

Distinct representation of absolute and relative auditory time

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Introduction

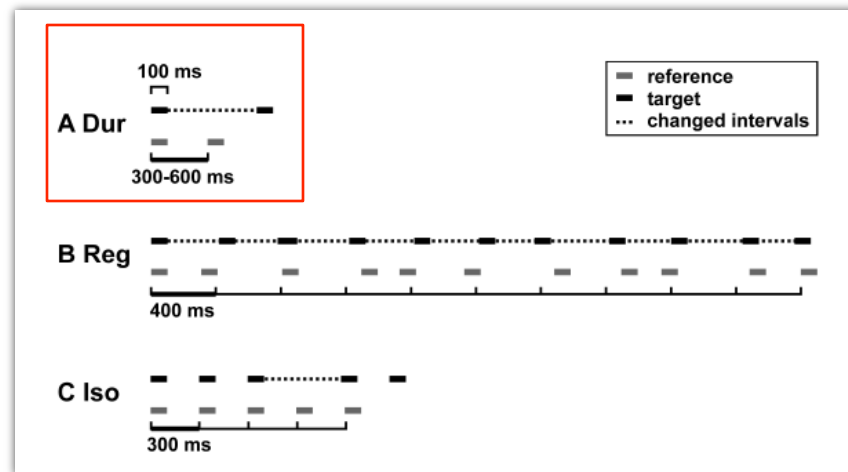
- **Timing network:** Cerebellum, basal ganglia, pre-SMA/SMA, pre-motor and prefrontal cortex.
- **Cerebellum:** Perception of absolute duration of discrete time intervals.
(Grube et al., 2010)
- **Basal ganglia:** Perception of beat-based, metrical rhythmic sequences.
(Grahn, 2009)

Aim:

**Test for dissociation between the timing functions
of cerebellum and basal ganglia**

Absolute, duration-based timing

- Patients with Spino Cerebellar Ataxia type 6: impaired in absolute timing of single intervals but not in relative timing of rhythmic sequences with a regular beat. *(Grube et al., 2010: PNAS)*



- Normal subjects with TMS over medial cerebellum: impaired on the same absolute timing task after stimulation

(Grube et al., 2010:

Frontiers)

➤ **Absolute, duration-based timing:**

Perception of absolute duration of discrete time intervals (ΔT)

Relative, beat-based timing

- A regular beat offers beneficial temporal cues in perceptual timing
- Parkinson's patients with decreased striatal dopamine release show deficits in perceptual timing tasks.

(Artieda et al. 1992, Harrington et al. 1998)

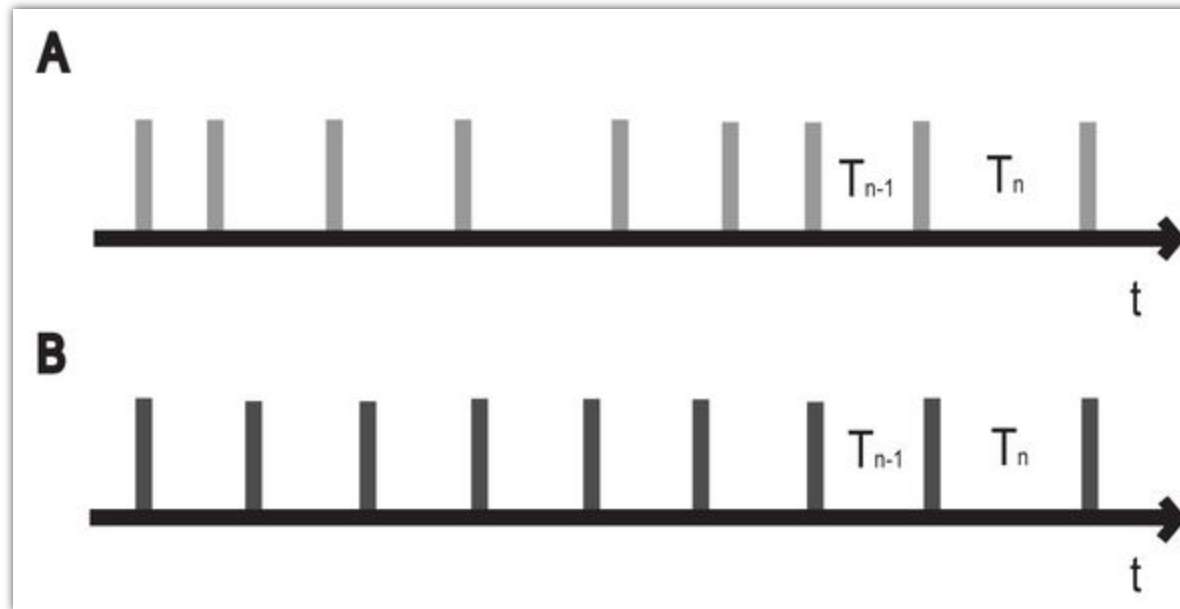
- Basal ganglia, pre-SMA/SMA, and pre-motor cortex implicated in perception of beat-based and metrical rhythmic sequences

