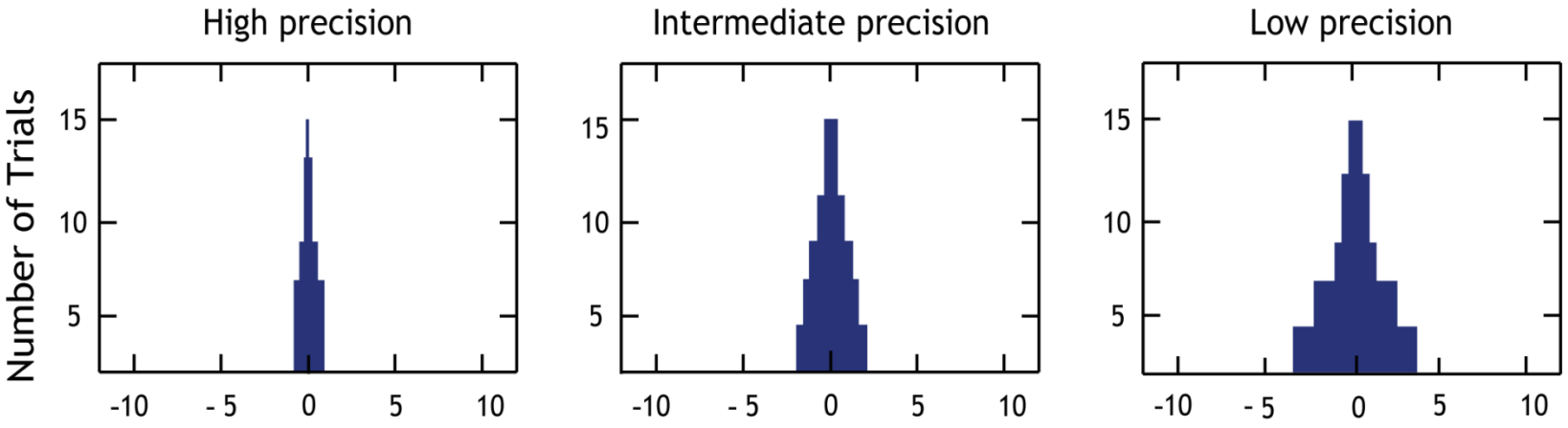


- discrimination task
- binary/categorical measure
- no variation of memory load
- isolated intervals; no variation of rhythmic structure
- Rao et al. (2001), Coull et al. (2008) show putamen activity related to WM

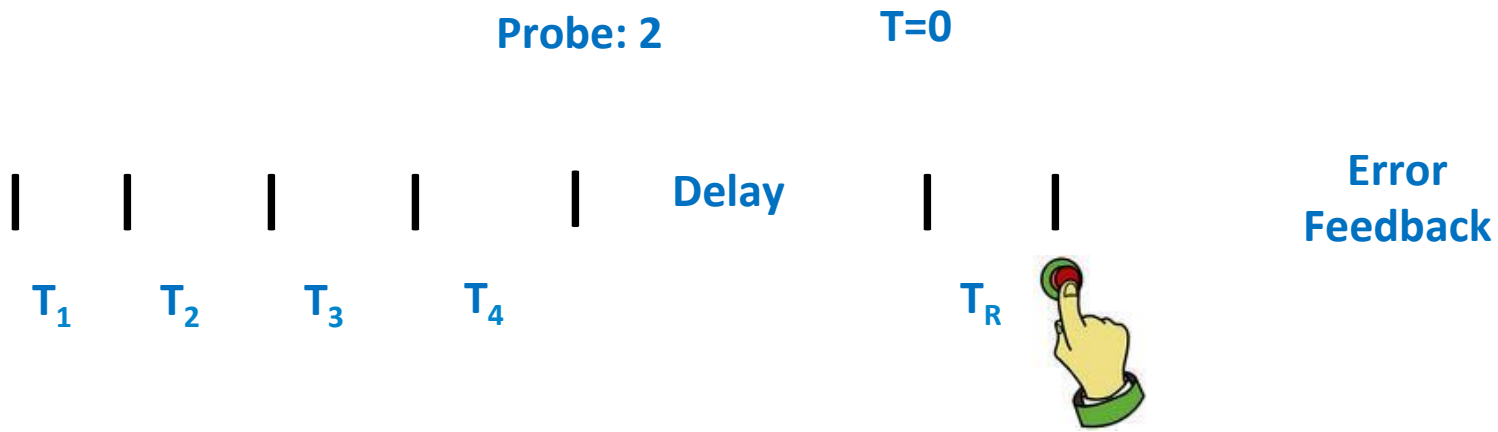
II. Precision

Precision: a continuous index that quantifies the fidelity of memory

Precision = 1 / standard deviation



III. Psychophysics



Perceptual time matching response	=	T_R **(adjusted for RTs)**
Timing error response	=	$T_R - T_{probe}$
Precision of WM for time	=	$1/STD\ (T_R - T_{probe})$

Bays & Husain, 2008
Kumar et al., 2013

III. Experiments

1: 'SUB'

- No. of intervals: 4
- IOI: 500-600 ms
- Jitter levels: 5-10%, 20-25%, 35-40%, 50-55%

