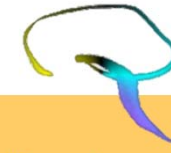


Computational and Applied
Neuroscience Lab

認知神經科學研究所



Institute of Cognitive Neuroscience, National central University, Taiwan

認知歷程中大腦所展現的複雜性與和諧

Wei-Kuang Liang (梁偉光)

Institute of Cognitive Neuroscience, National Central University

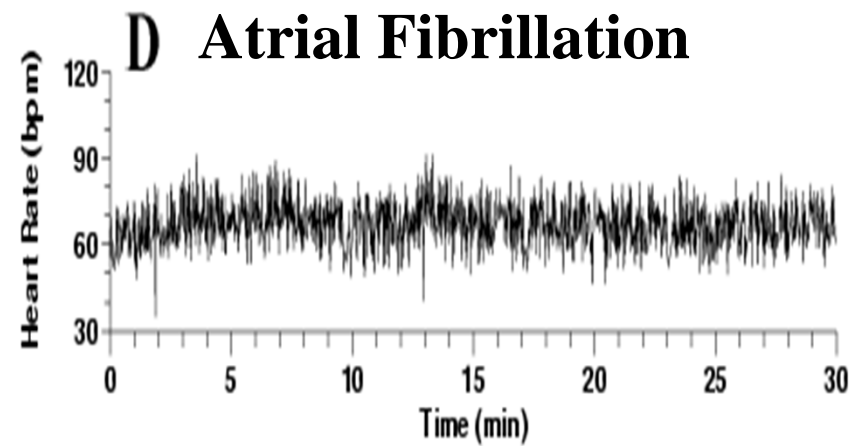
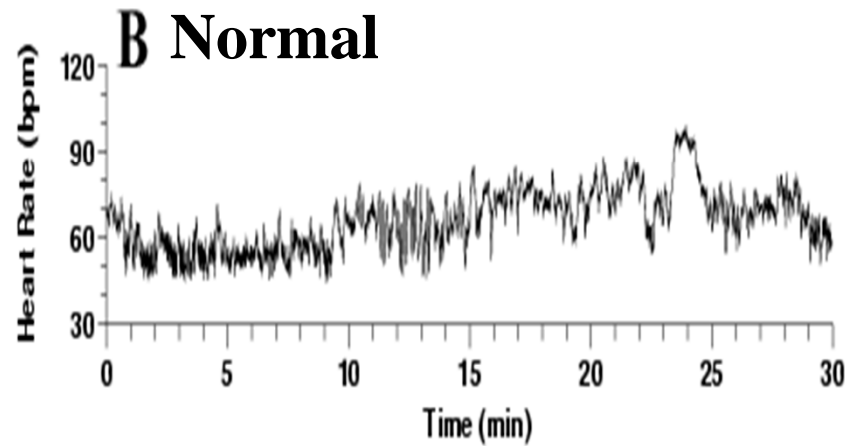
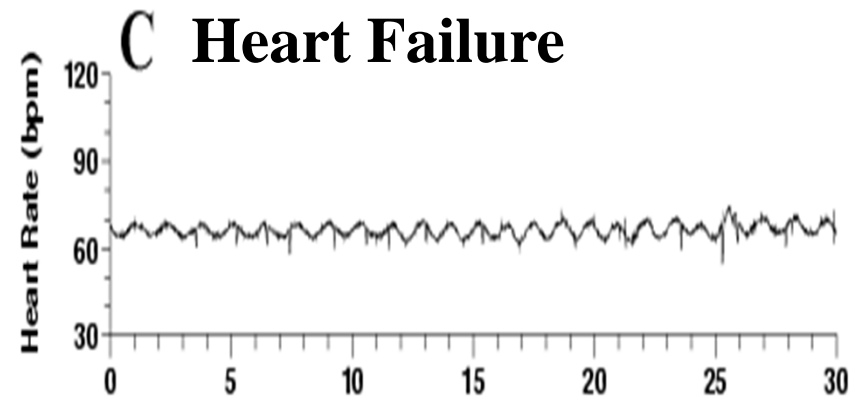
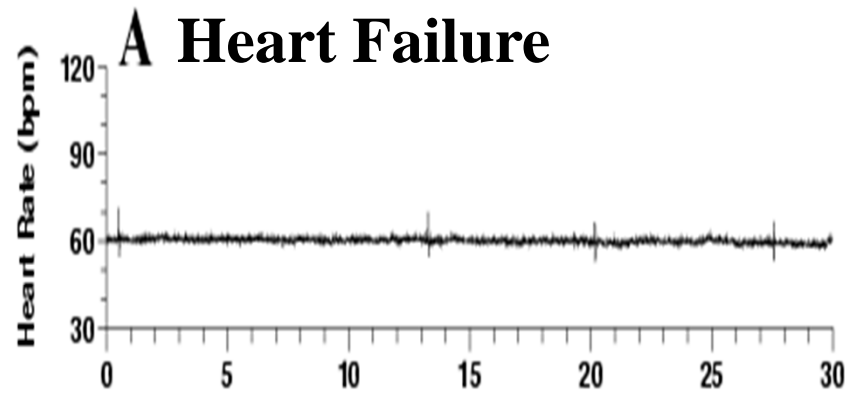
Multiscale Entropy (MSE)