(Grahn, 2009)

➤ Relative, beat-based timing:

Perception of time intervals relative to a regular beat ($\Delta T_i / T_{\text{beat}}$)

Stimulus and Task



- *Judge the duration of the final compared to the penultimate interval*
 $T_n > / < T_{n-1}$

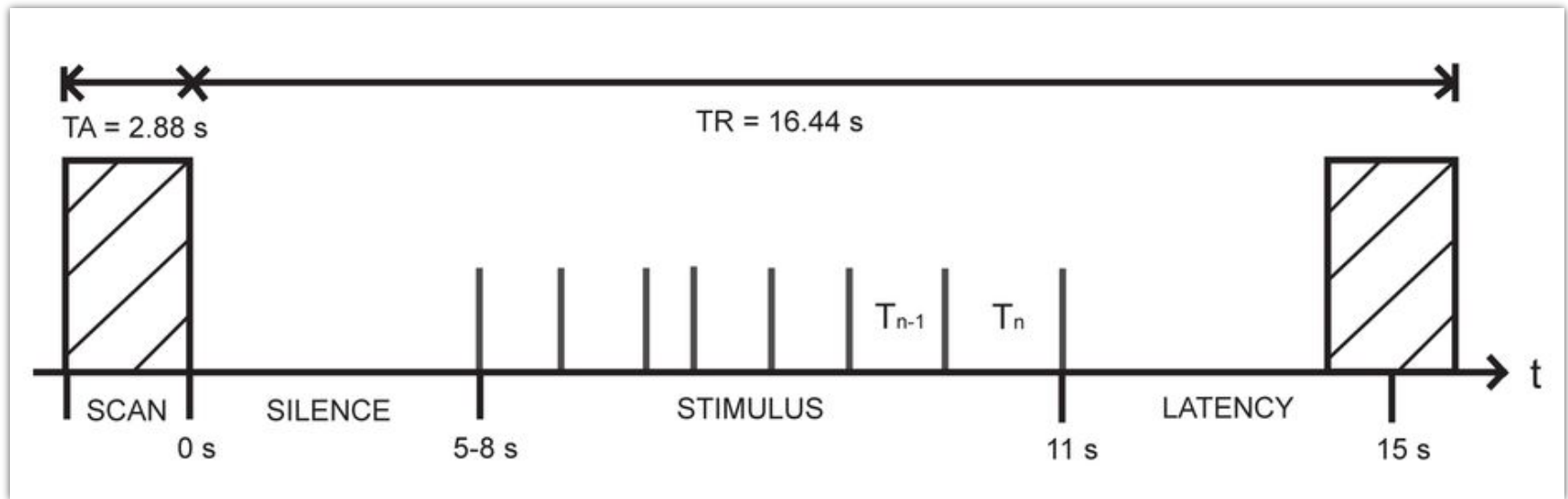
Sequence A: Irregular sequence (15% mean jitter)

Sequence B: Regular sequence (isochronous)