2: 'SUPRA'

- No. of intervals: 4
- IOI: 1.0 - 1.2 s
- Jitter levels: 5-10%, 20-25%, 35-40%, 50-55%

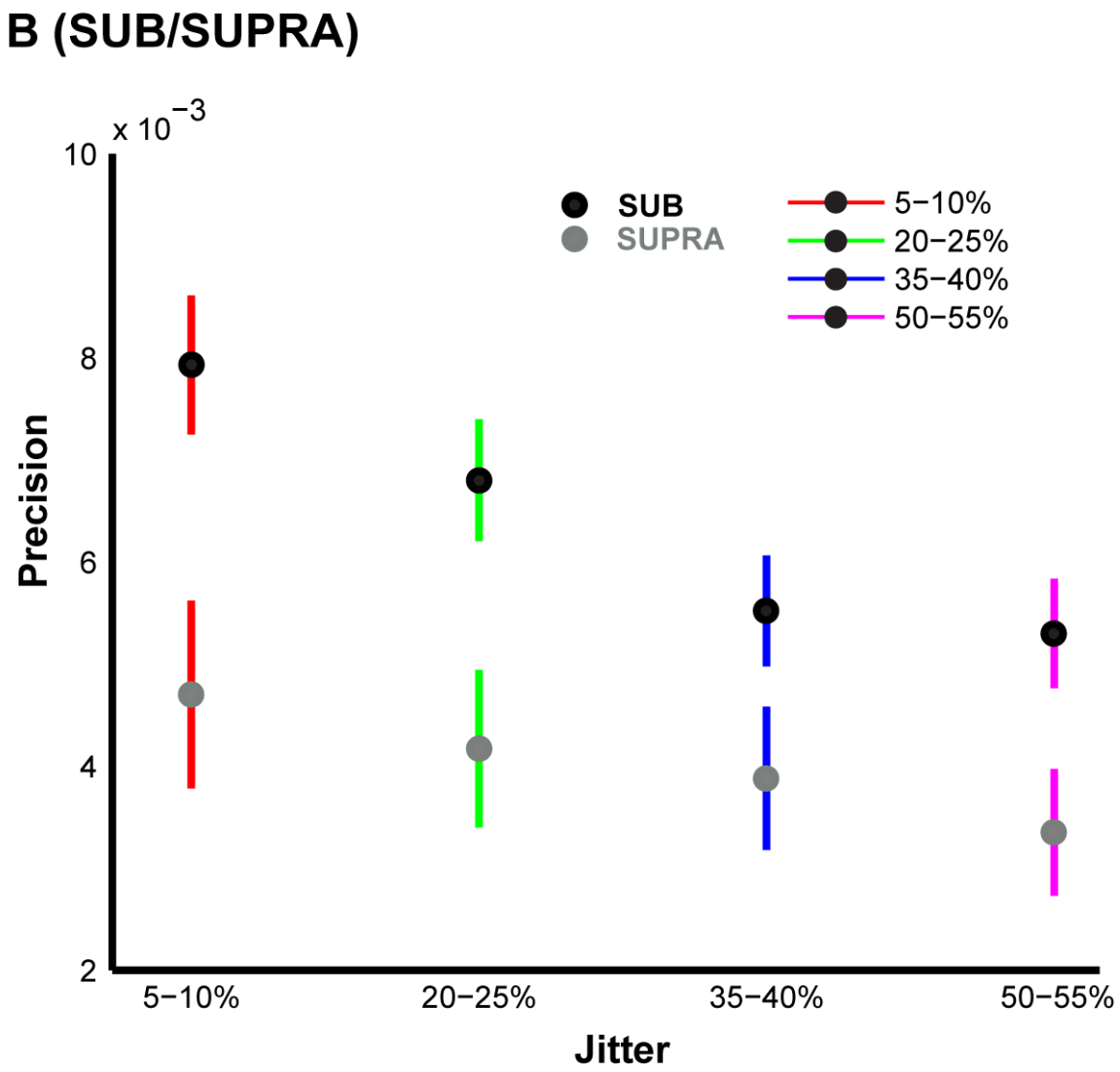
3: 'WM'

- No. of intervals: 1 - 4
- IOI: 500-600 ms
- Jitter levels: 5-10%, 20-25%, 35-40%, 50-55%

4: 'CUED'