Quantify the complexity or the degree of variability for biological signals

Costa, Goldberger, Peng: Phys Rev Lett 2002, 2003, 2004; Phys Rev E 2005

- Originally developed for the analysis of heartbeat signals
- Measure the health status of heart

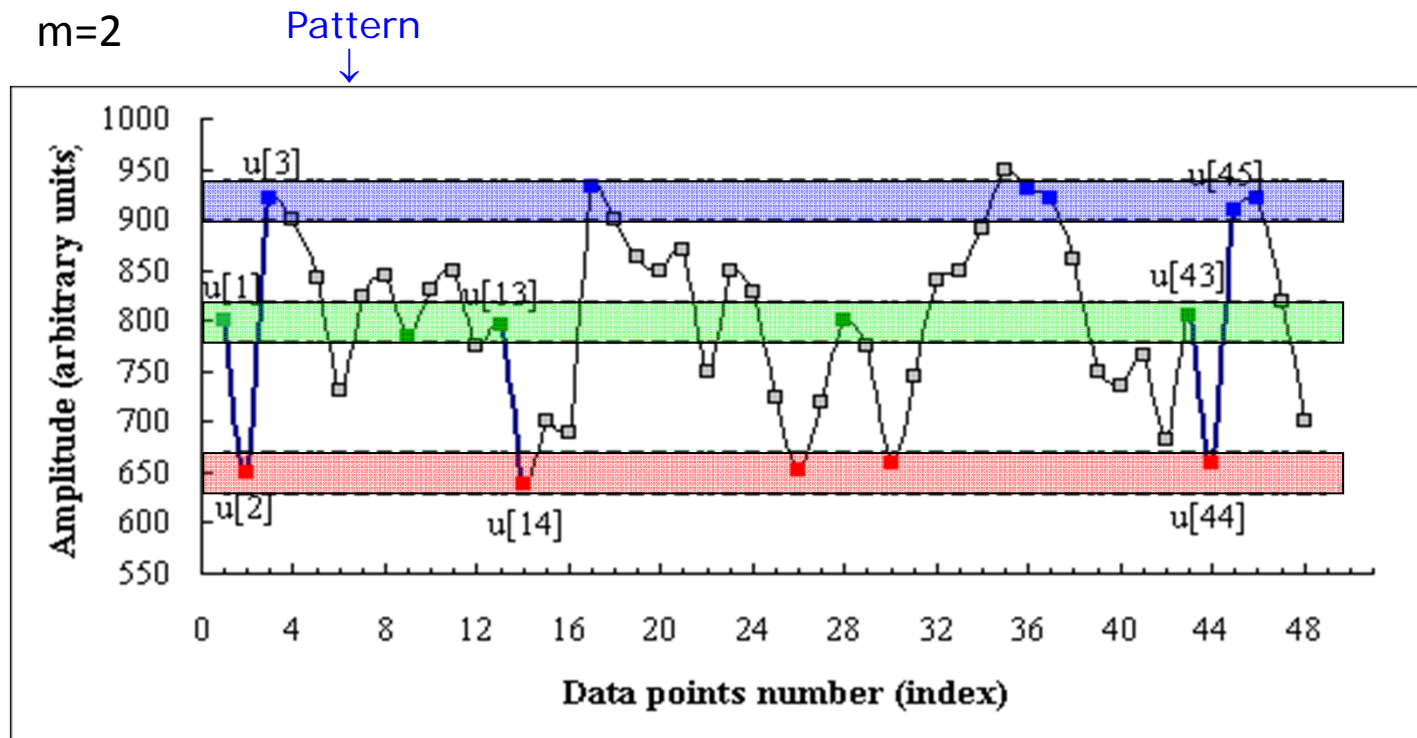
Which One is Healthy?



- Loss of variability is bad.
- Not all kinds of variability are good.
- For a biological system, what we want is a measure that can optimize at its healthy condition.