Stimulus Design

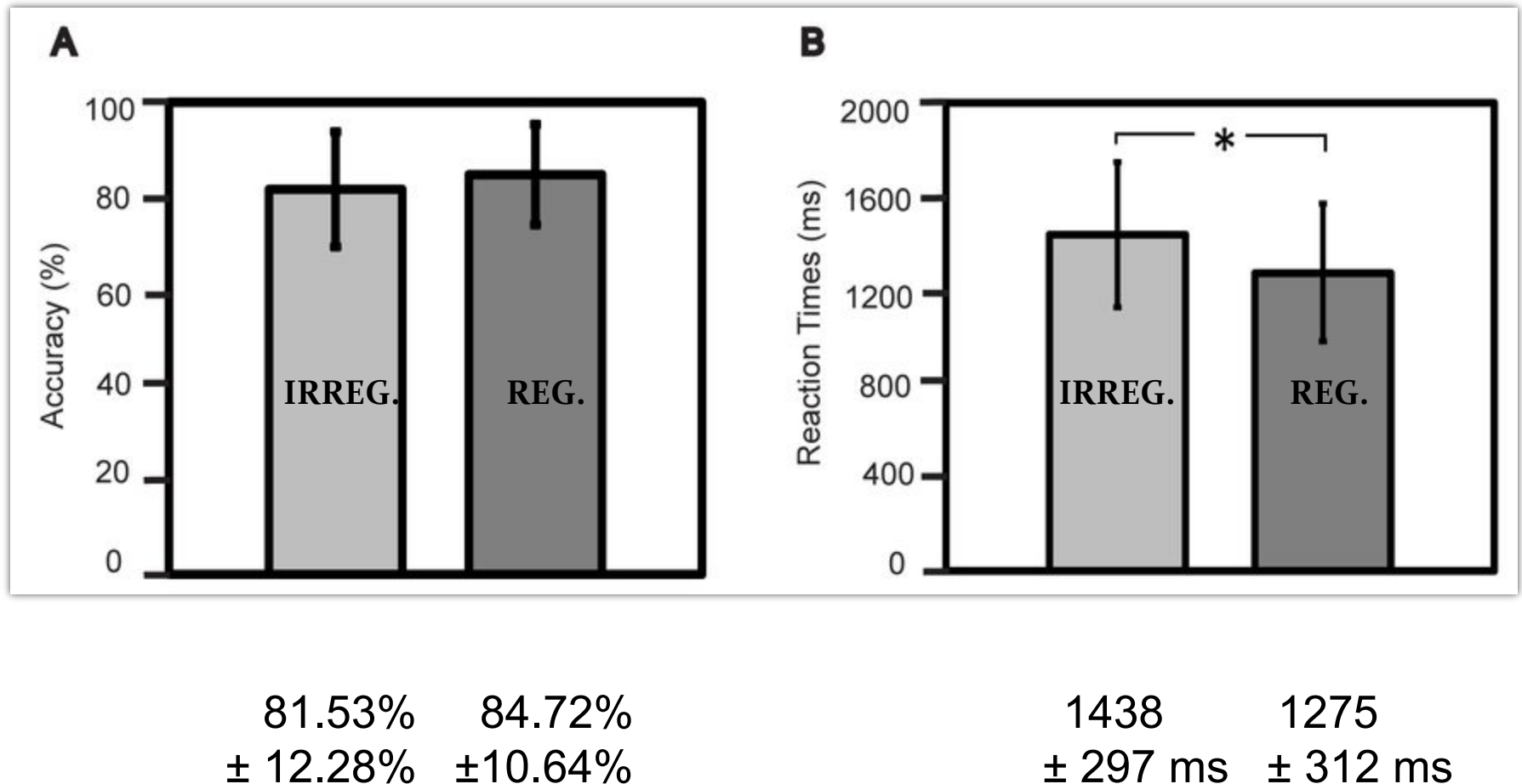
- Click duration: 0.5 ms
- Inter-onset interval (ioi): 440 - 560 ms (roved in steps of 30 ms)
- Total no. of intervals: 7 – 10
- Max. Response time: 3 s
- 40 conditions/sequence: 5 ioi x 4 no. of intervals x 2 (shorter or longer)
- Time difference between final and penultimate interval:
 - 30% of ioi for irregular sequences
 - 15% of ioi for regular sequences

Functional imaging paradigm



- Sparse temporal sampling; 3 Tesla Siemens Allegra MRI Scanner
- 48 contiguous slices per volume
- TR: 16.44 s; TA: 2.88 s; flip angle α : 90°
- Slice thickness: 2 mm
- In-plane resolution: $3.0 \times 3.0\text{ mm}^2$
- Slices were tilted by -7° ($T > C$) to obtain full coverage from the cerebellum

Behaviour in scanner (n=18)