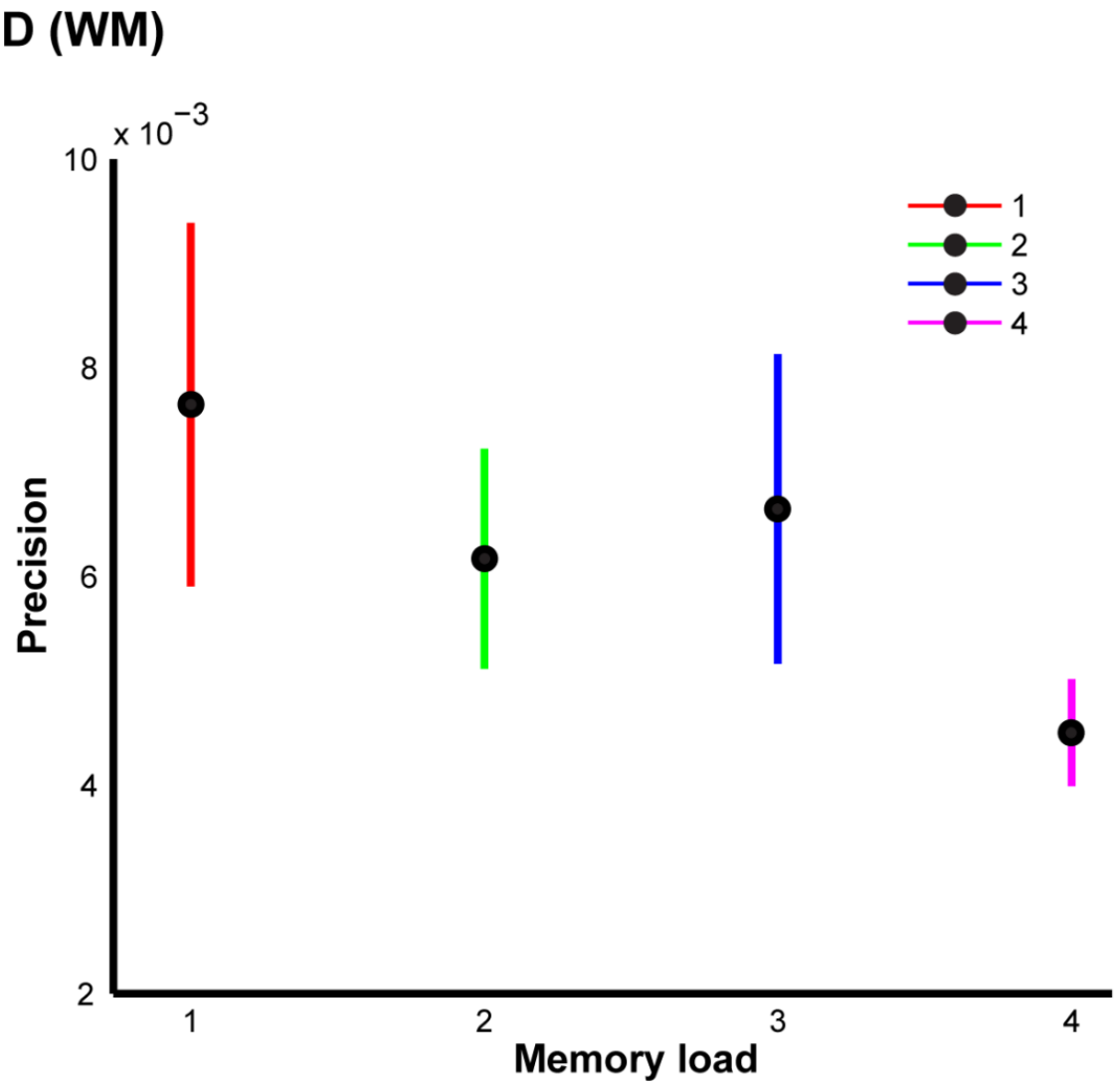
- No. of intervals: 4
- IOI: 500-600 ms
- Jitter levels: 5-10%
- Cue: Valid (56.2%), Invalid (18.8%), Neutral (25%)