Sample Entropy

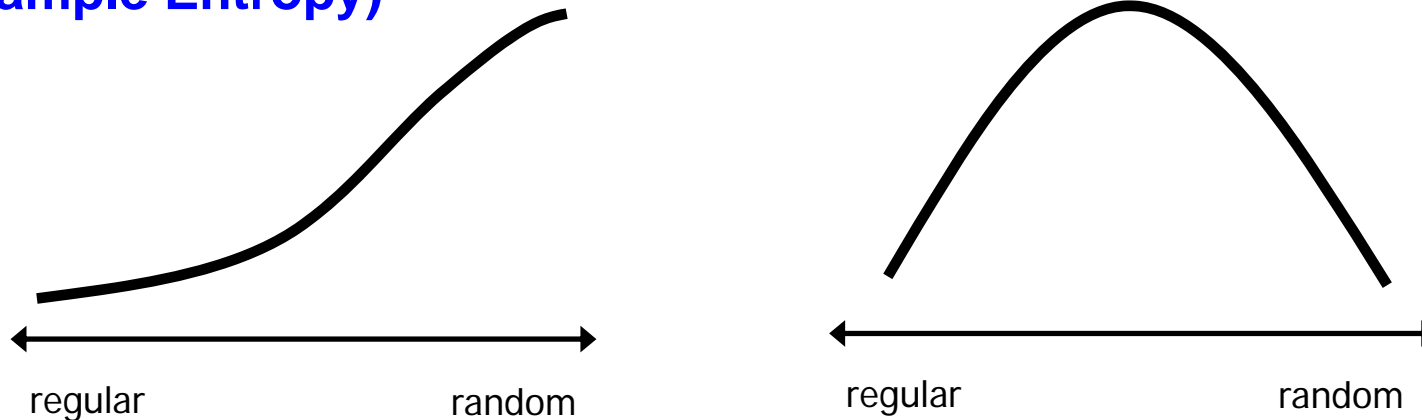
Conditional probability that subseries of length m that match pointwise within a tolerance r also match at the next point





Use Entropy as a Complexity Measure

Conventional Entropy Measure (Sample Entropy) Expected Complexity Measure

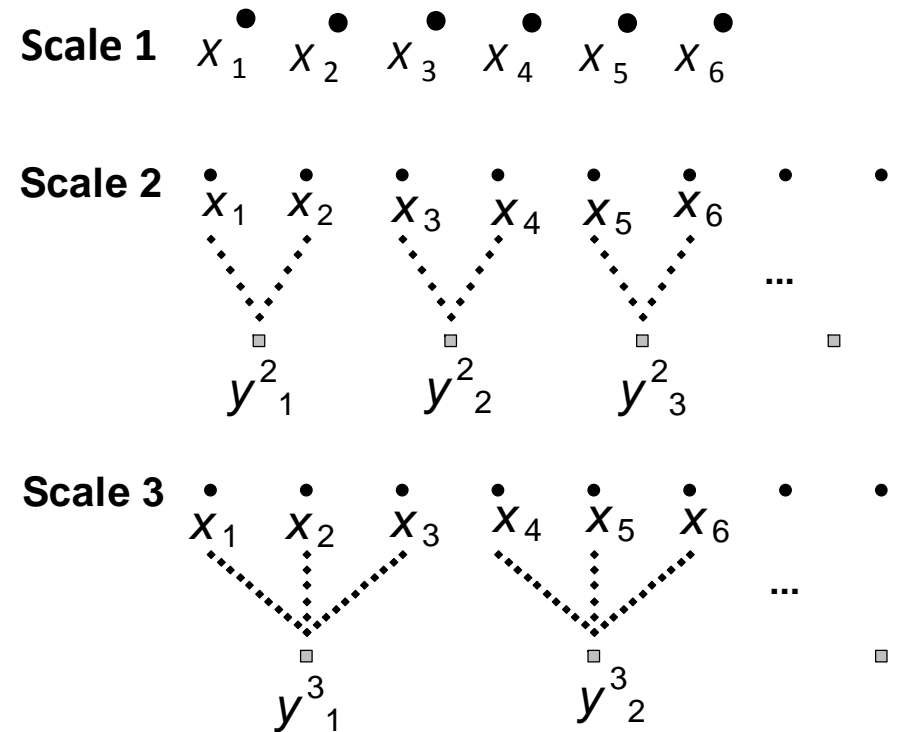


Multiscale Entropy (MSE) is a quantitative measure to estimate the complexity of a system through examining the information richness of its output signal on **multiple time scales**.

