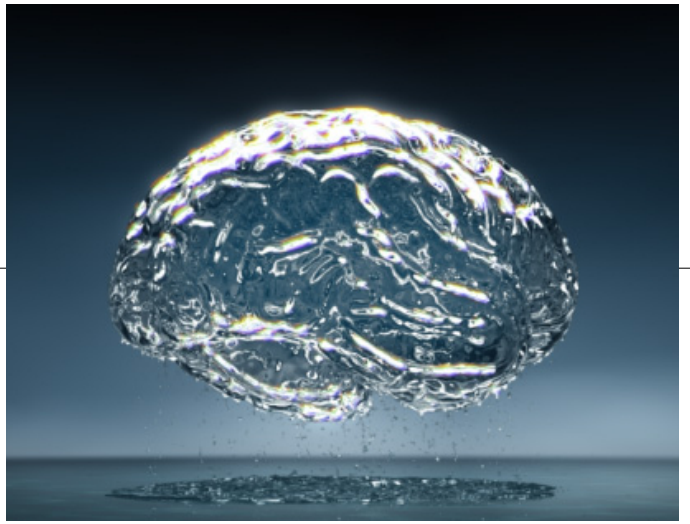
The relationship between brain structure, motor performance, and early musical training

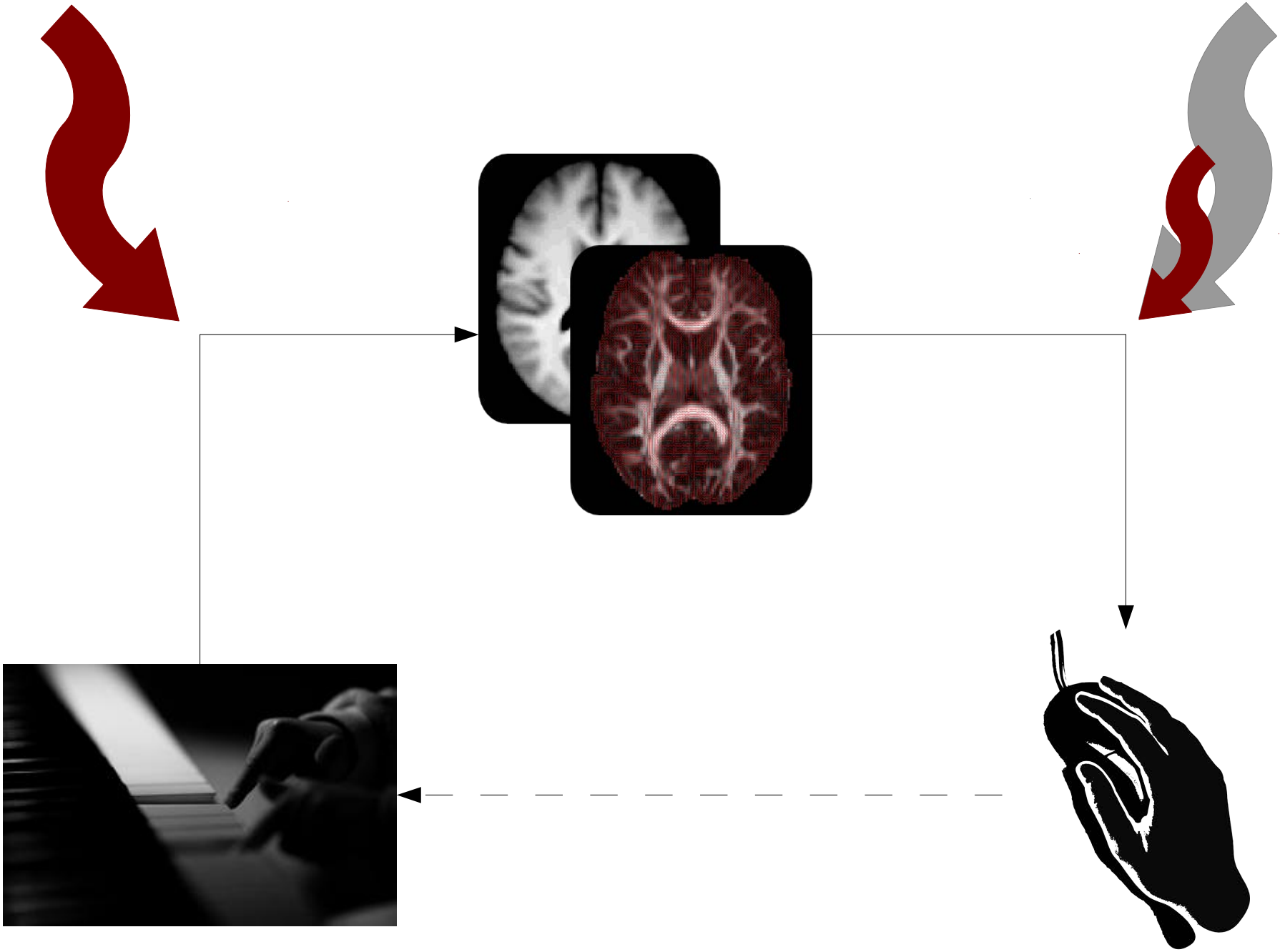
Evidence from diffusion tensor imaging

Supervised by Dr. Virginia Penhune
Concordia University
Montreal, Quebec, Canada

Christopher J. Steele
March 5, 2012

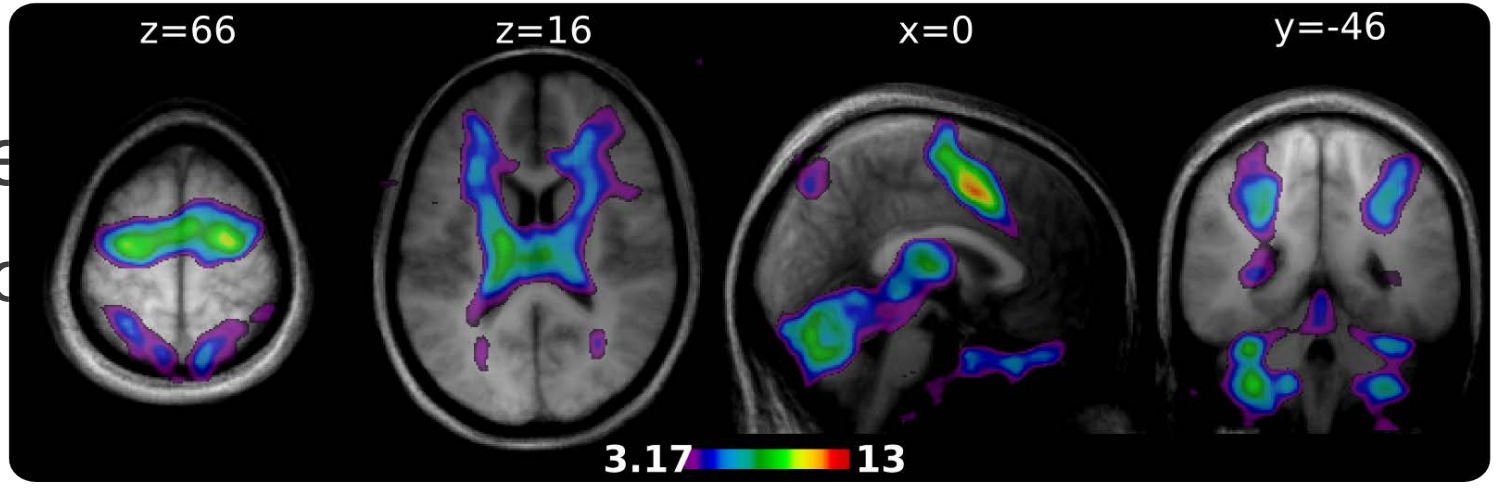
Brain Structure, Motor Performance, and Training





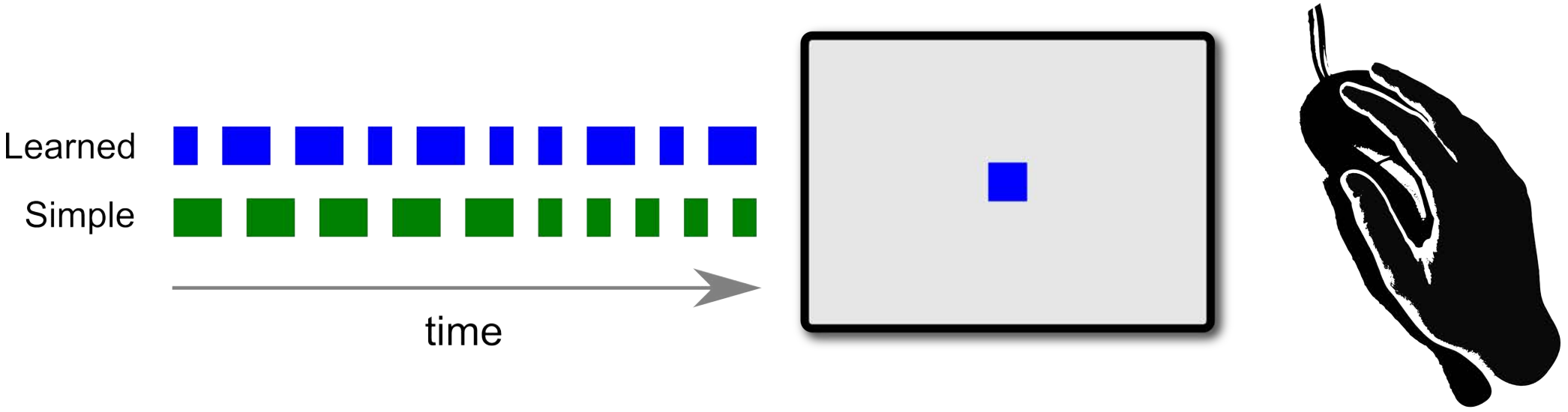
Motor Performance & the Brain

- Motor Sequence Learning
  - Acquisition and optimisation of a series of interrelated movements through practice (Penhune and Steele, 2012)
  - Fundamental for our interaction with the environment
- Recruits a well-documented functional network including
  - Motor are
  - CB, PL, fr



Motor Performance

- Temporal Motor Sequence Task



Sequence Ordering Accuracy (PCOR)

response within window? → short → response duration < M+2SD
response within window? → long → response duration > M−2SD

Response Synchronisation (PSYN)

$$100 - \left[\frac{\text{abs(stimON - keyON)} + \text{abs(stimOFF - keyOFF)}}{\text{stimulus duration}} \right]$$