Exp 1 & 2: Precision vs. Rhythm



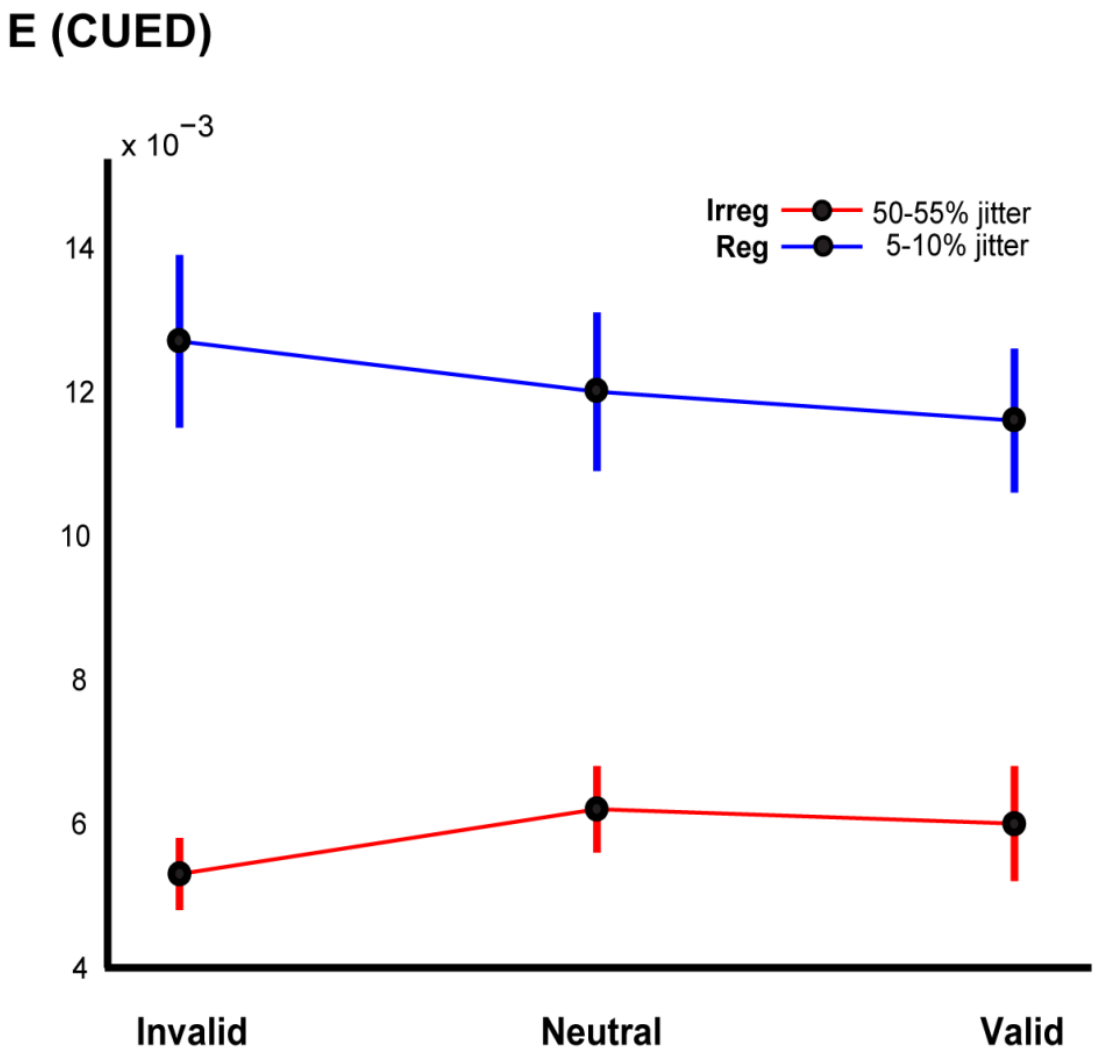
- **Main effect of jitter ($p < 0.02$) for SUB but not SUPRA**

Exp 3. Precision vs. WM load



• **Main effect of WM load (adj. for jitter): $p < 0.05$**

Exp 4. Precision vs. Cue



- 75% cued trials; 75% cues were valid
- No effect of cueing ($p > 0.05$)

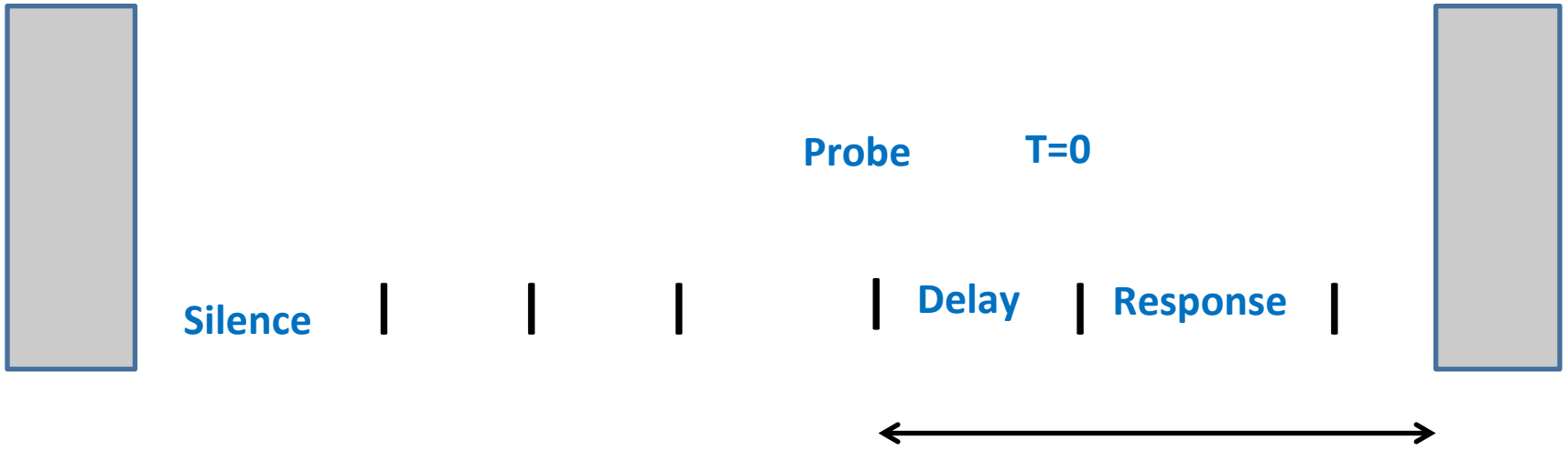
IV. fMRI experiment

WM load (# intervals)	**Temporal regularity** (% jitter)
4	5-10%, 20-25%, 35-40%, 50-55%
3	20-25%
2	20-25%
1	20-25%

Adapted experiments 1 and 3 for a parametric fMRI design to find regions:

- Activated as a function of no. of intervals (with fixed regularity)
- Activated as a function of temporal regularity (with fixed WM load)