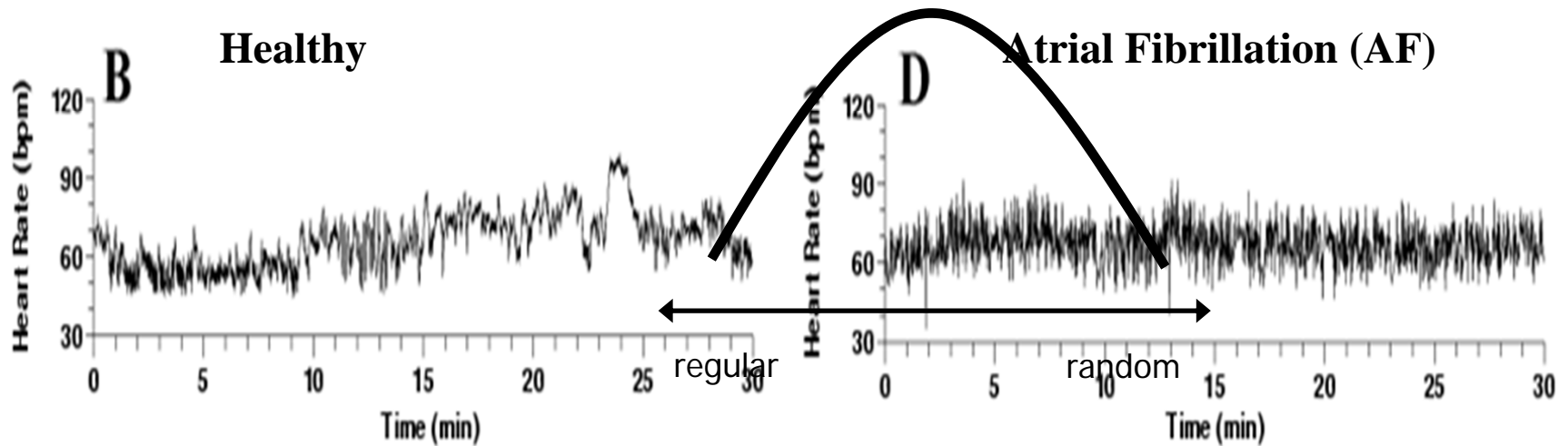
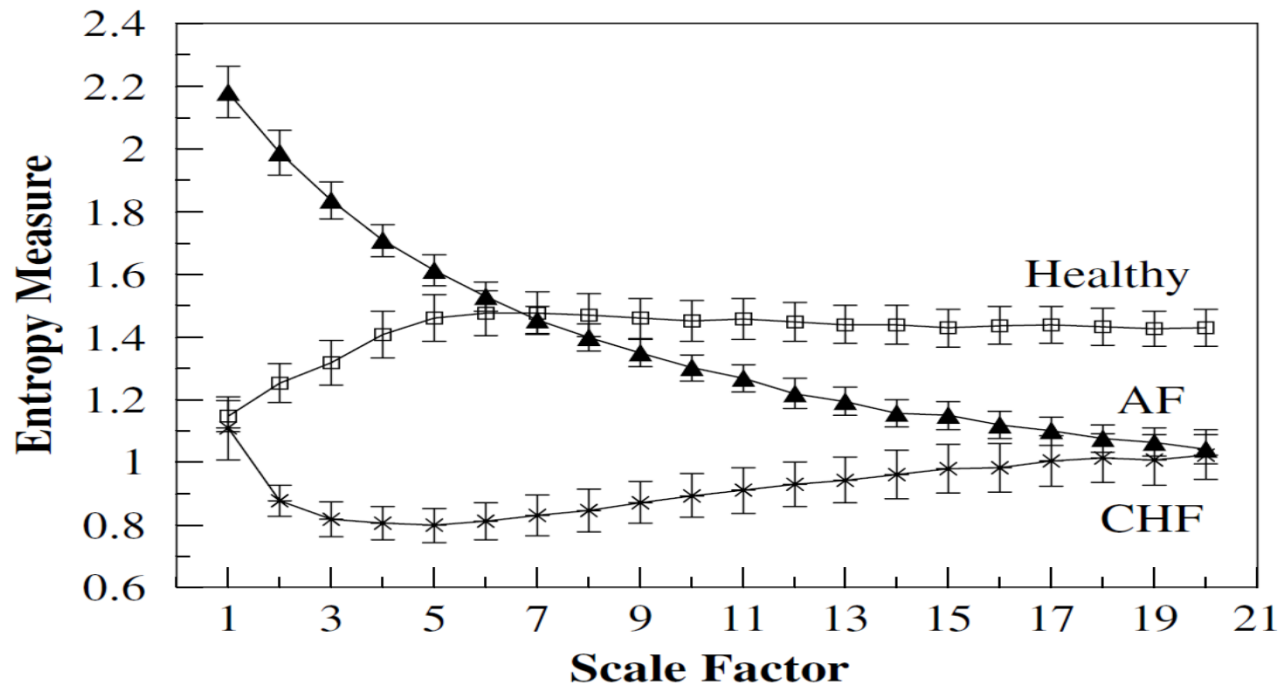
Costa, Goldberger, Peng: Phys Rev Lett 2002;89:068102 ; Phys Rev Lett 2003;91:119802 ; Phys Rev Lett 2004;92:089804 ; Phys Rev E 2005; 71:021906

Multiscale Entropy (MSE)