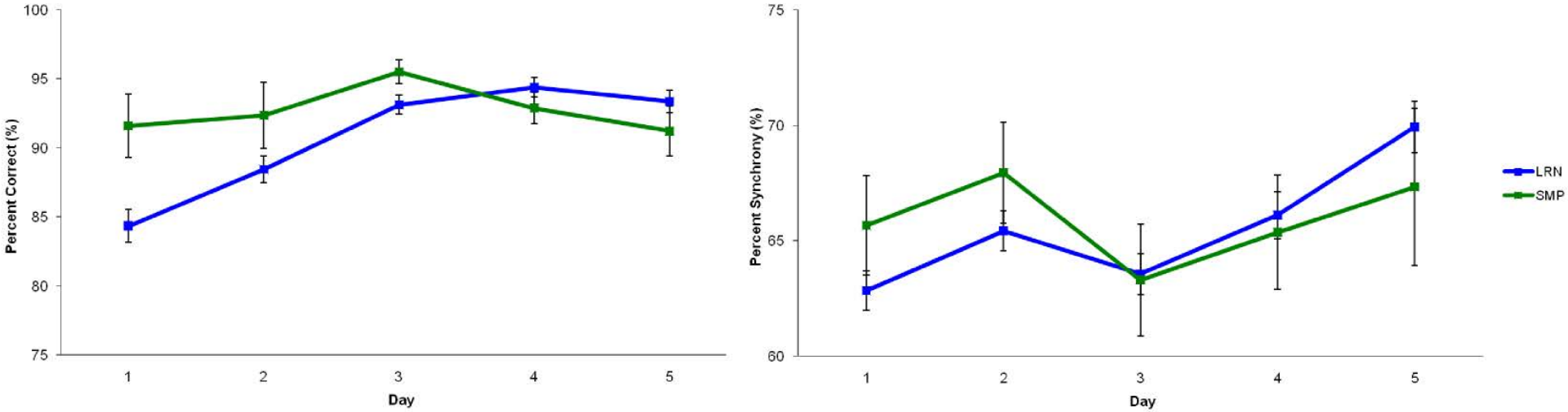
Motor Performance and fMRI

- A 5-day study that follows motor sequence learning in a single population
  - Identify the specific contributions of M1 and the cerebellum during specific points in learning
    - early learning, consolidation, later learning
  - Identify the interactions between M1 and the cerebellum
  - Investigate the regions underlying the optimisation of different components of performance

Steele & Penhune, 2010

Results: Motor Performance

A



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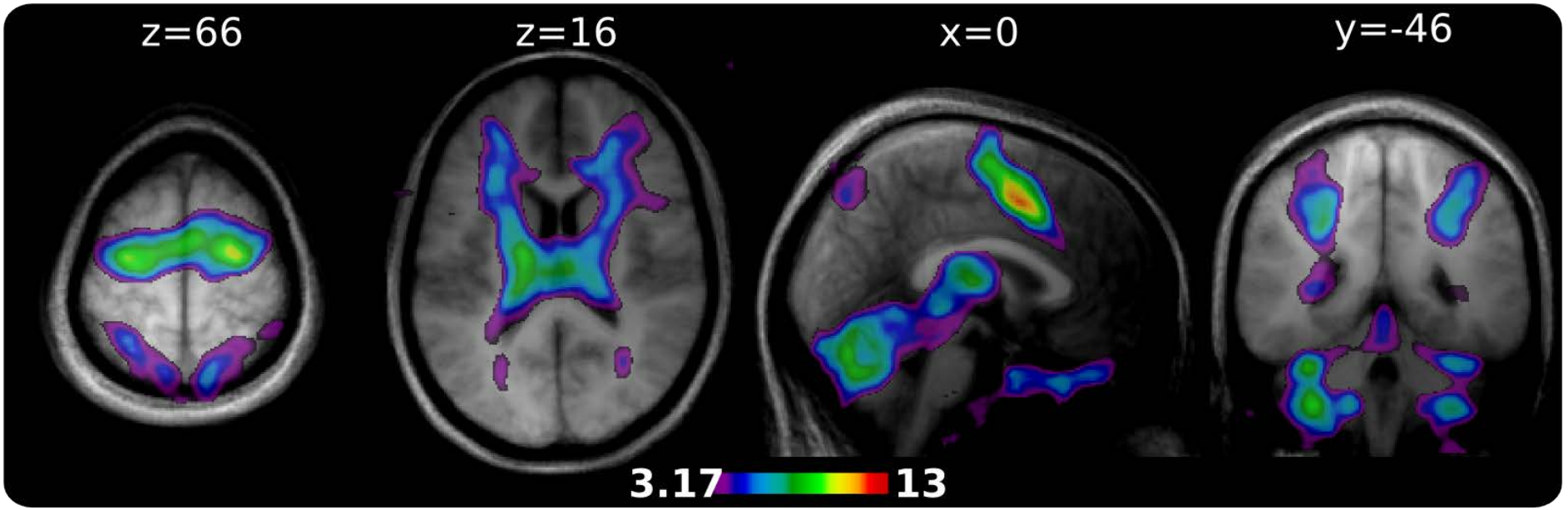
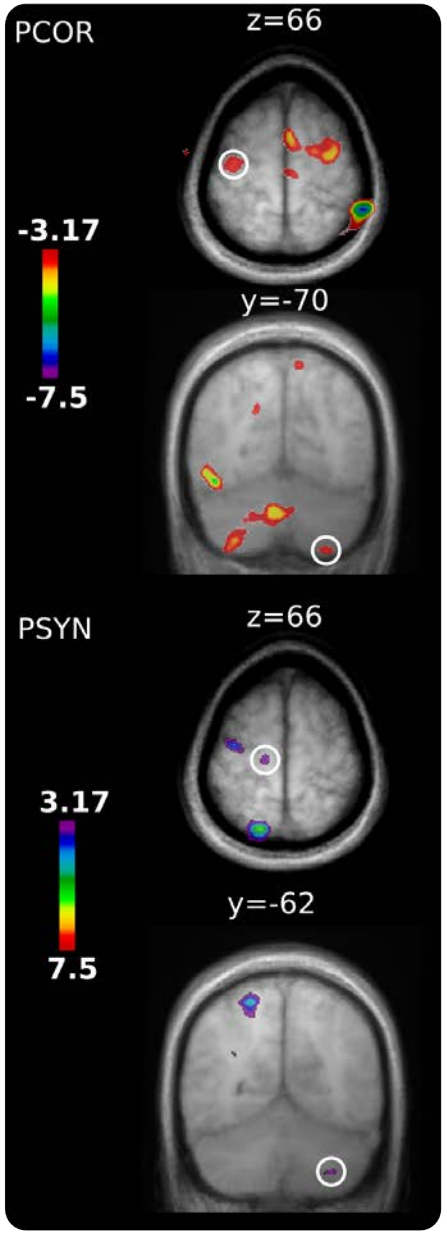
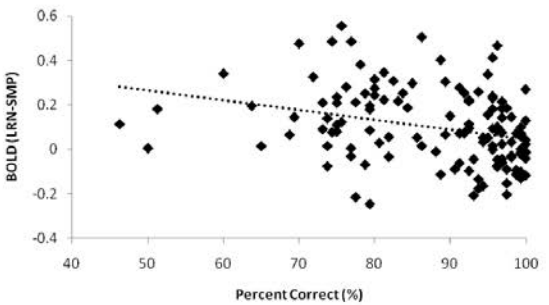
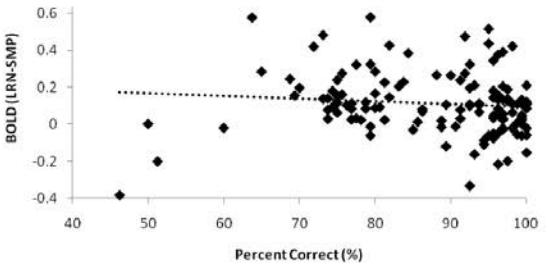


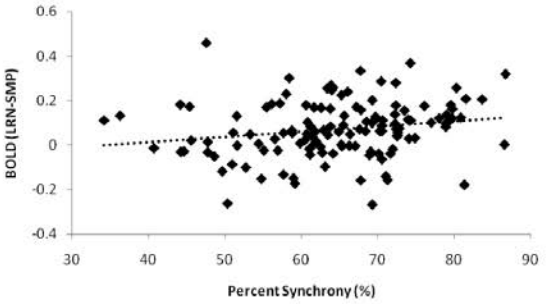
Steele & Penhune, 2010

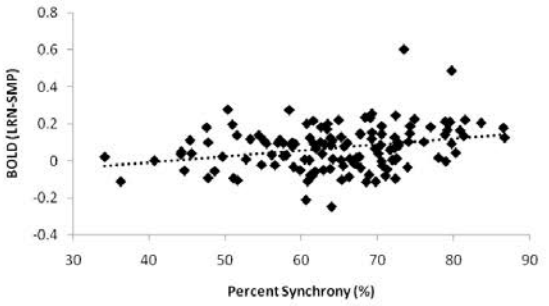
Components of Learning











- PCOR
  - Mirrors btw-day contrasts
  - Decreases in PMC/M1, pre/SMA, CB ctx
  - Increases in medial BA 9/10, hipp, putamen
- PSYN
  - Specific increases in contra M1/PMC and ipsi CB VIIIa/VIIb

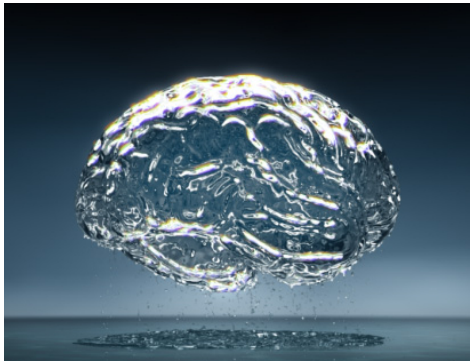
Steele & Penhune, 2010

Components of Learning

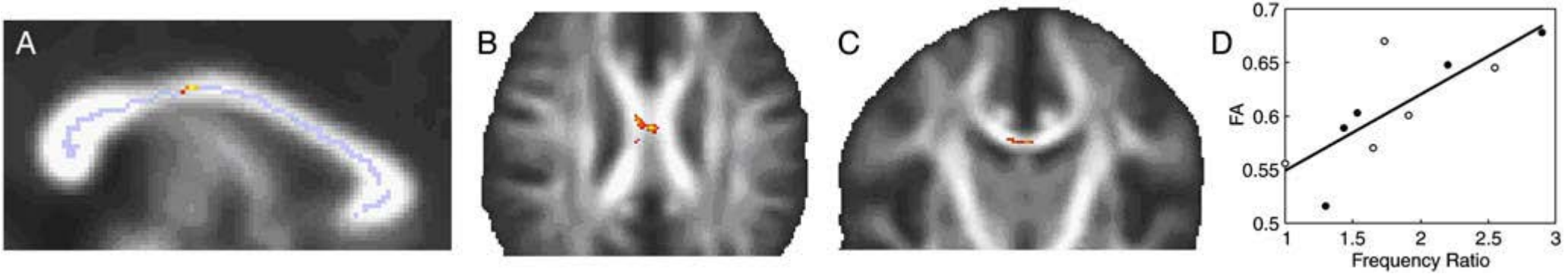
- Accuracy corr. ~ btw-day improvement
  - more explicit sequence ordering component
- Synchronisation corr. implicates motor areas
  - more procedural sensorimotor integration component

- Specific M1 and CB areas increase with improvements in synchronisation

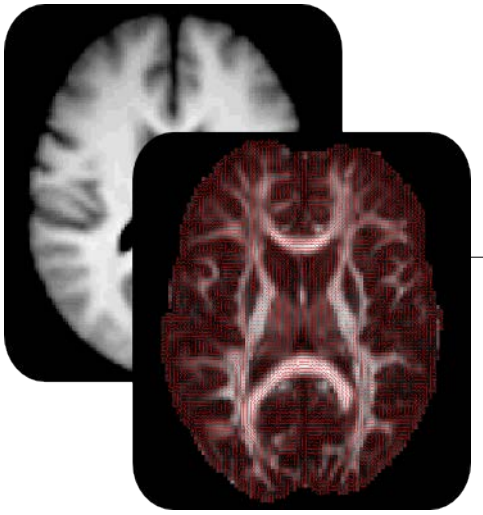
White-matter & Performance

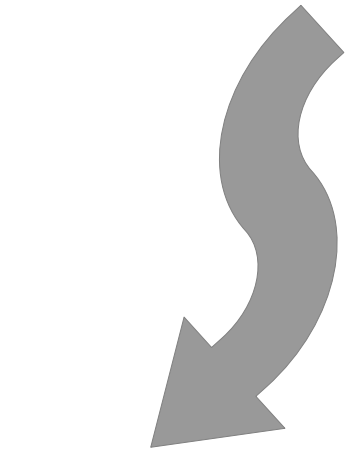


- Inter-individual differences in WM are related to performance
  - Choice reaction time and WM supporting visuospatial attention (Tuch et al., 2005)
  - Bimanual coordination and CC (Johansen-Berg et al., 2007)



Question





- Is there a relationship between brain structure and performance on the TMST?