IV. fMRI acquisition



Sparse sampling design:

- TR = 14.76s
- Response window = 2.5s
- Fixed latency from onset of delay period to scan acquisition
- 2 rhythm followed by 2 WM blocks: 32 trials per block

IV. fMRI analysis

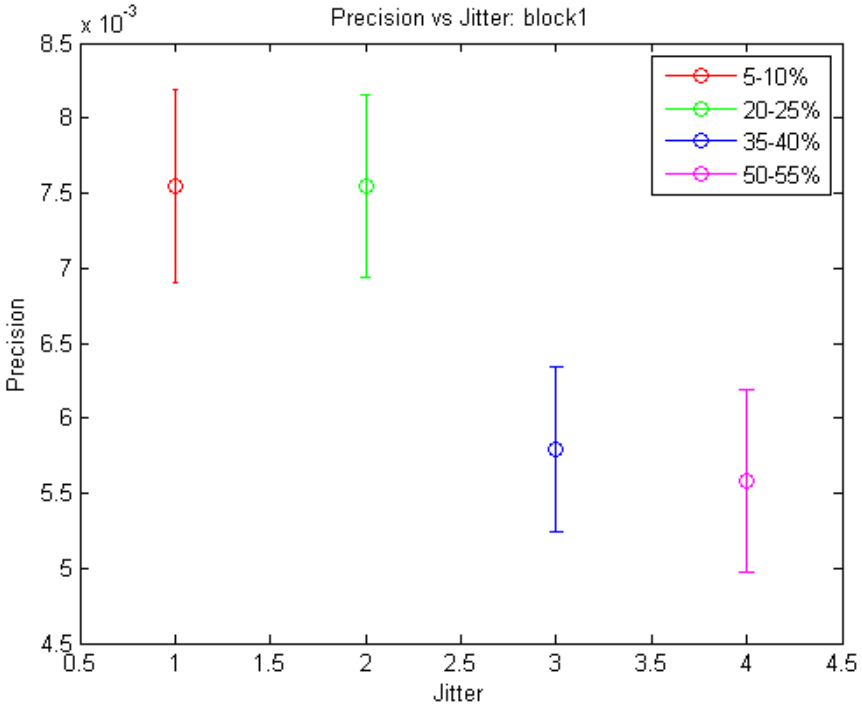
- *A priori* hypotheses for cerebellum and basal ganglia
- 12 subjects so far (normal hearing, no current musical training)
- Standard pre-processing in SPM12, normalization using DARTEL
- Whole brain analysis; random effects design

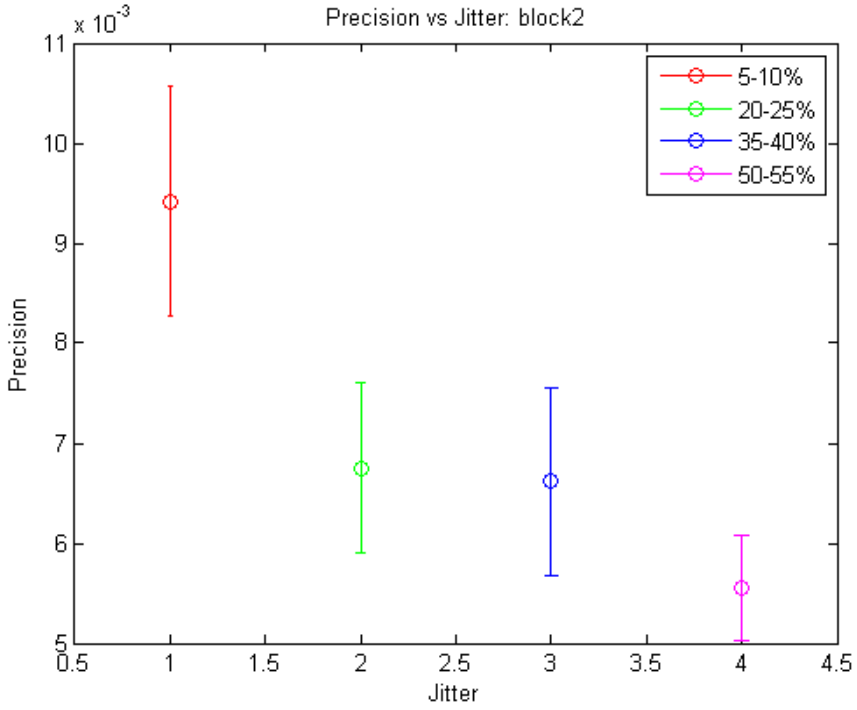
- **Parametric analysis:**

  (a) Effect of varying regularity (for fixed no. of intervals)