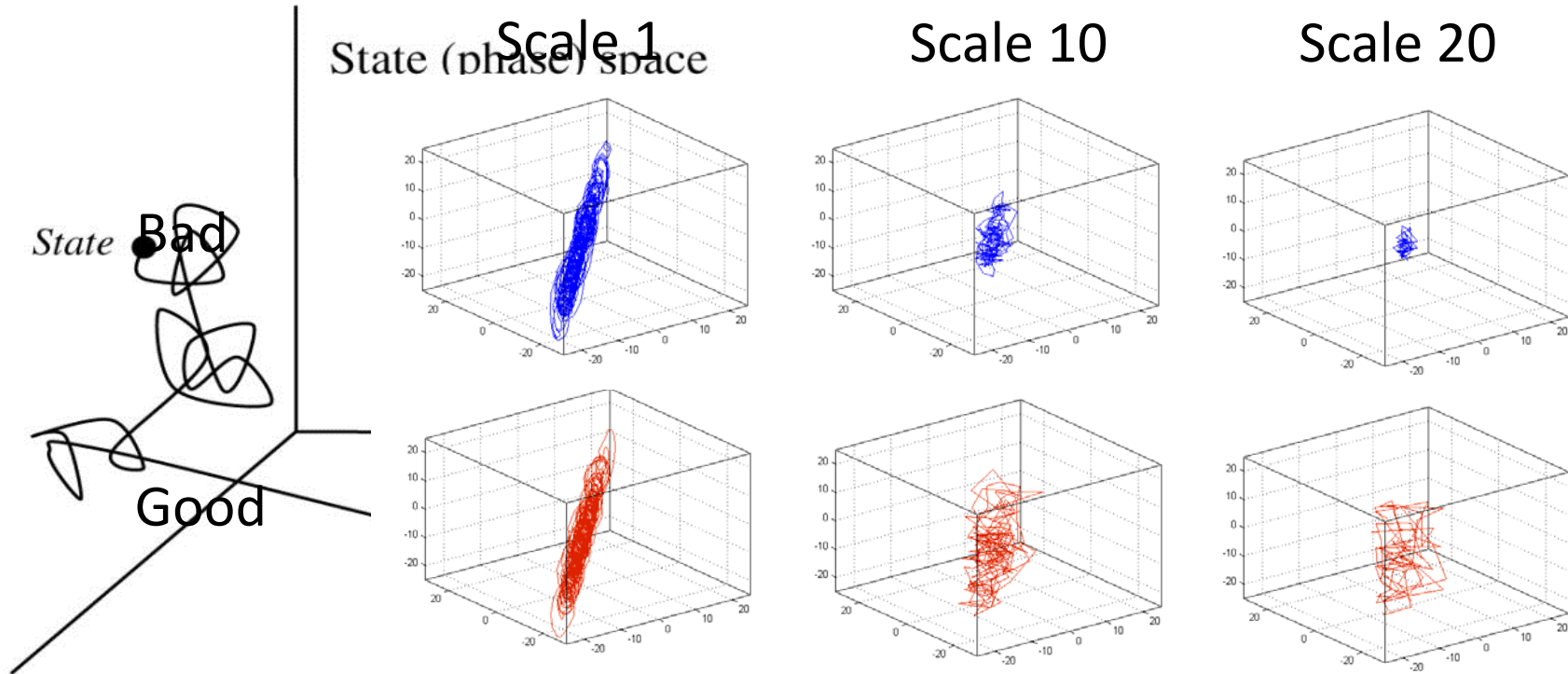
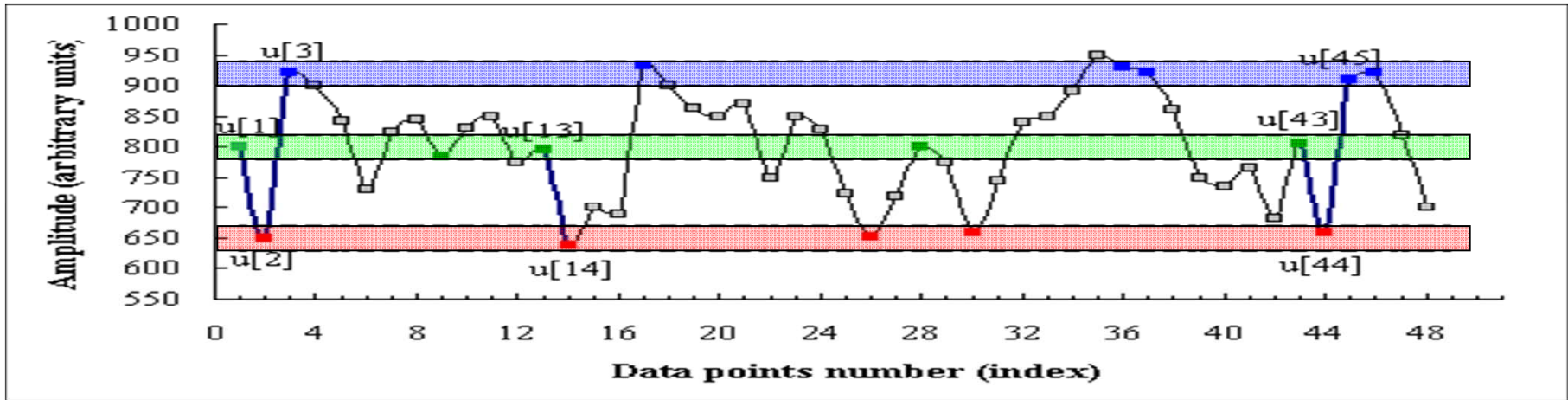
- **Coarse-grain** the time series in various scales
- Calculate **Sample Entropy** for each coarse-grained series
- Plot it as a function of **scale factor**
- Analyze the MSE curve profiles



MSE Analysis of Heart Rate in Healthy vs. Heart Failure vs. Atrial Fibrillation



Interim conclusions



We employ MSE to measure the brain's complexity and the **tDCS** facilitating effect during **inhibitory control** !