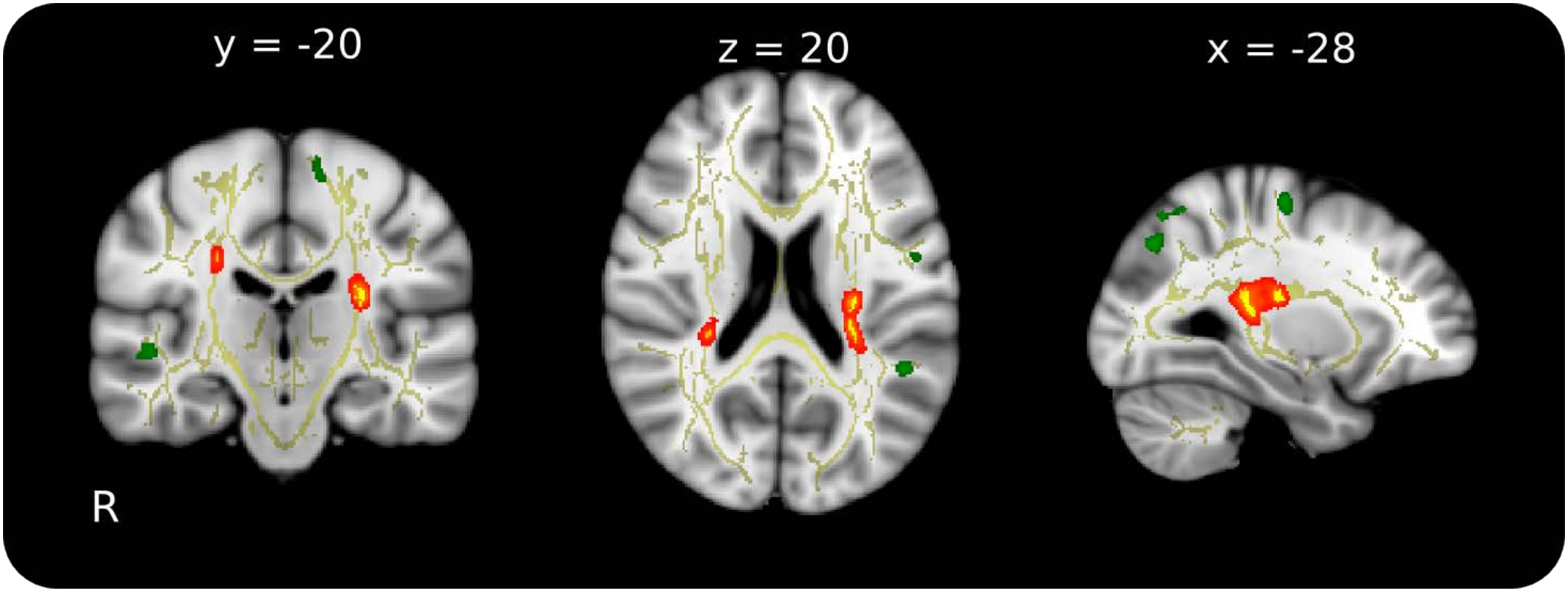
Method

1) Calculate behavioural measures
   - PCOR/PSYN final performance & slope
   - Learning potential & rate of learning
2) Correlate with whole-brain FA & VBM
   - T1 (1x1x2mm)
   - DTI (3 runs of 32 directions, b=1000, 2x2x5mm)
   - FSL TBSS
   - TFCE ($p<.05$, fully corrected)
3) Examine axial and radial diffusivity
4) Conduct fibre tractography to assist with tract identification and interpretation

Steele, Scholz, Douaud, Johansen-Berg, Penhune (in prep)

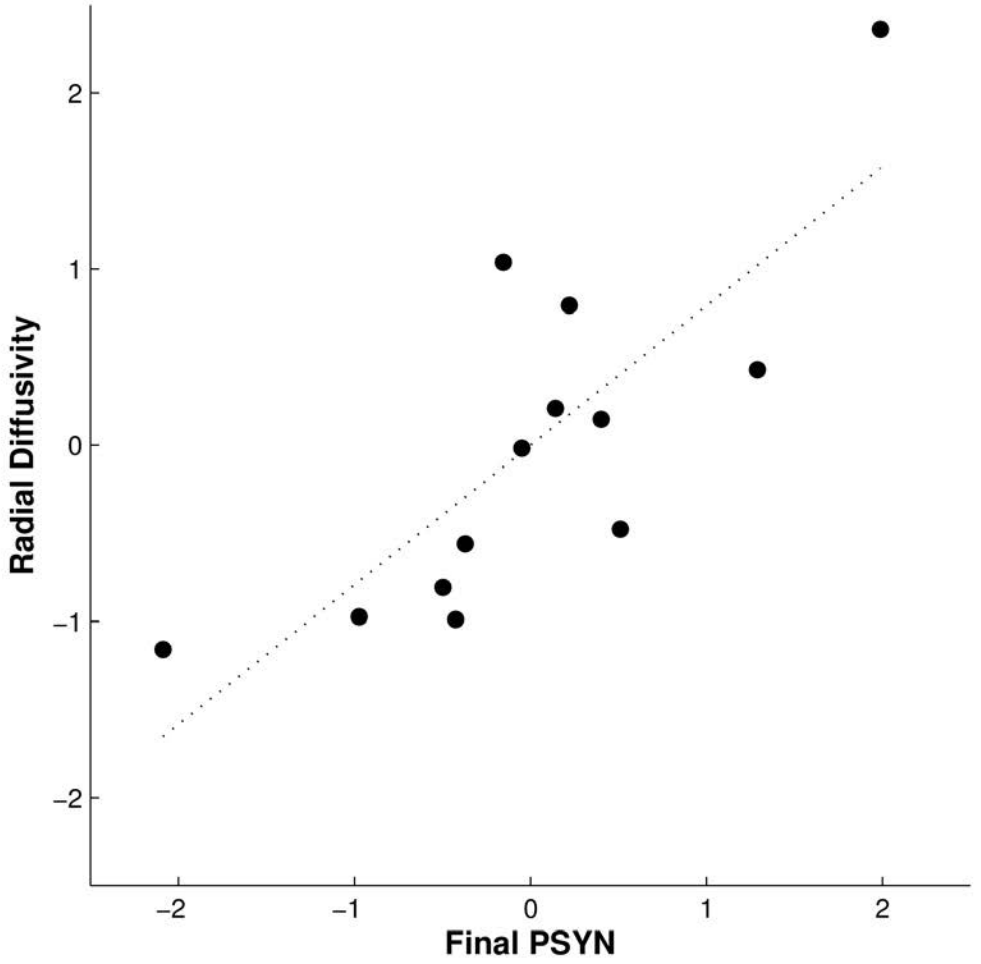
FA Results

- Final Synchronisation
  - Lower FA in bilateral CS tract correlated with greater final performance on visuomotor synchronisation measure