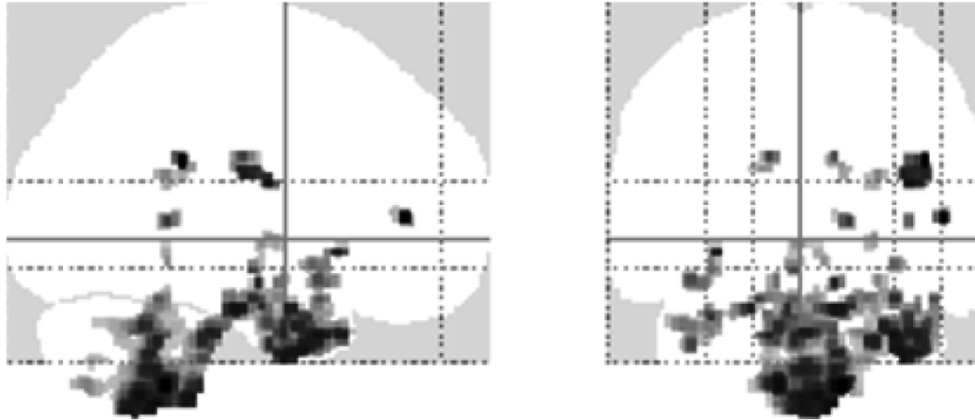
➤ Relative timing more accurate and faster than absolute timing

fMRI analysis

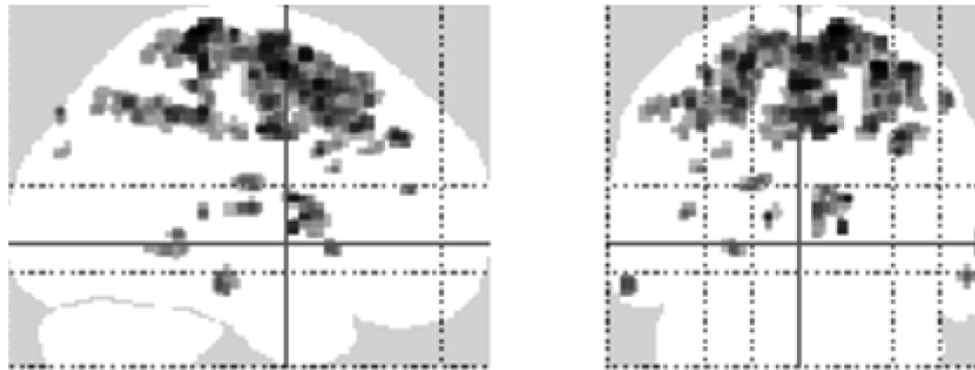
- *A priori* hypotheses for cerebellum and basal ganglia
- 18 subjects (normal hearing, no current musical training)
- Standard pre-processing with SPM8, normalization using DARTEL
- Whole brain analysis; random effects design
- **Key contrasts:**
 - (a) Irregular vs. Regular (measure of absolute timing)
 - (b) Regular vs. Irregular (measure of relative timing)

fMRI Results

A Activations for absolute, duration-based timing



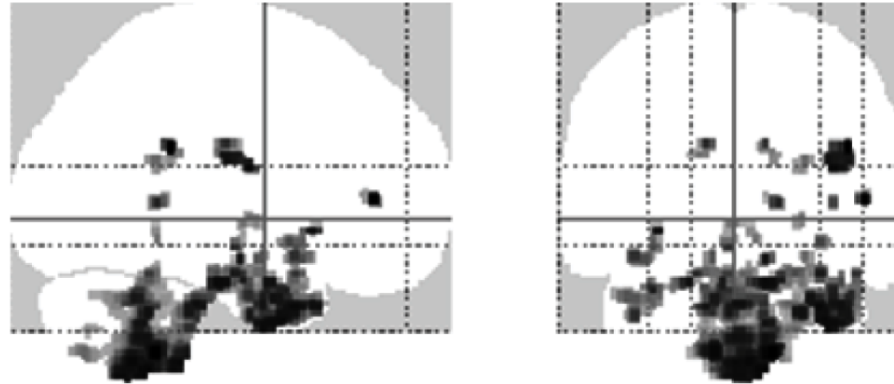
B Activations for relative, beat-based timing