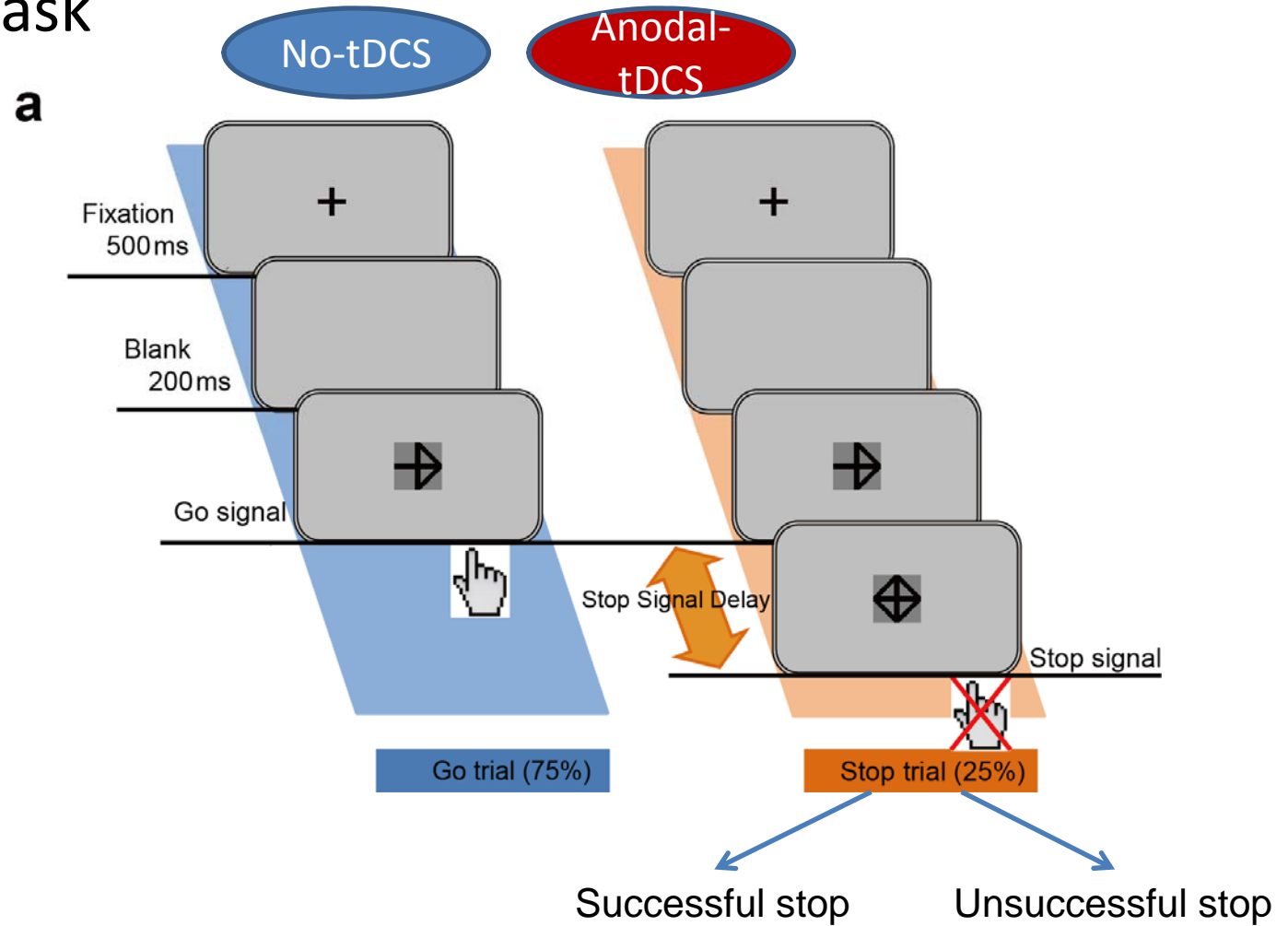
Liang et al., 2014. *NeuroImage*

Inhibitory control is important in our daily life



Inhibitory control

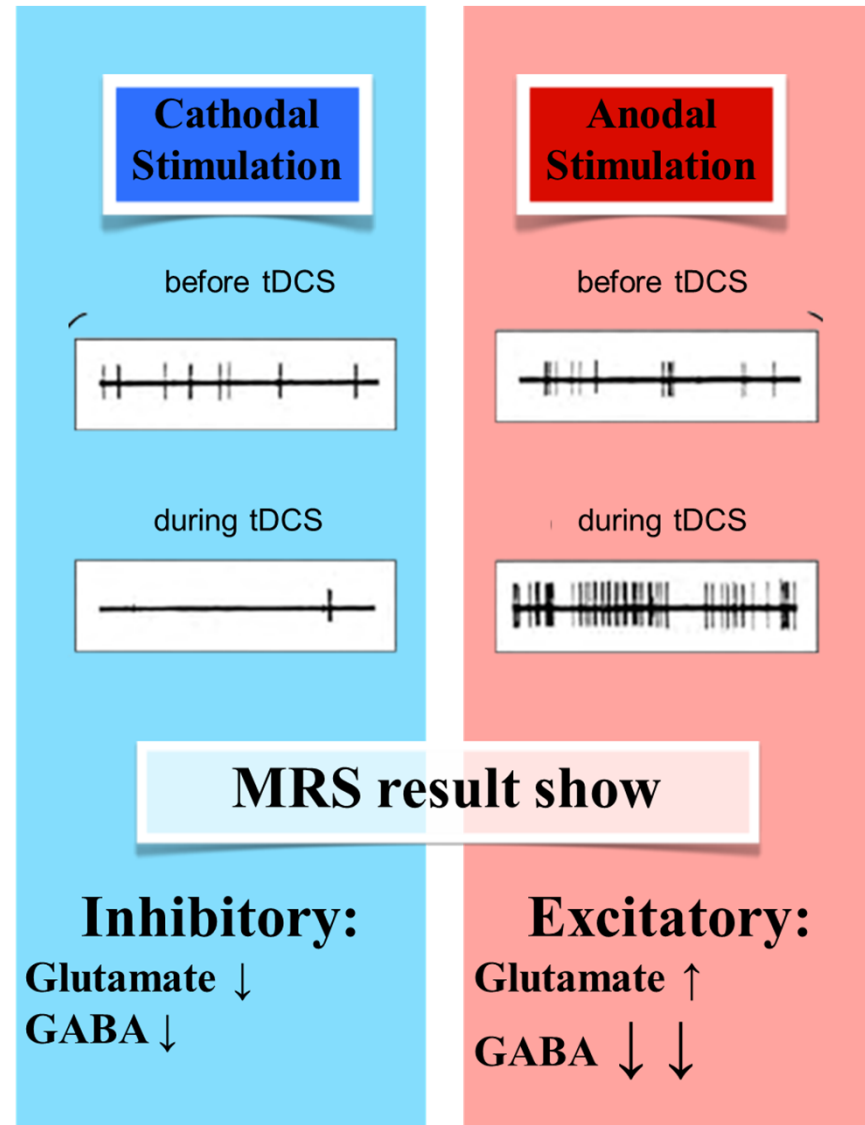