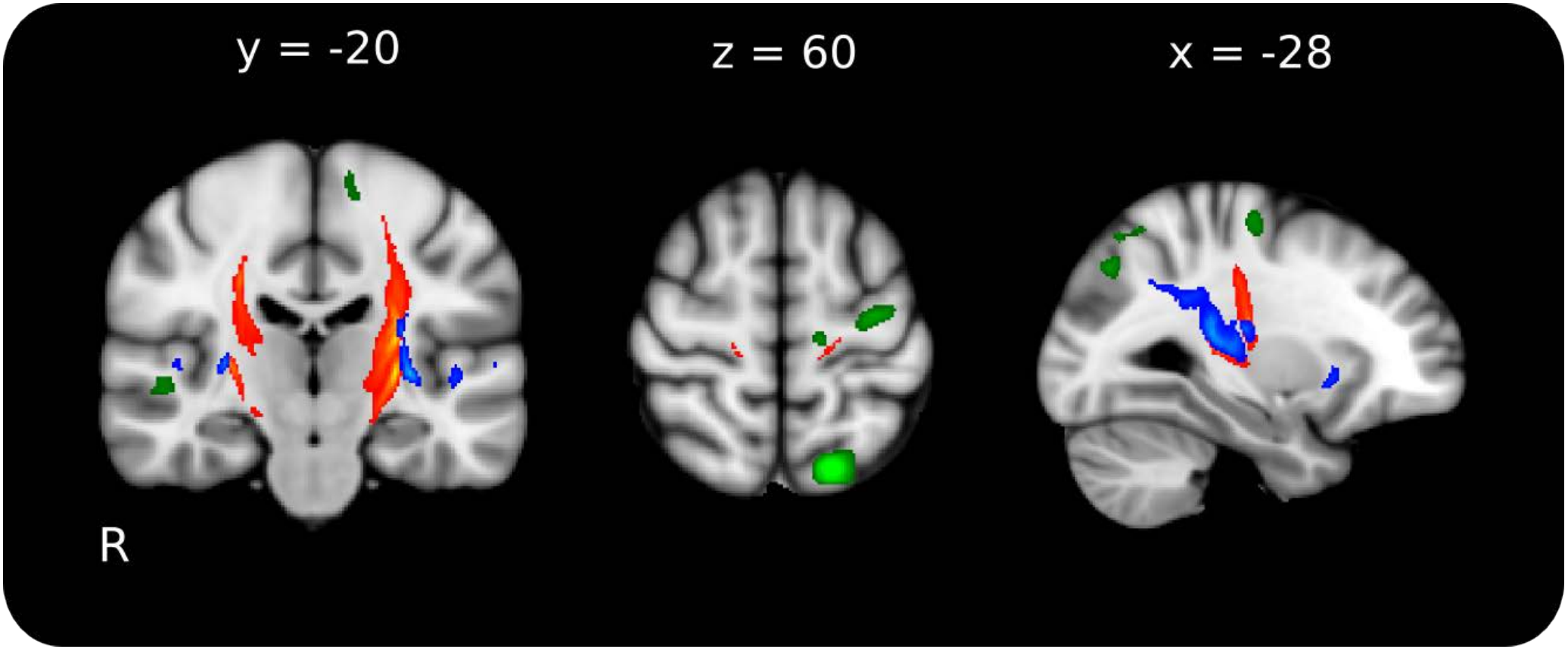
Diffusivity Results

- Axial – no sig. Relationship
- Radial – +ve correlation



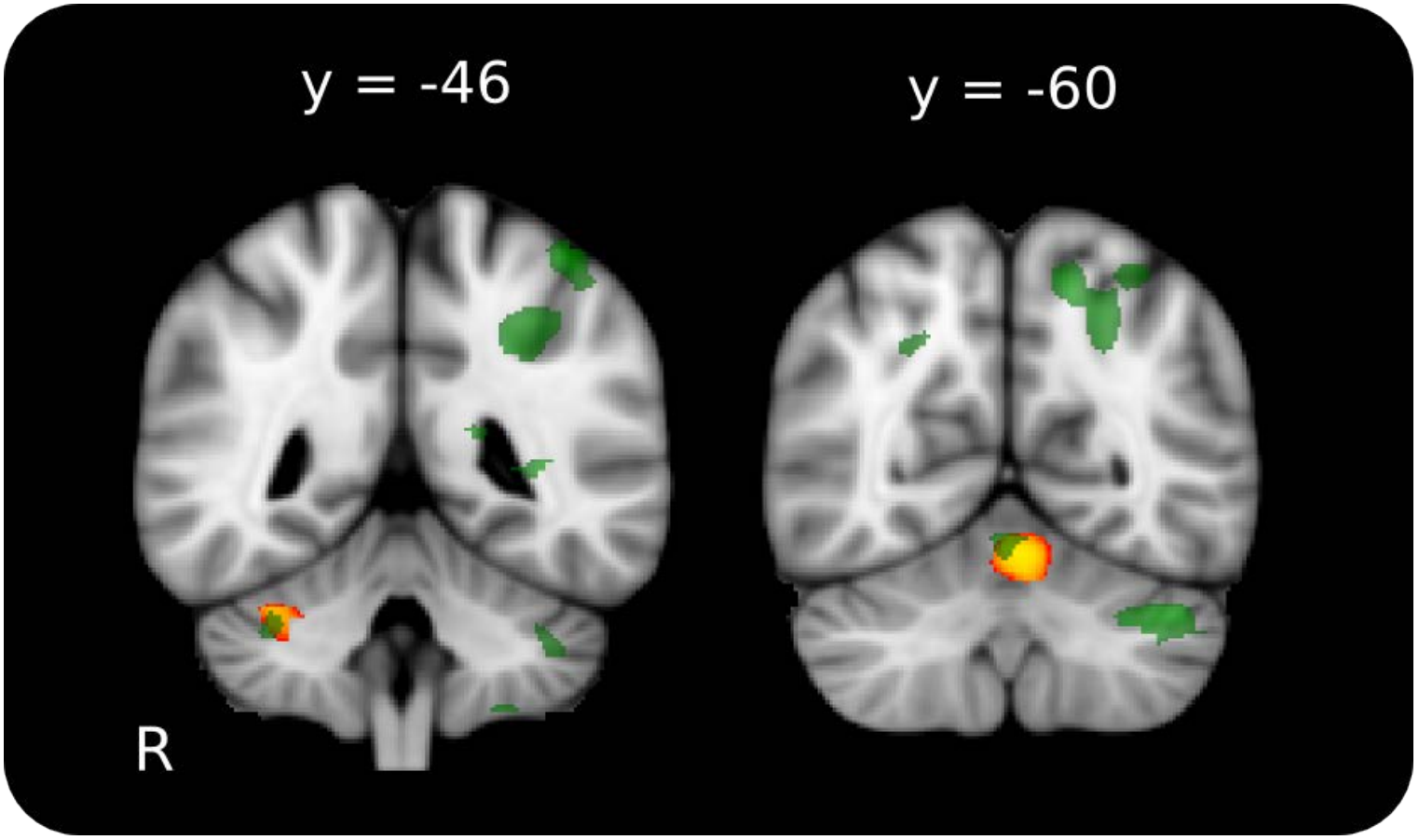
Tractography

- First ≅ CST; Second ≅ SLF
  (green = +ve BOLD-PSYN correlation)



VBM: Synchronisation Rate and the CB

- Right CB HVI and V
- (green = BOLD decreases across learning)



Recap

- Synchronisation performance is not just about M1
  - frontal, parietal, temporal regions were also identified in functional contrasts
  - auditory recoding?
- Improvement linked with CB GM differences
  - enhanced error correction?
  - greater GM volume = better internal models?

Take-away

- Individual differences in performance can map to individual differences in brain structure
- FA is not more than it claims to be
  - Summary measure
    - Diameter, myelination, packing density, fibre orientation(s)
    - No 1-1 mapping to biology
  - Combining diffusion measures with tractography should help

But...

- Training/Experience-related WM structural plasticity?
  - Longitudinal designs
    - Juggling (Scholz et al., 2009)
    - Balance task (Taubert et al., 2010)
  - Group differences
    - Experts vs. controls

Children and Expertise

- Garry Kasparov
- Tiger Woods
- Yo-Yo Ma

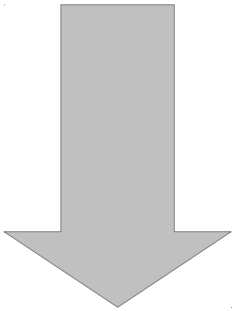
Sensitive Period

- Period of time during early development when experience has a differential effect on the brain and behaviour (Penhune, 2011; Knudsen, 2004)
- Critical periods in sensory systems
  - Experience/stimulation is essential for normal development
    - Cat visual cortex (Wiesel & Hubel 1963; Hubel & Wiesel, 1970)
    - Rat auditory cortex (de Villers-Sidani et al., 2007)
- Sensitive period in humans
  - Congenital deafness and early cochlear implantation (Kral & Sharma, 2012)

Enter the Musicians

Musicians

Extensive practice and expertise
Sensorimotor integration
Training often begins early
(but can start at any time)



Brains?
Motor Performance?

Musicians & Brains

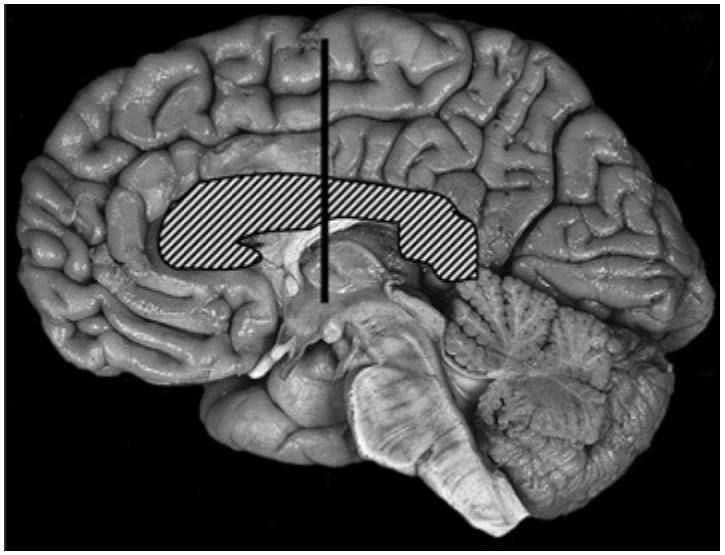
- Some evidence that early musical training influences brain structure

  1) > ant CC (area) in those who began training before age 7 (Schlaug et al., 1995)

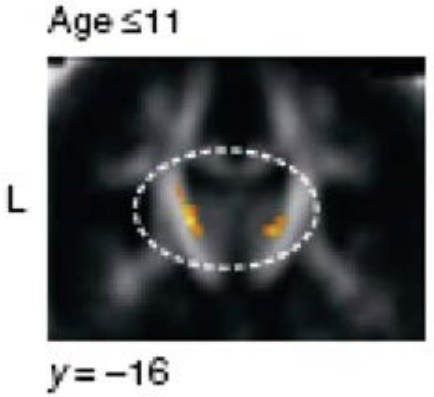
  2) FA linked to childhood practice

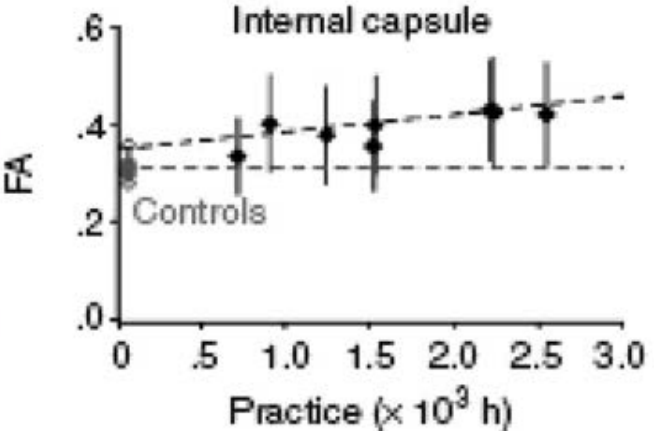
  (≤ age11) in isthmus, splenium, body of CC and descending motor pathways (Bengtsson et al., 2005)

  - Age of onset of musical training 5.8 +/- 1.4 yrs



	Total CC area	Anterior half of CC area	Posterior half of CC area
ET (< 7) (n= 21)	709 ± 81	384 ± 42	321 ± 44
LT (≥ 7) (n= 9)	637 ± 77	340 ± 43	297 ± 38

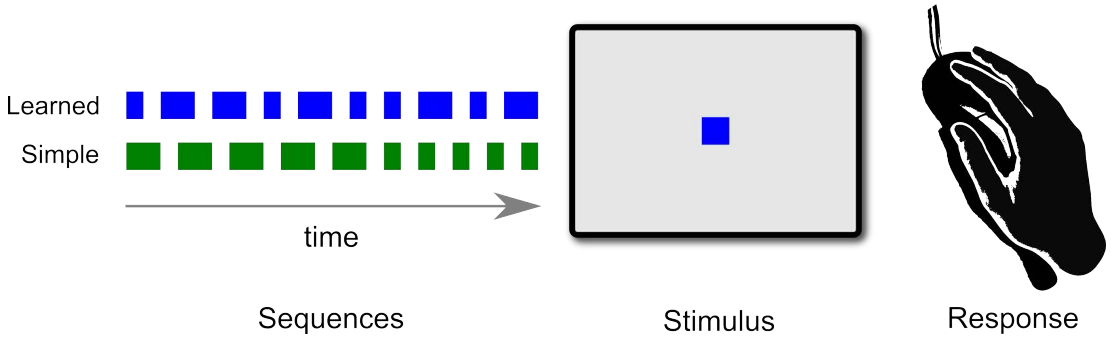


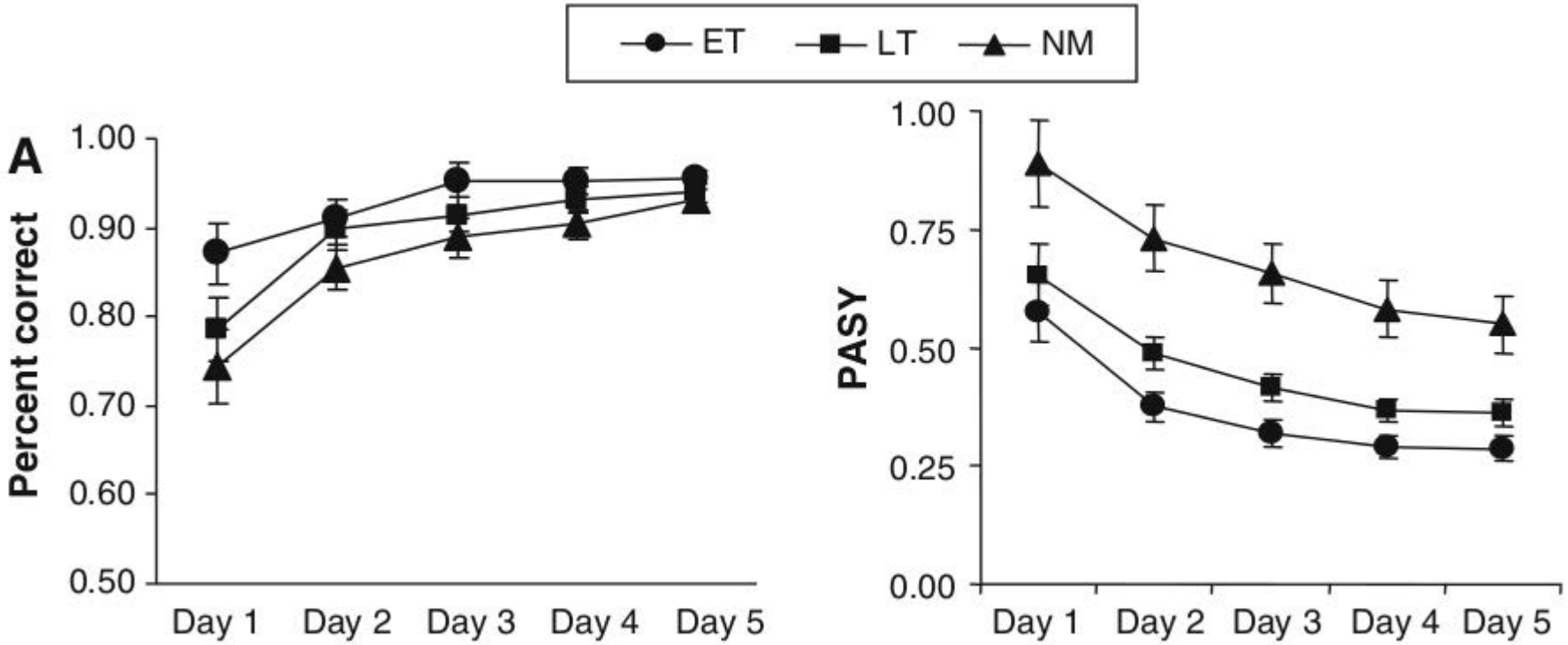


But...