MNI space; $t\text{-value} > 4.00$; extent threshold > 10 voxels

I. Absolute Timing

A Activations for absolute, duration-based timing



OLIVO-

CEREBELLAR NETWORK

Inferior Olive

Vermis

Cerebellum

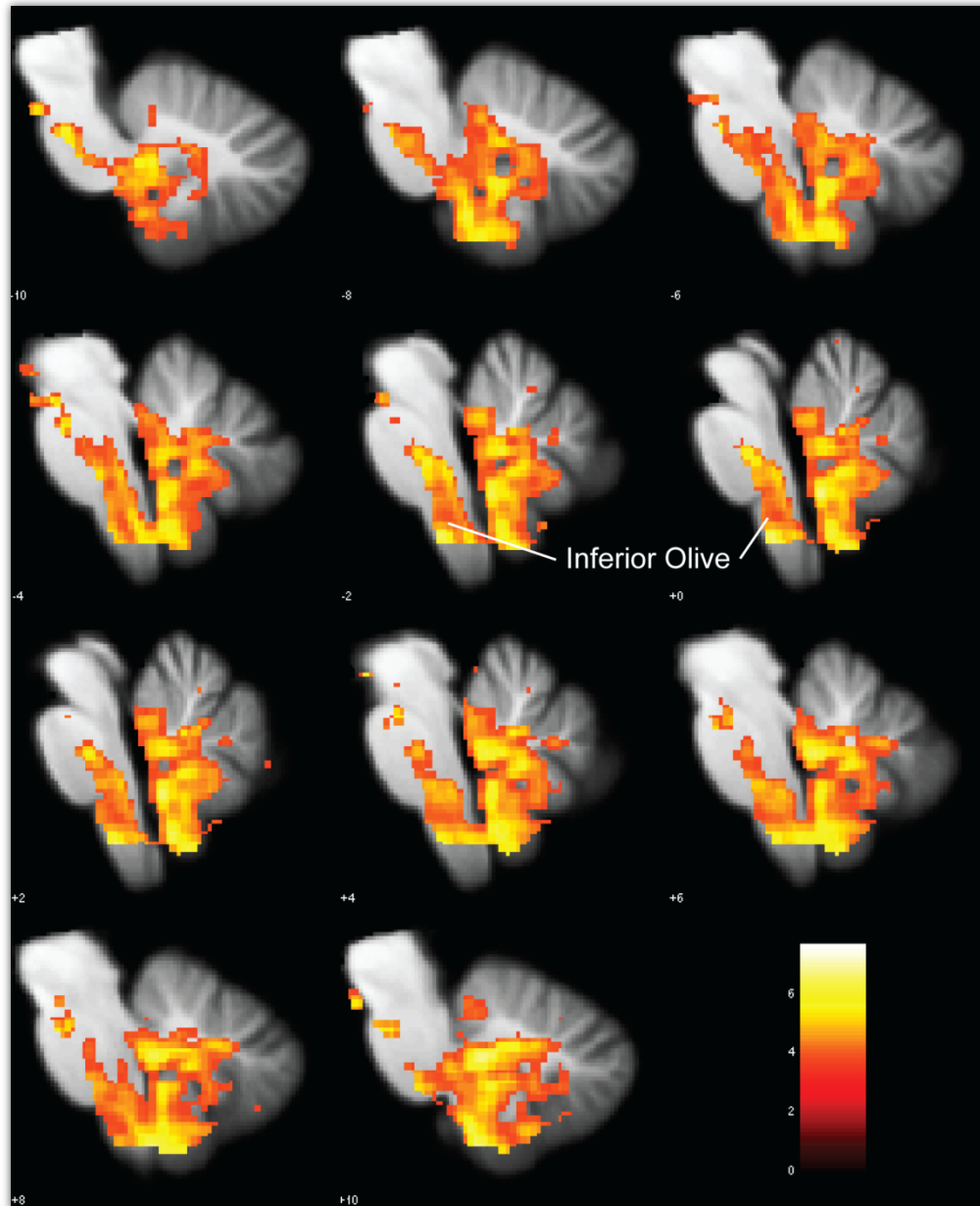
Dentate Nucleus

Cerebellar Lobules IX and X

Also: Superior Temporal Gyrus, Cochlear nucleus

[Table of activations](#)