Stop-signal task



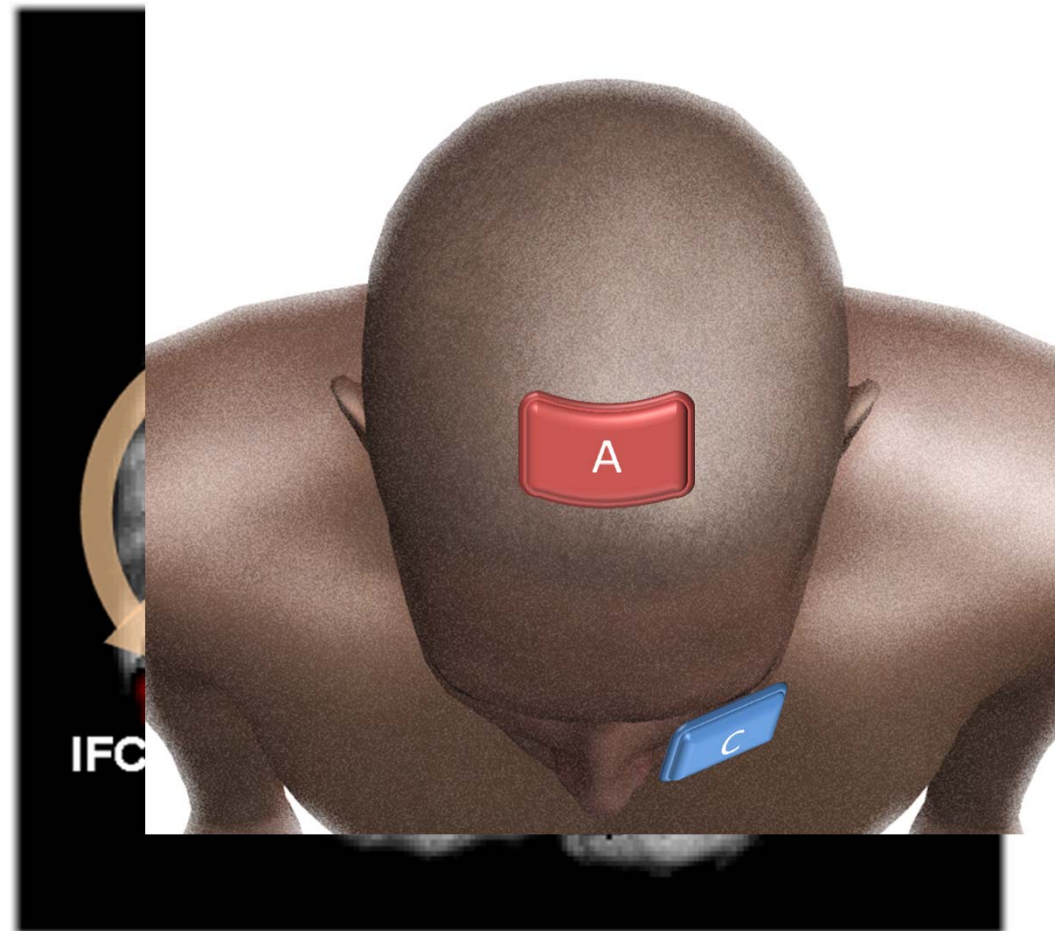
tDCS



- Transcranial Direct Current Stimulation
 - Non-invasive
 - Anodal (positive) increases activity