- Is this evidence for a sensitive period?
  - Starting earlier also means more years of training and experience
- No controls for the amount of training or practice
  - We know that training/practice can result in WM change
  - A potential confound
- Matching paradigm
  - Early-trained (≤ 7) and Late-trained (>7)
  - Formal training and experience
  - Current hours of practice

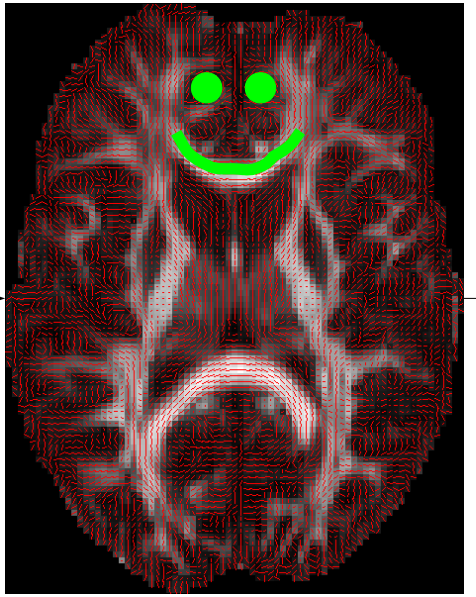
Matched Musicians & Motor Performance





Watanabe, Savion-Lemieux, Penhune, 2007

ET LT



ET LT

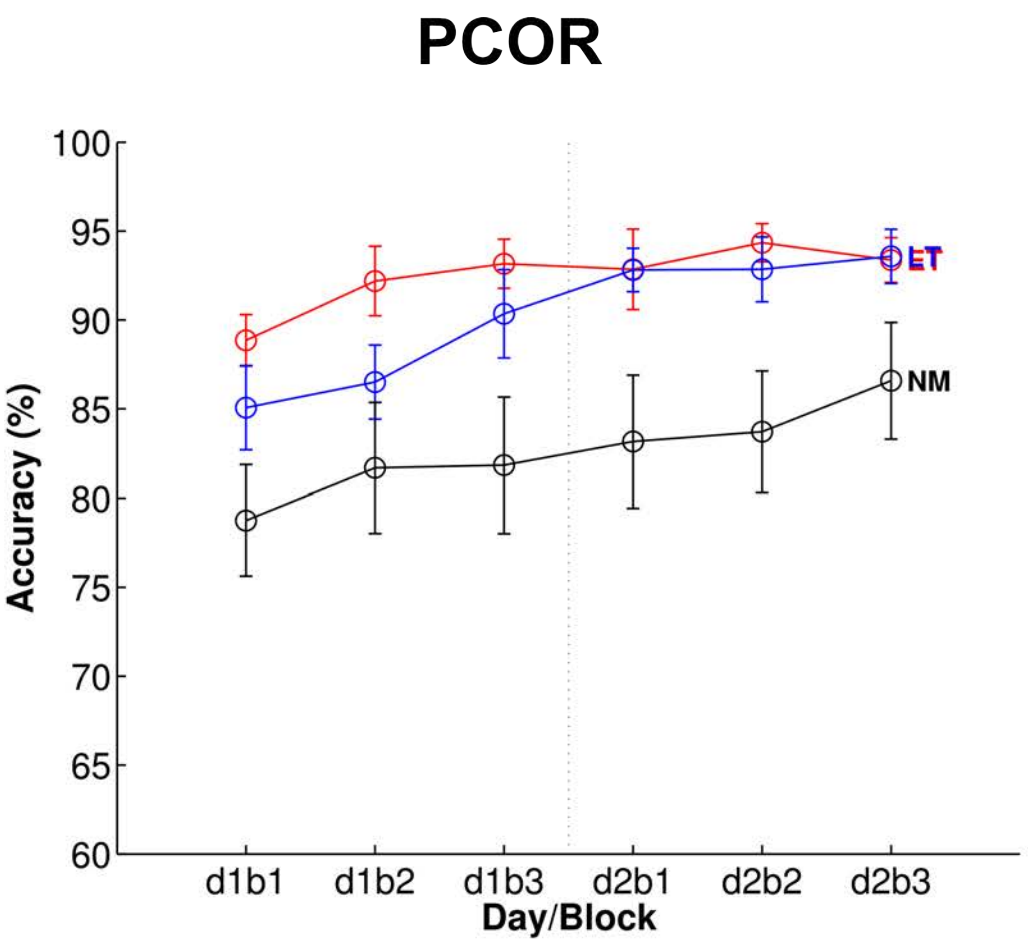
- Behavioural
  - 2 musician groups & control (18:18:17)
  - 2 days of training on the TMST
  - Accuracy and visuomotor synchronisation
- Imaging
  - DWI (99 directions, b=1000, 2x2x2mm)
  - FSL TBSS
  - Controlled for age and sex
  - TFCE ($p<.05$, fully corrected)

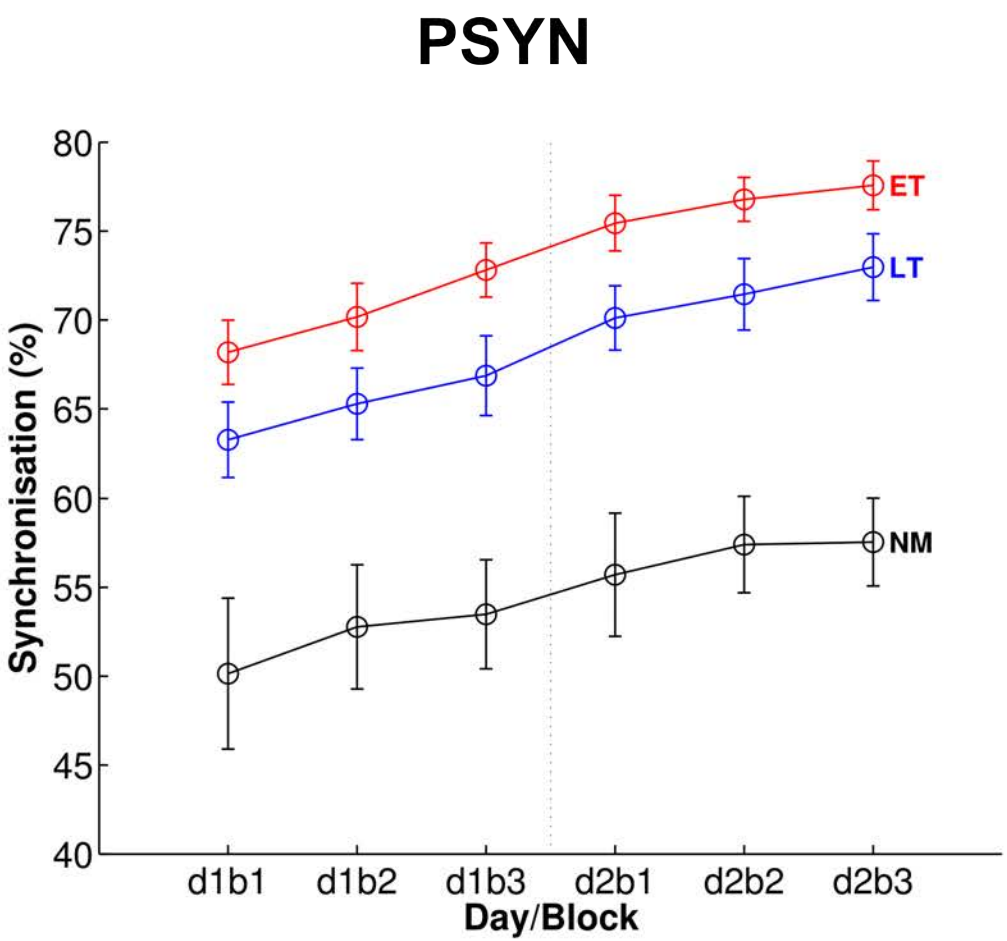
Steele, Bailey, Zatorre, Penhune (in prep)

Demographics

- Matched
  - Years of formal training (p=.16)
  - Years of experience (p=.822)
- Differed
  - Age of onset (ET=5.72; LT=10.78; p<.001)
  - Age (ET=22.74; LT=27.61; p<.001)