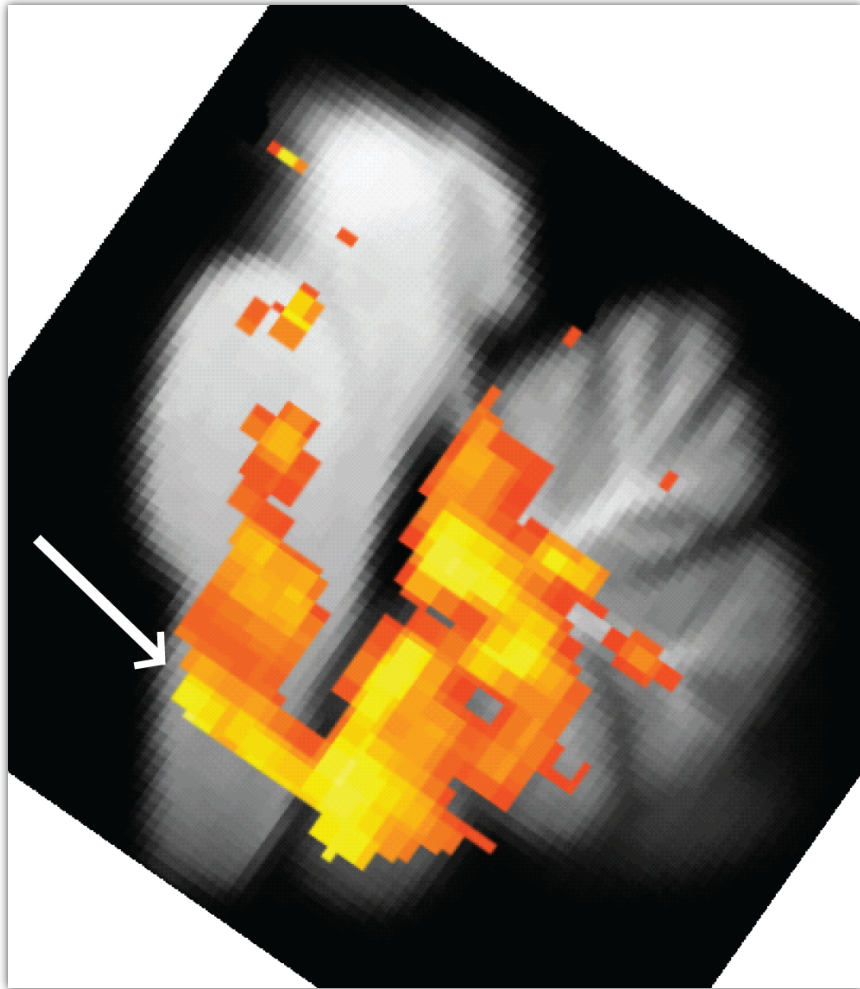
Olivocerebellar activations



x = -10 to +10 mm

p < 0.001 (unc.)

Inferior Olive



present study

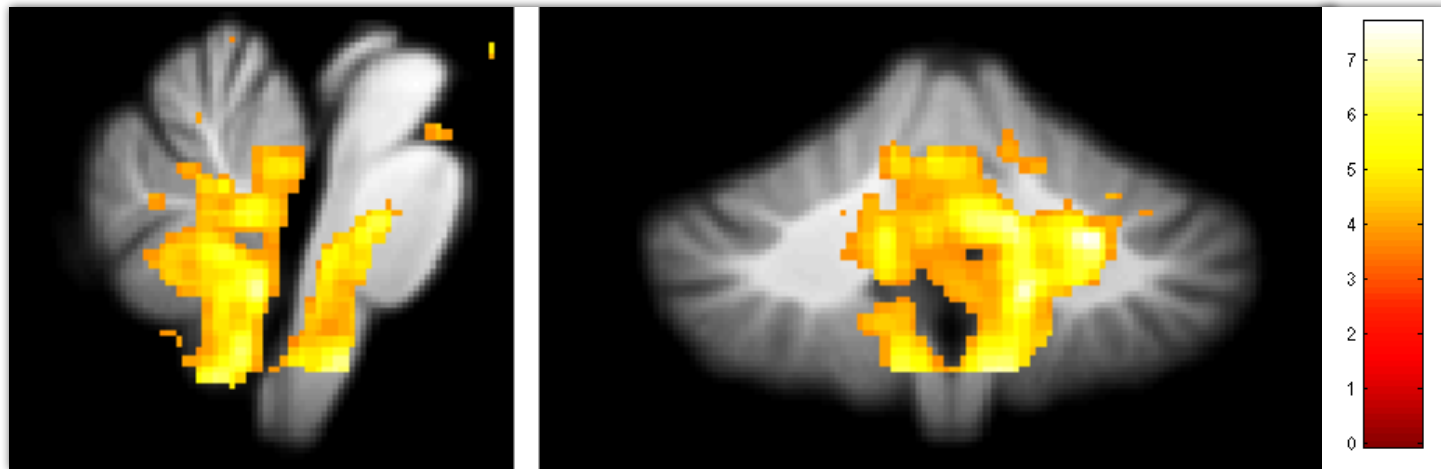


reproduced from Xu et al. (2006)

$p < 0.001$ (unc.)