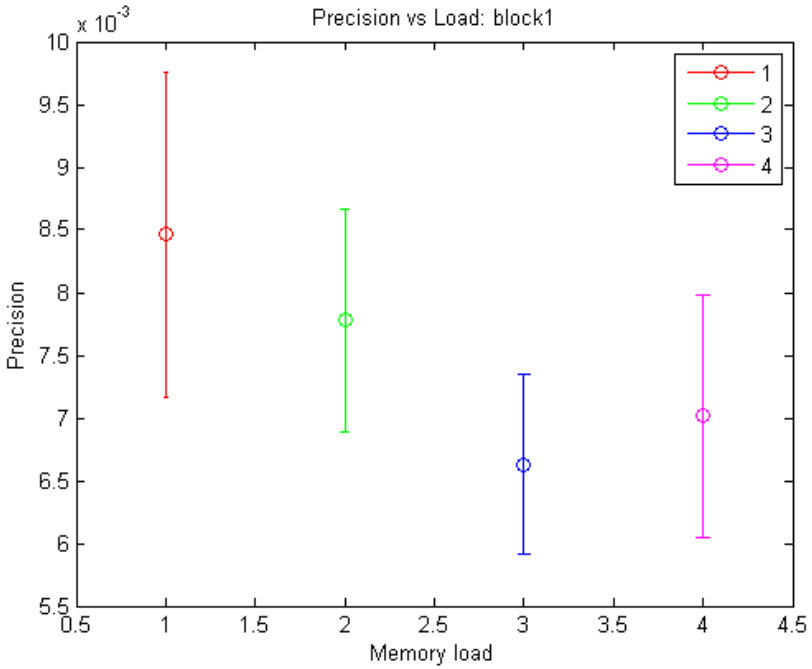
  (b) Effect of varying WM load (for fixed temporal regularity)