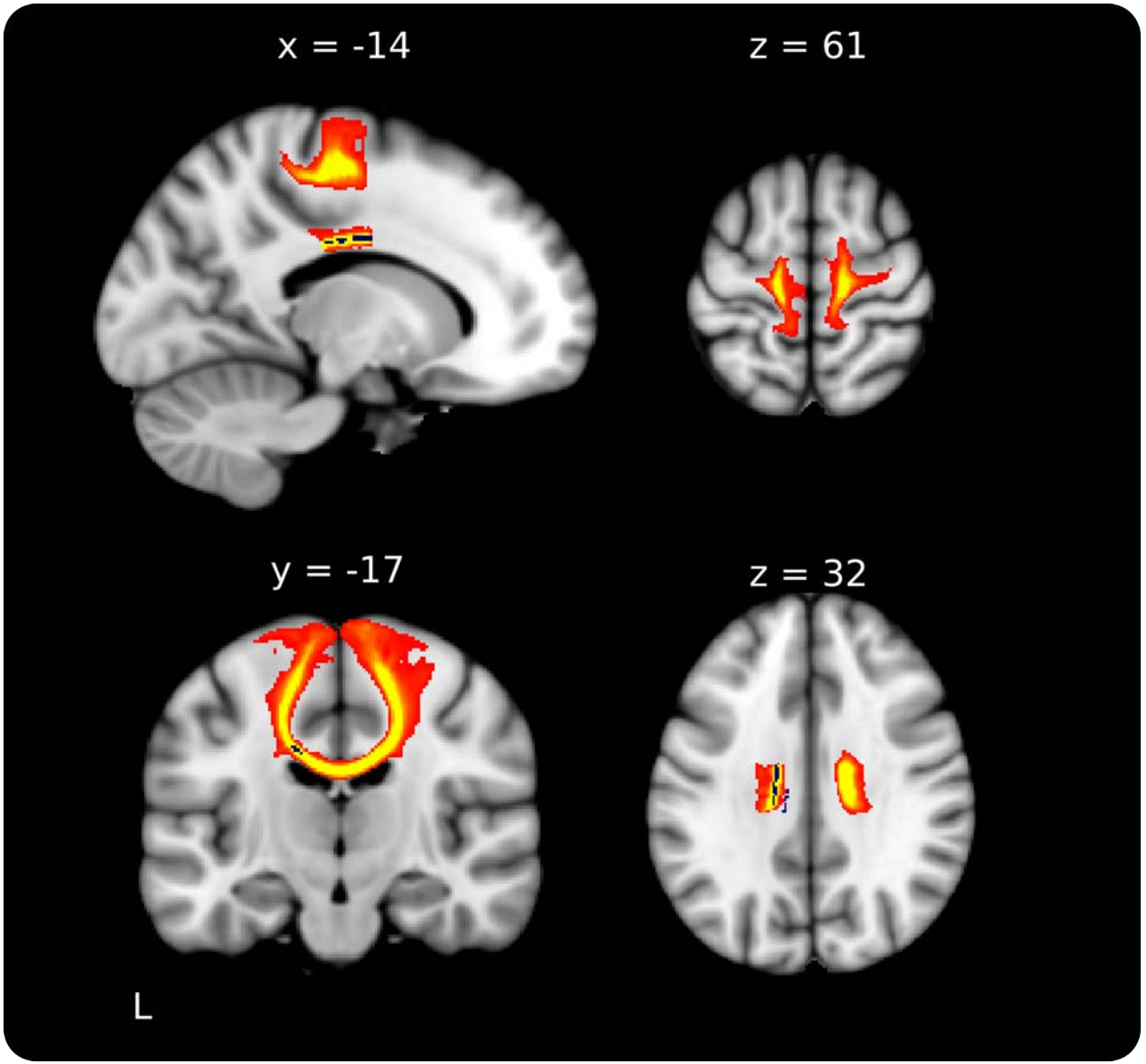
Performance





Early **T**rained **L**ate **T**rained **N**on**M**usicians

ET > LT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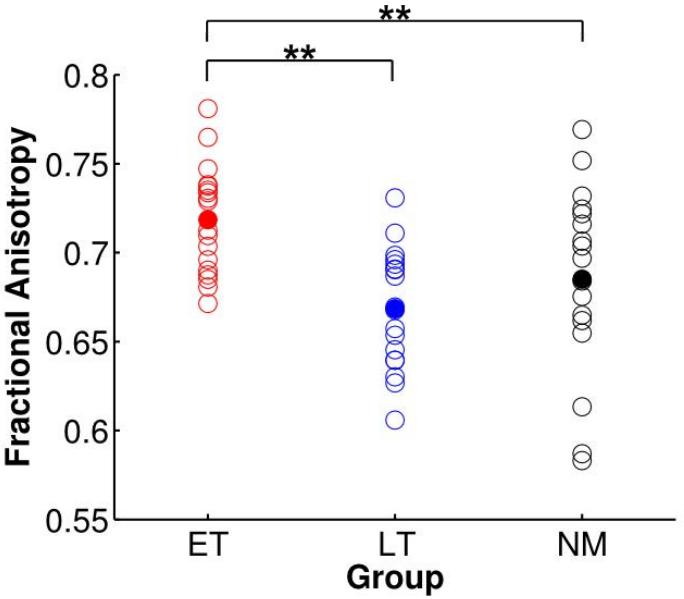
z = 61
y = -17
z = 32
L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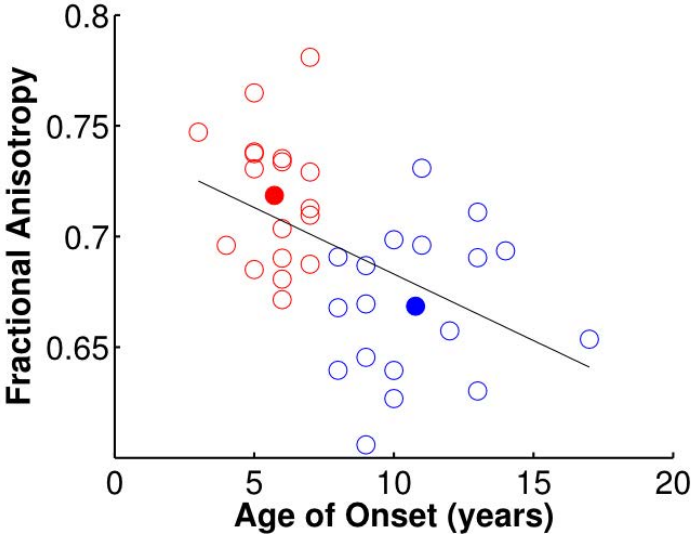
Fractional Anisotropy
0.8
0.75
0.7
0.65
0.6
0.55
ET
LT
NM
Group


Fractional Anisotropy
0.8
0.75
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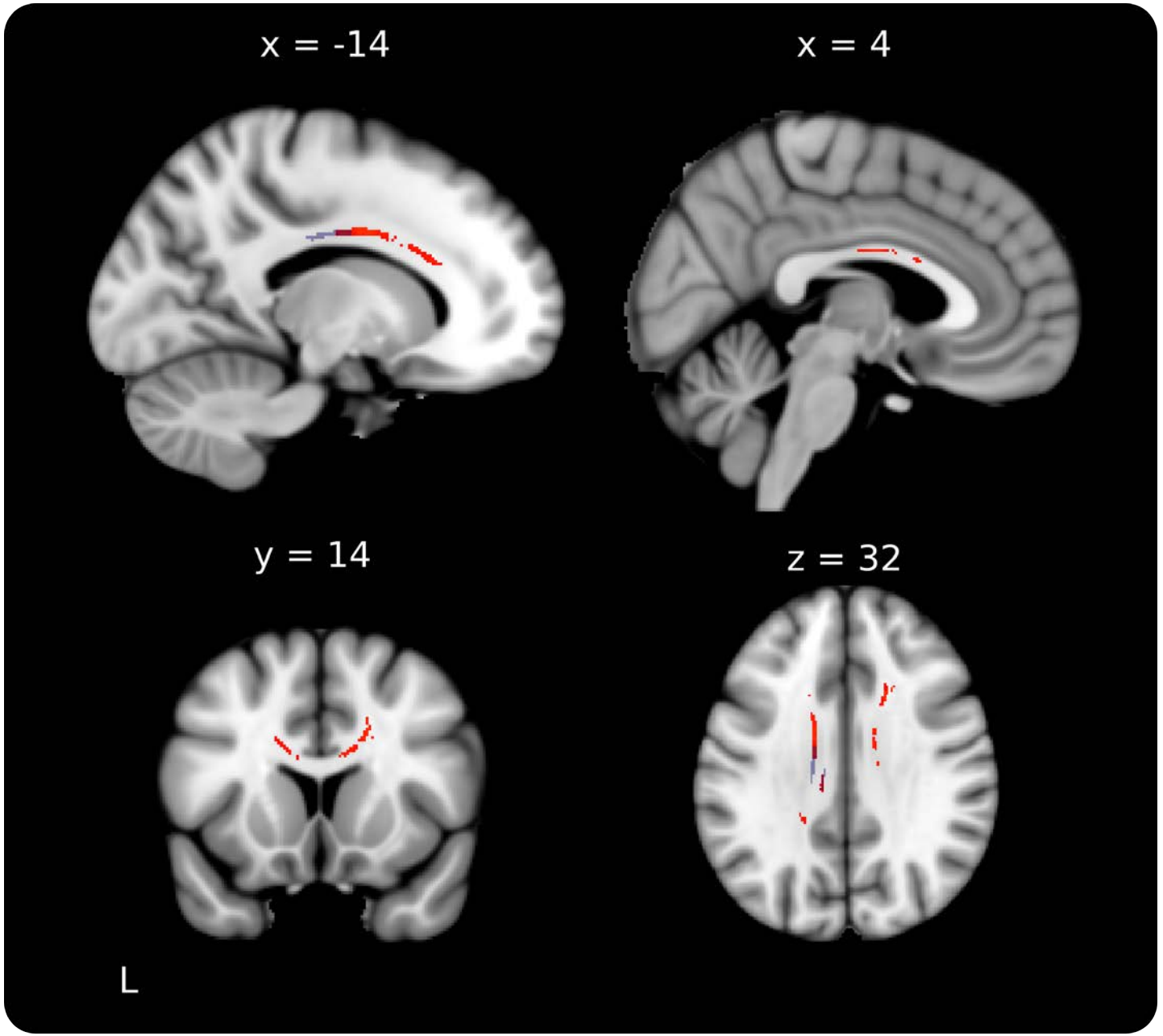
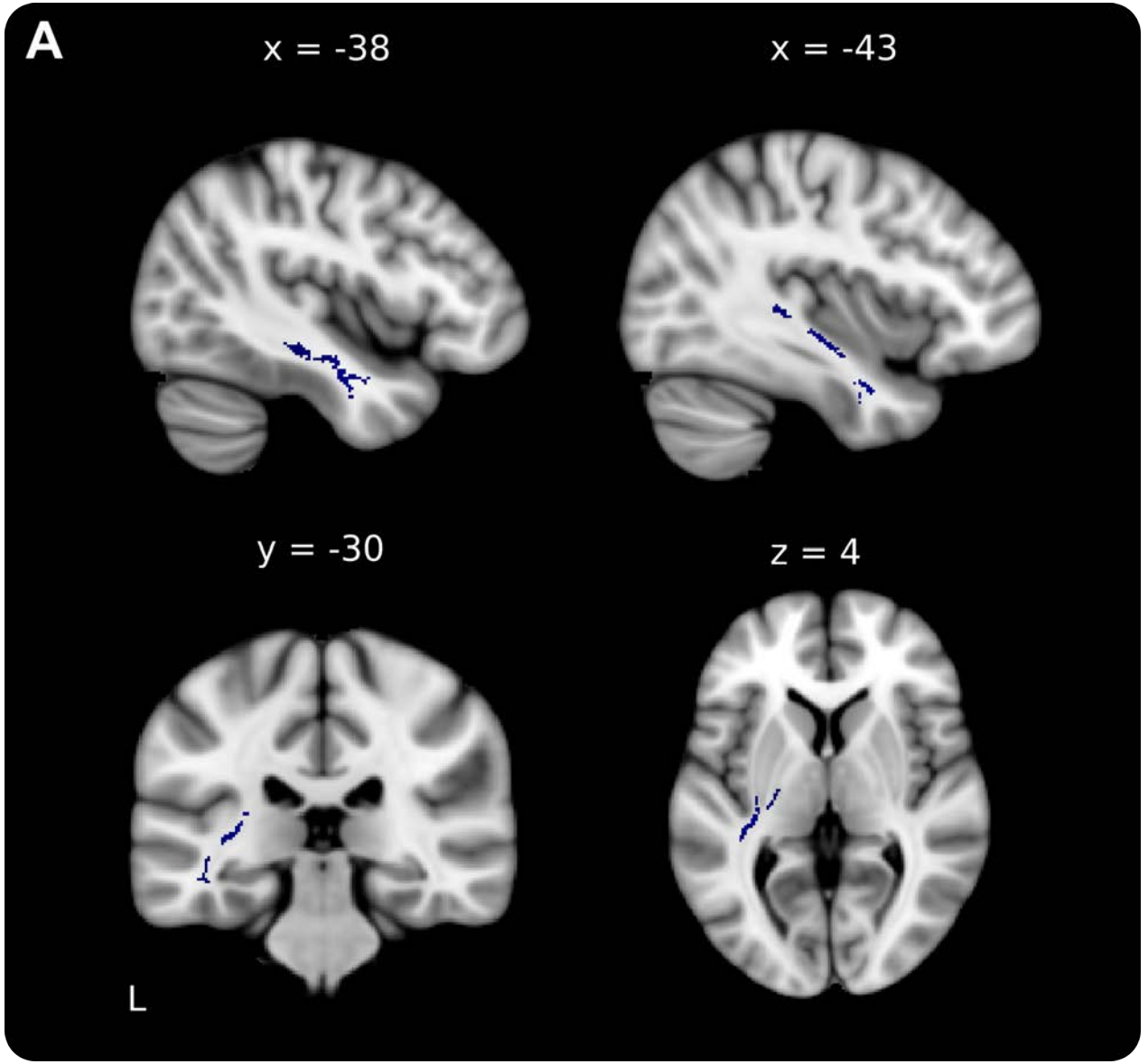
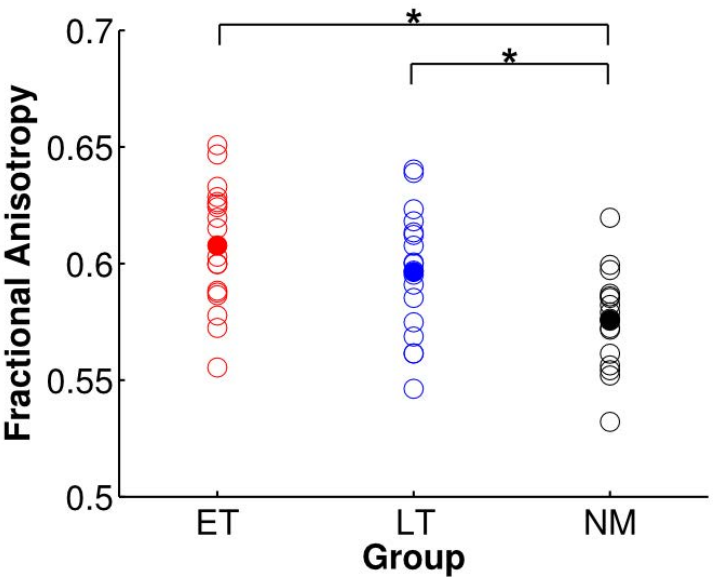
5
10
15
20
Age of Onset (years)