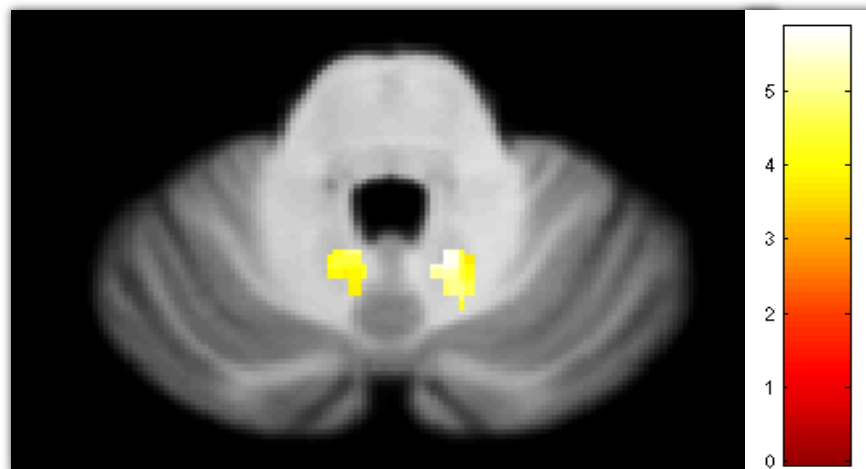
Cerebellum

$x = 0$



Dentate nucleus

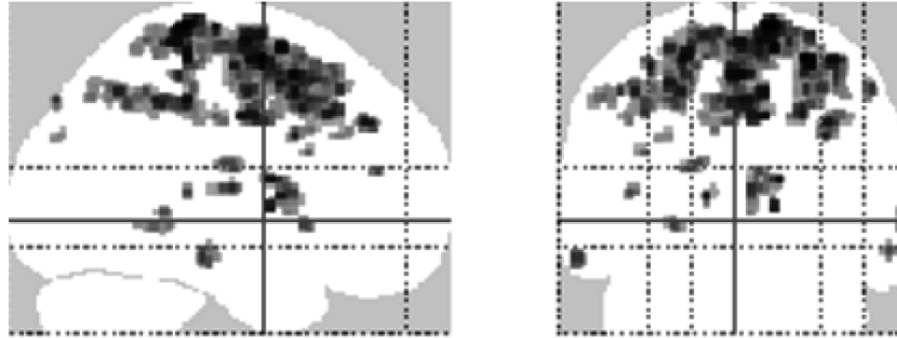
$x = 9$



$p < 0.001$ (unc.)