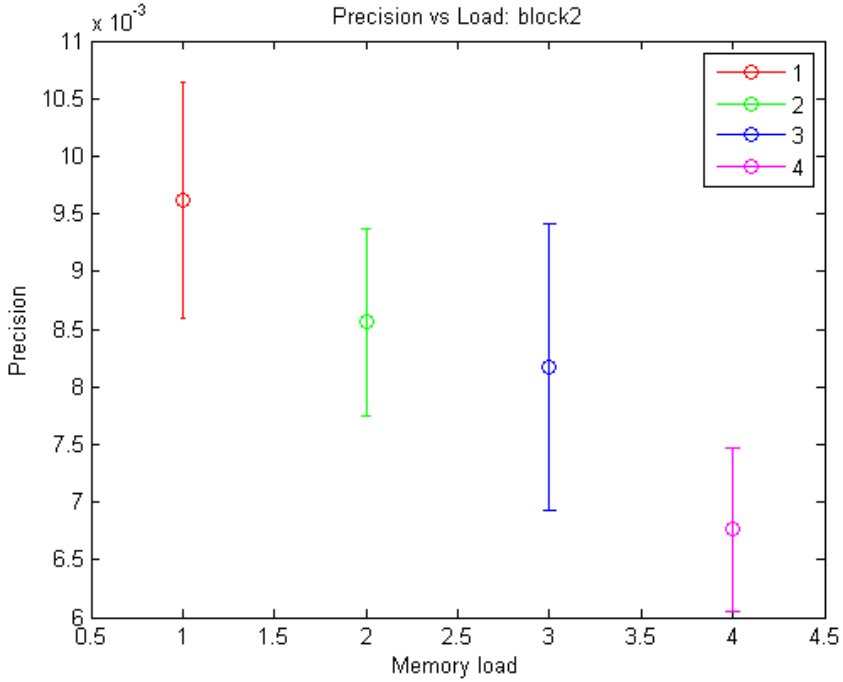
IV. Behaviour in fMRI: Rhythm





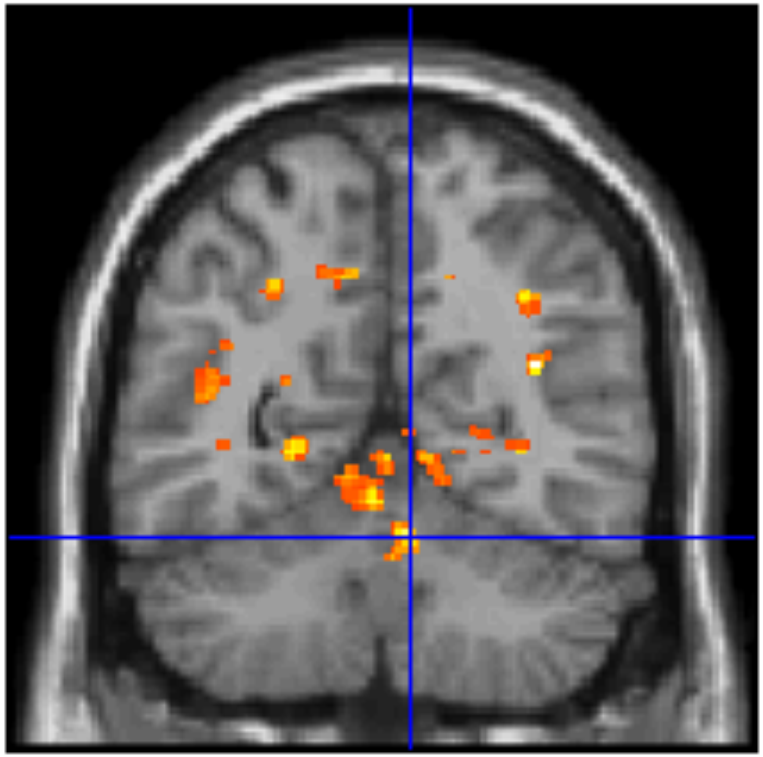
IV. Behaviour in fMRI: WM





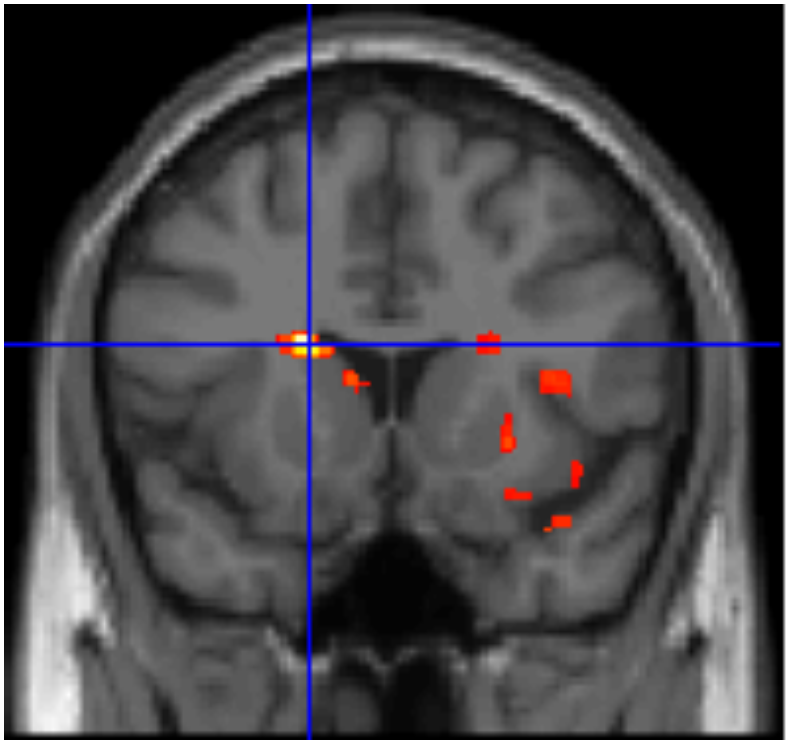
IV. fMRI: effects of increasing jitter (fixed WM)

CEREBELLUM



T = 4.44

CAUDATE

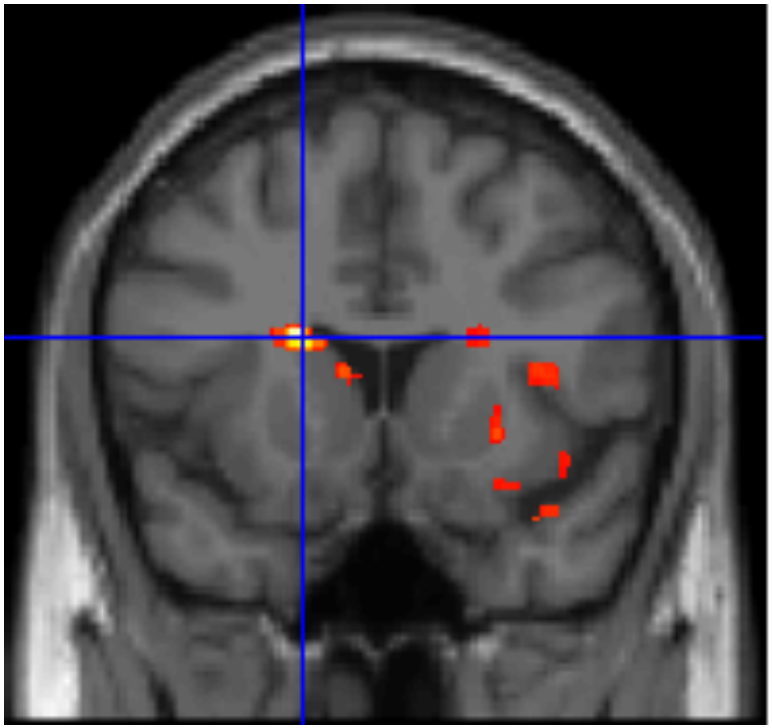


T = 3.04

P<0.001 unc.

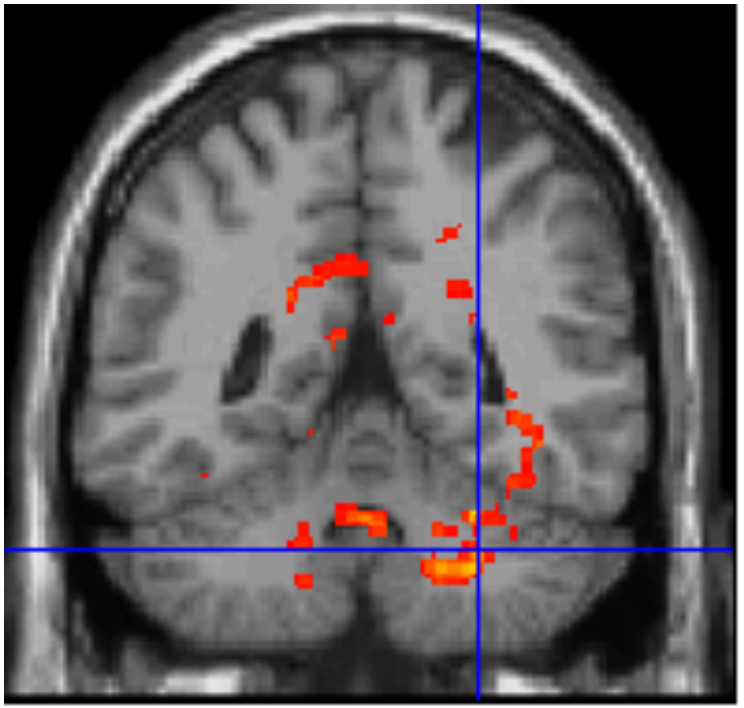
IV. fMRI: effects of decreasing jitter (fixed WM)