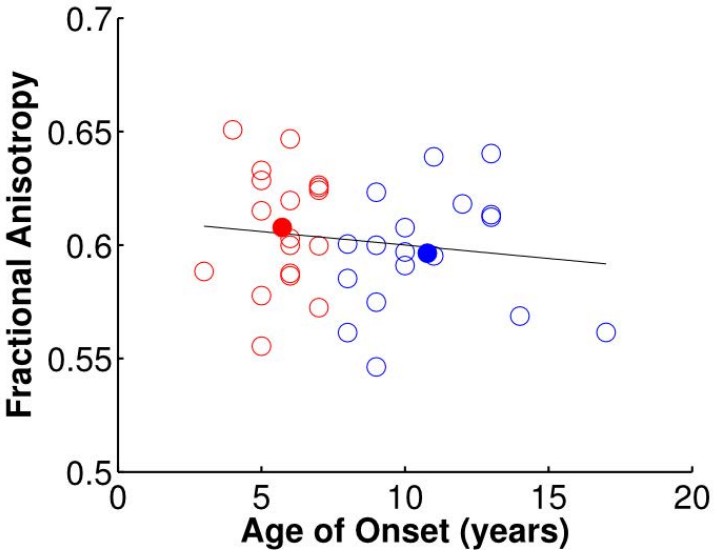
Age of Onset



Motor Synchronisation Performance







Recap

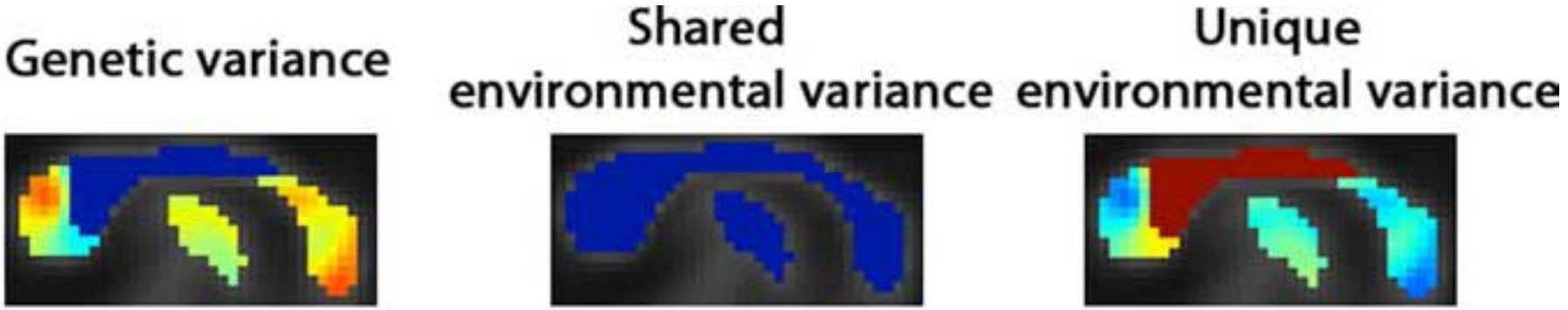
- Robust behavioural differences
  - Replicated previous findings (Watanabe et al., 2007)
- ET > LT posterior midbody/isthmus (FA)
  - Even after matching years of training and experience
  - Extracted FA related to age of onset, even after controlling for age, sex, and years of formal training
  - ET > LT in mean tract connecting sensorimotor cortices (10% threshold)
- Across ET & LT, midbody of CC related to age of onset
  - Earlier training leads to greater FA
- Across all groups, synchronisation performance related to FA in TL, posterior limb of int/ext capsules

Take-away

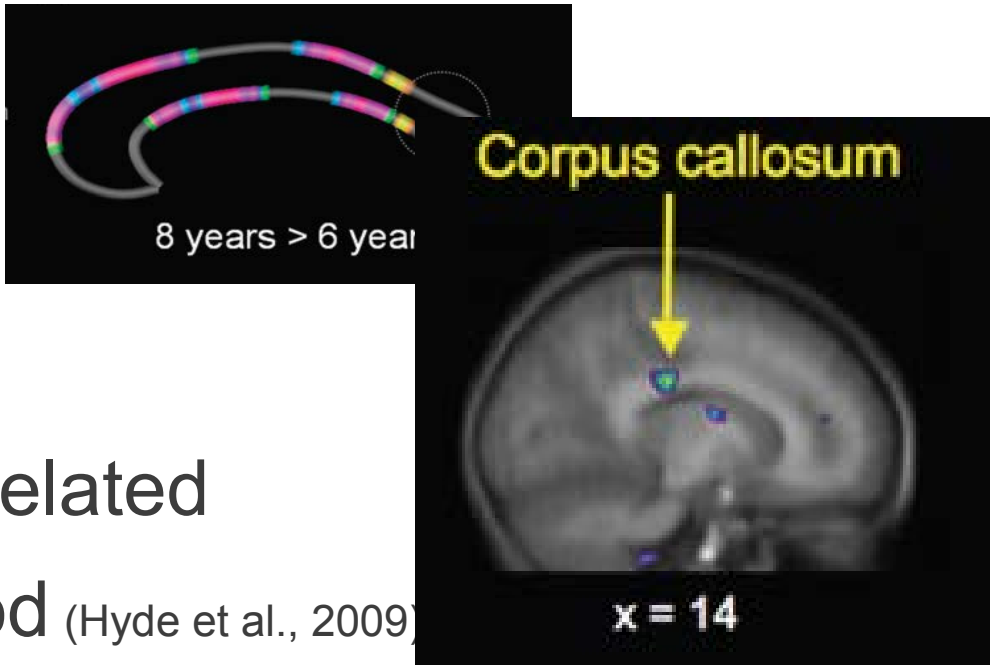
- Musicians as an expert group
- Evidence for a sensitive period
  - Earlier training provides a specific advantage for visuomotor synchronisation
  - CC posterior midbody sensitive to the effects of musical training during early development
    - Connects sensorimotor cortices
  - Age of onset correlated with FA in CC
    - It appears to be primarily about callosal connectivity
    - Premotor, motor, somatosensory
  - Extracted FA values correlate with age of onset

Were they just born that way?

- Training can still play a role (Chiang et al., 2009)

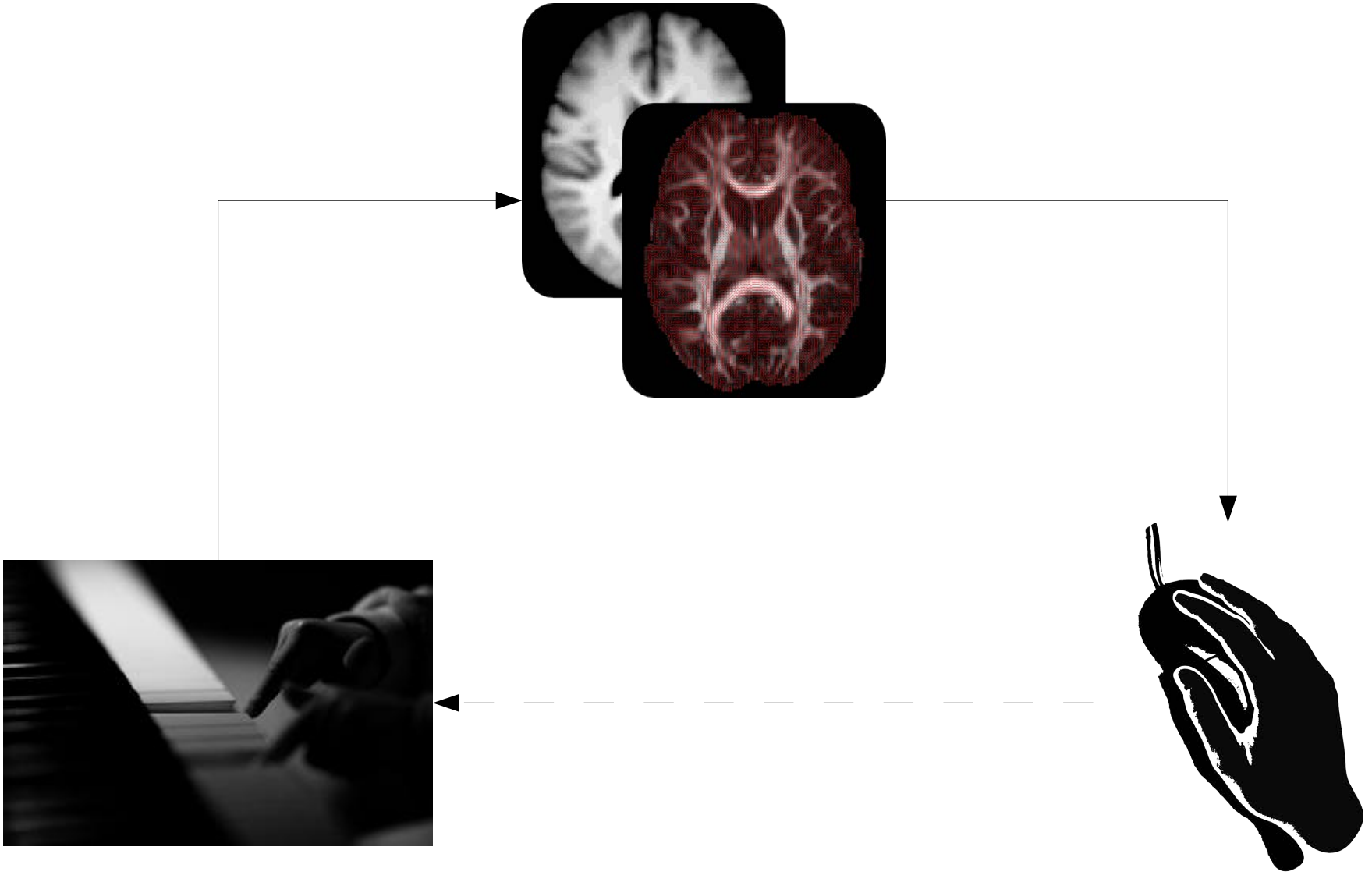


- Normative developmental changes (Westerhausen et al., 2011)