II. Relative Timing

B Activations for relative, beat-based timing



STRIATO- NETWORK

Putamen
Caudate Nucleus
Internal Capsule

THALAMO-

Thalamus

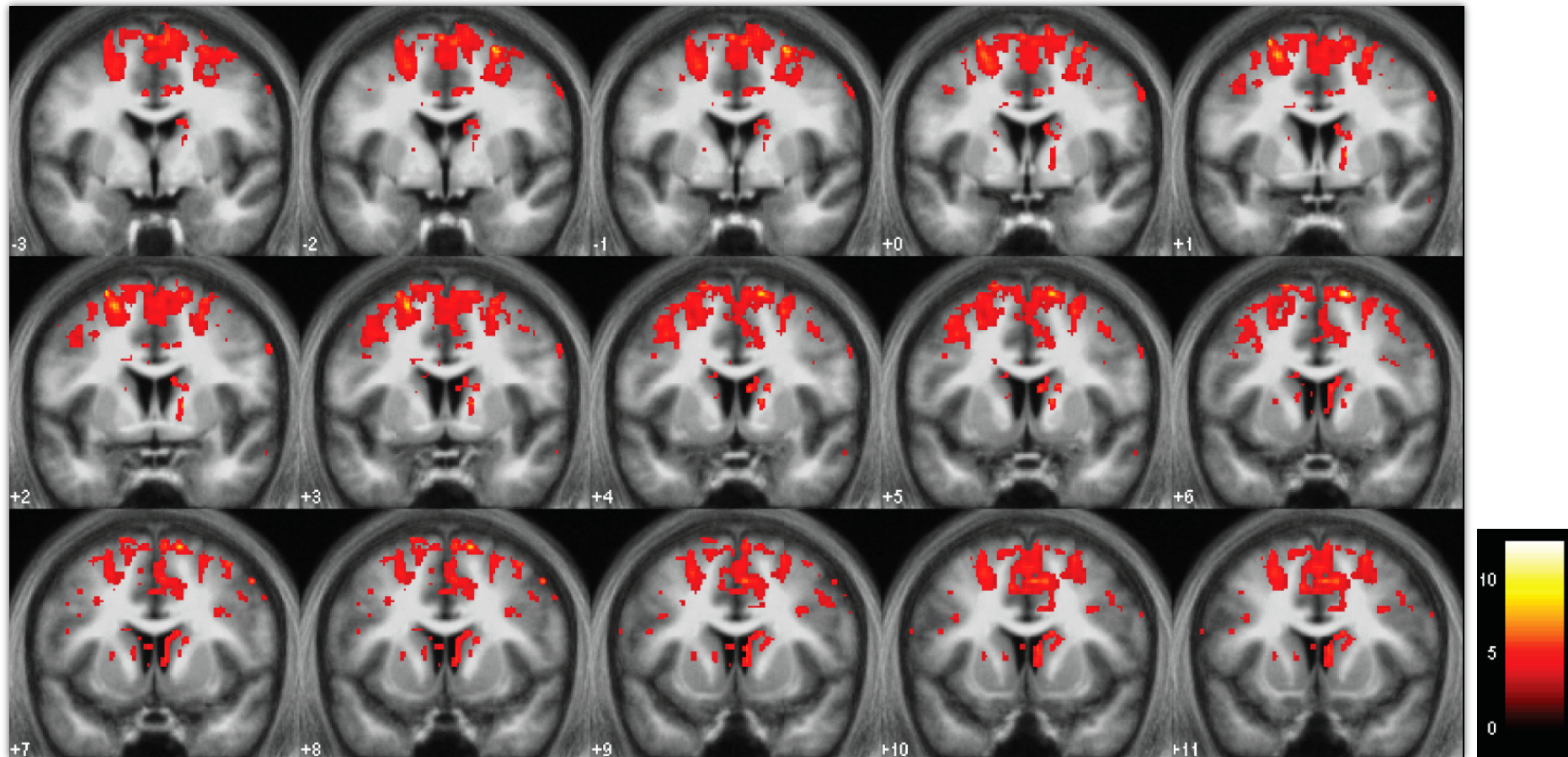
CORTICAL

Pre-SMA/SMA
Pre-motor cortex
Dorsolateral prefrontal

Also: Superior Temporal Gyrus

[Table of activations](#)

Striatal, premotor & prefrontal activations



$y = -3 \text{ mm to } +11 \text{ mm}$

$p < 0.001 \text{ (unc.)}$

Summary

- Results consistent with previous work:
 - Absolute, duration-based timing in the Cerebellum
 - Relative, beat-based timing in the Basal ganglia
- Distinct timing mechanisms and underlying subsystems:
 - Olivocerebellar network mediates absolute, duration-based timing
 - Striato-thalamo-cortical network mediates relative, beat-based timing
- First study to implicate **inferior olive** in auditory timing using fMRI

Inferior Olive and Timing

- motor timing and timing error correction of ongoing movement
- adaptive timing in vestibulo-ocular reflex and eye-blink conditioning

(Ito and others)

- sole source of climbing fibre input to the Purkinje cells (PC)
- displays sub-threshold oscillations at ~5-15 Hz
- intrinsic oscillations are synchronized via electrical coupling
- electrical coupling regulated by deep cerebellar nuclei (inhibited by PC)
- organized into dynamic, functional subgroups

(Llinas, Yarom, de Zeeuw and others)

- receives visual, somatosensory and auditory inputs
- implicated in perceptual timing of visual sequences using fMRI

(Xu et al., 2006; Liu et al., 2008)

Acknowledgments



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**Thank you for your interest and/in
time!**