CAUDATE



T = 8.13

CEREBELLUM

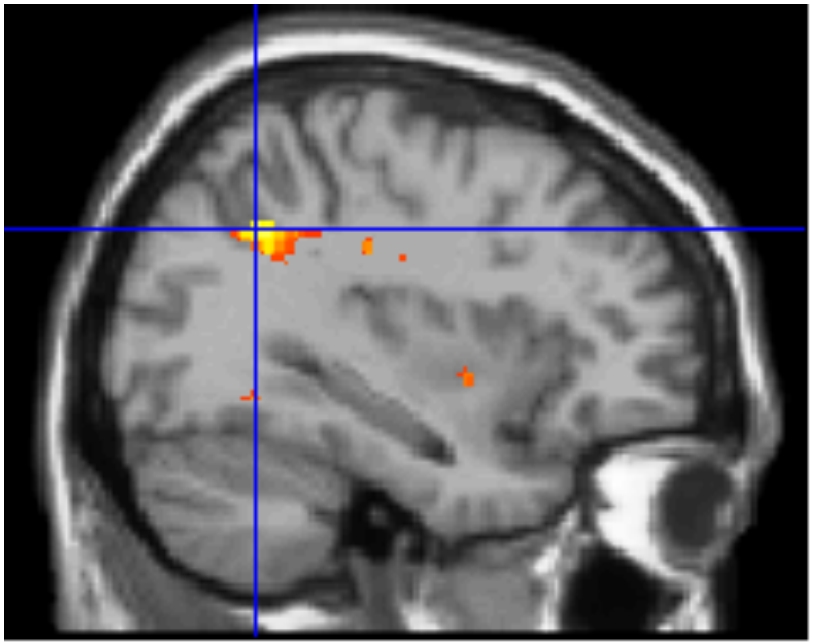


T = 4.05

P<0.001 unc.

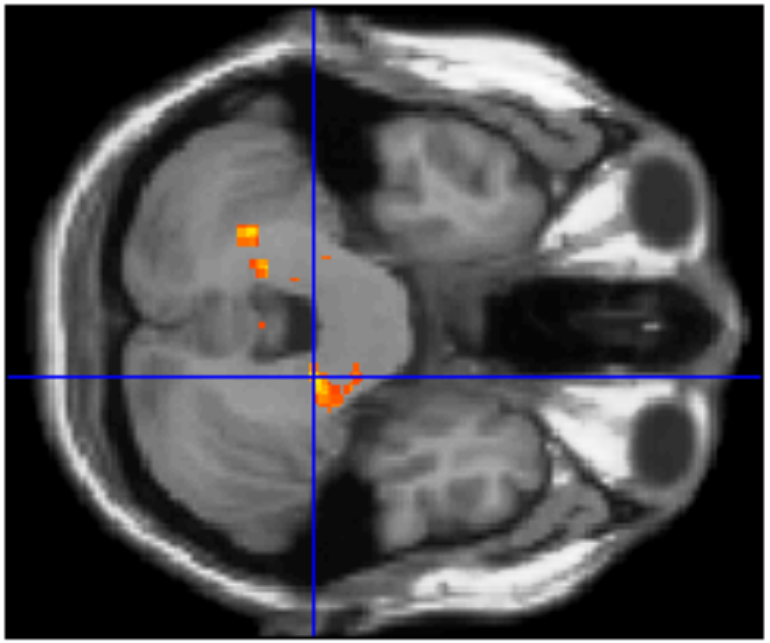
IV. fMRI: effects of increasing WM load (fixed jitter)

PARIETAL CORTEX



T = 5.82

CEREBELLUM



T = 3.59

P<0.001 unc.

V. Summary

- Memory for time not studied for intervals in the context of sequences with more than one interval and with different temporal structures

- A new paradigm and measure of temporal memory.

Characterized of memory for time intervals for sequences with different
temporal structure
inter-onset intervals
working memory loads
attentional conditions

- fMRI paradigm to investigate bases of memory for time in progress.

Preliminary analysis suggests:

Both cerebellum and striatum involved in encoding memory for time as a function of the rhythmic context (cf. Teki et al., 2012)

Parietal cortex and cerebellum involved in encoding memory for time as a function of increasing memory load.

Acknowledgments

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