- CC shows music training-related
- increases in early childhood (Hyde et al., 2009)

Brain Structure, Motor Performance, and Training

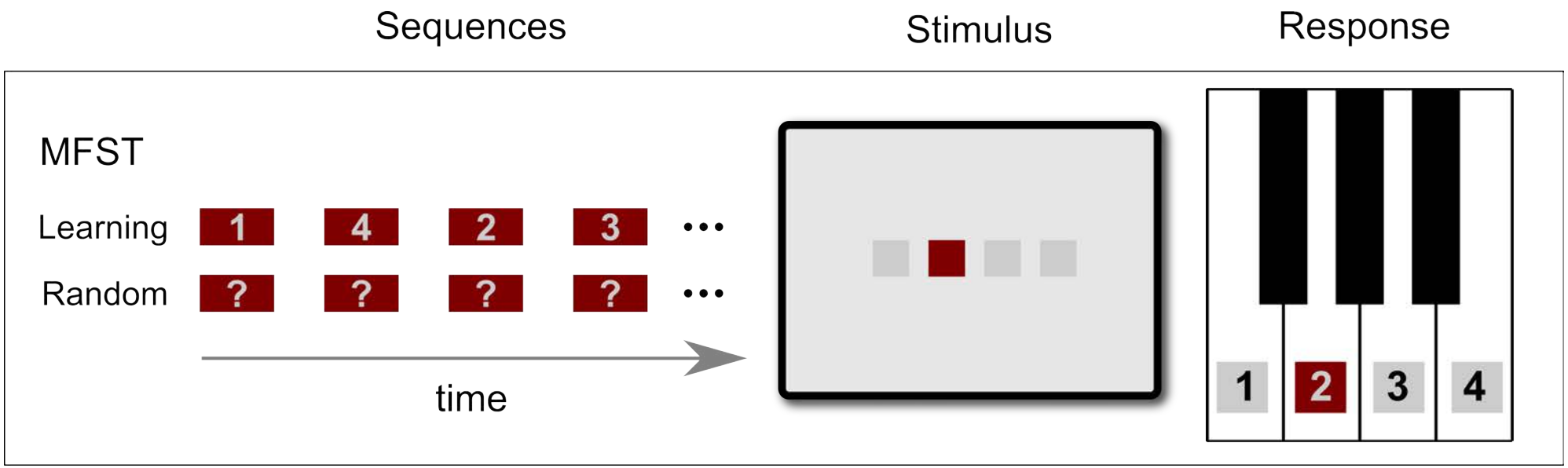


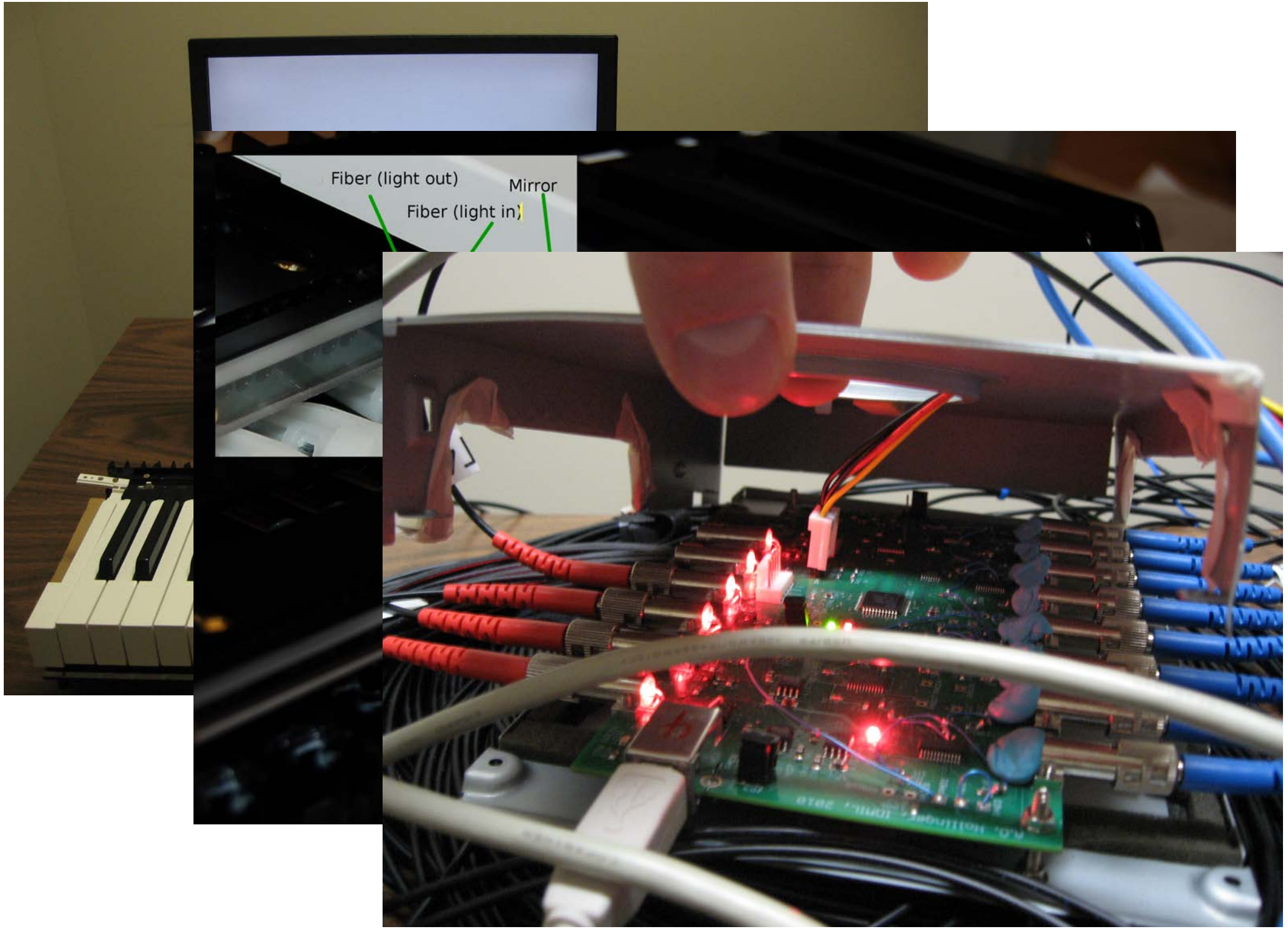
Future Projects

- MTR and T1 data with this same sample
- Long-term musical training in children

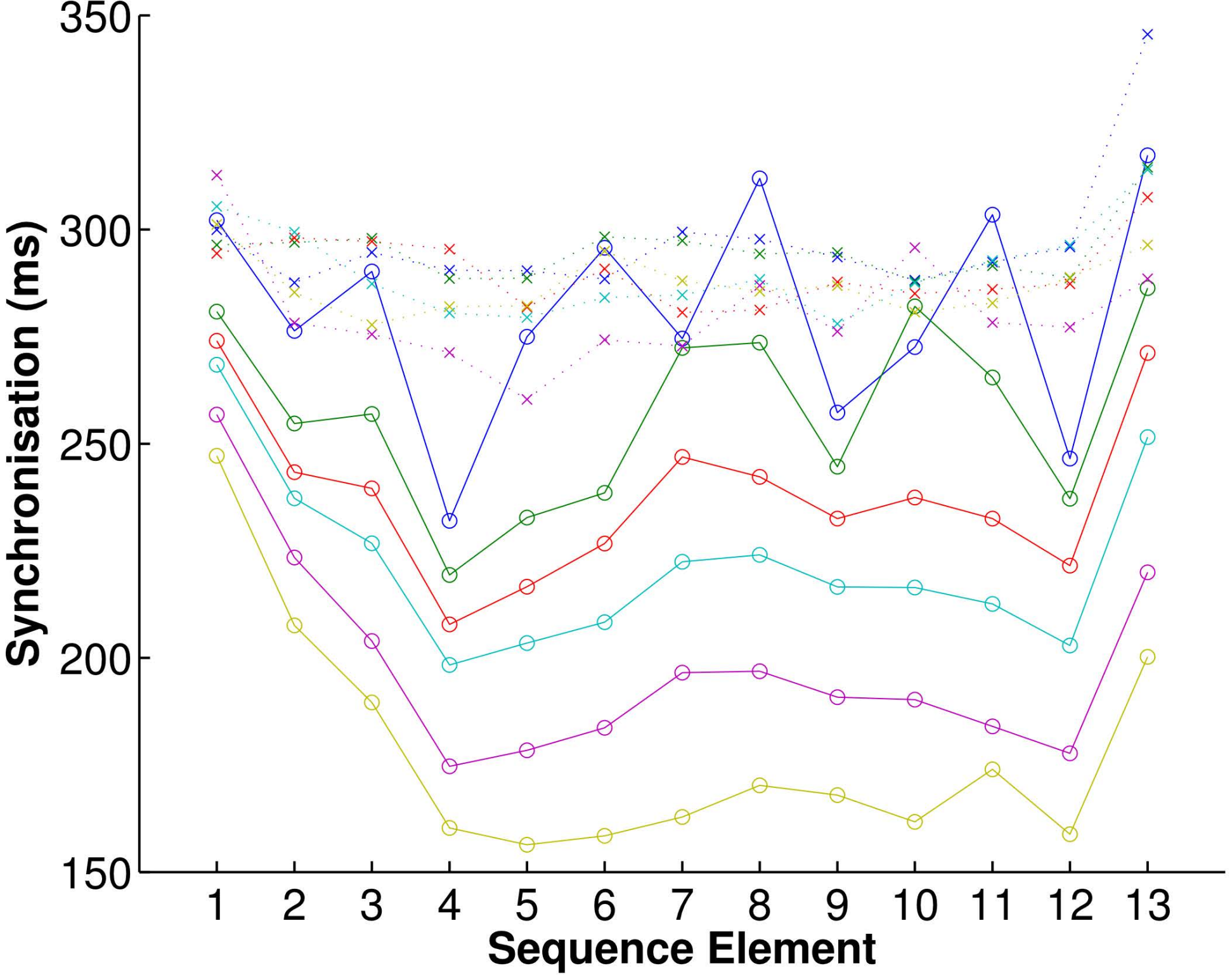
Future Projects

- Brain structure and function, motor performance, training
  - 2 weeks of motor sequence training
  - Pre/post imaging sessions
    - T1, DTI, MTR, fMRI





Hollinger, Steele, Penhune, Zatorre, Wanderley (in prep)


350
300
250
200
150
Synchronisation (ms)
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2
3
4
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8
9
10
11
12
13
Sequence Element

Acknowledgements

- Concordia University, Montreal
  - Virginia Penhune
  - Anne Bailey
- McGill University, Montreal
  - Robert Zatorre
  - Avrum Hollinger
- FMRIB, Oxford UK
  - Heidi Johansen-Berg
  - Jan Scholz
  - Gwen Douaud

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Magritte