 - Cathodal (negative) decreases activity



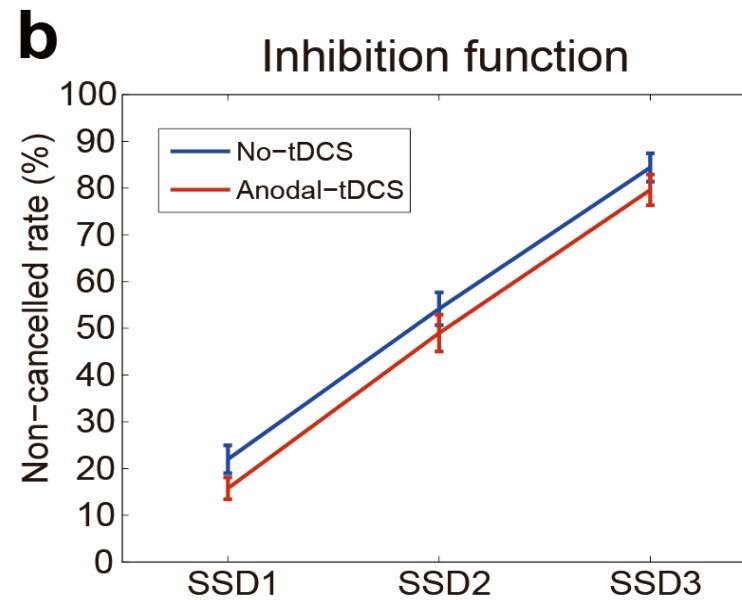
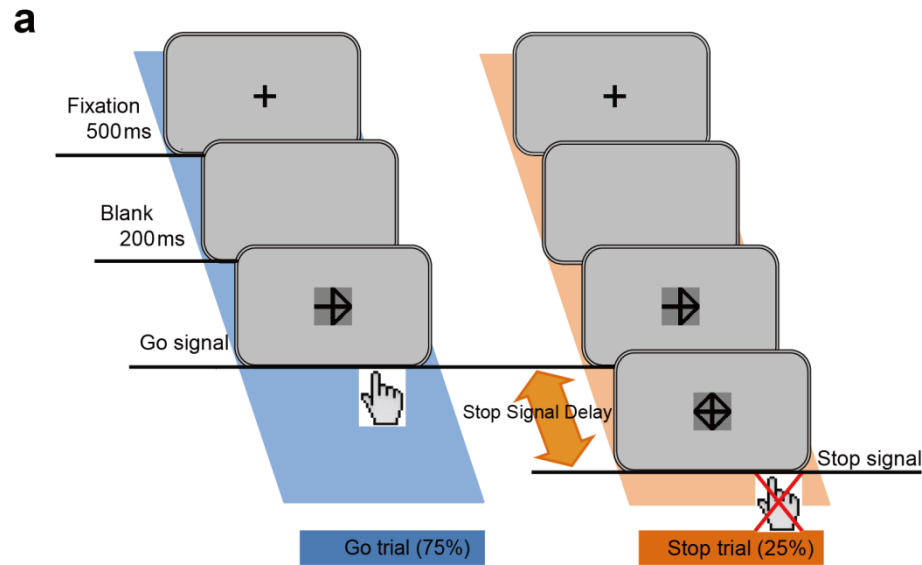
Brain network of inhibitory control



Hsu et al., 2011

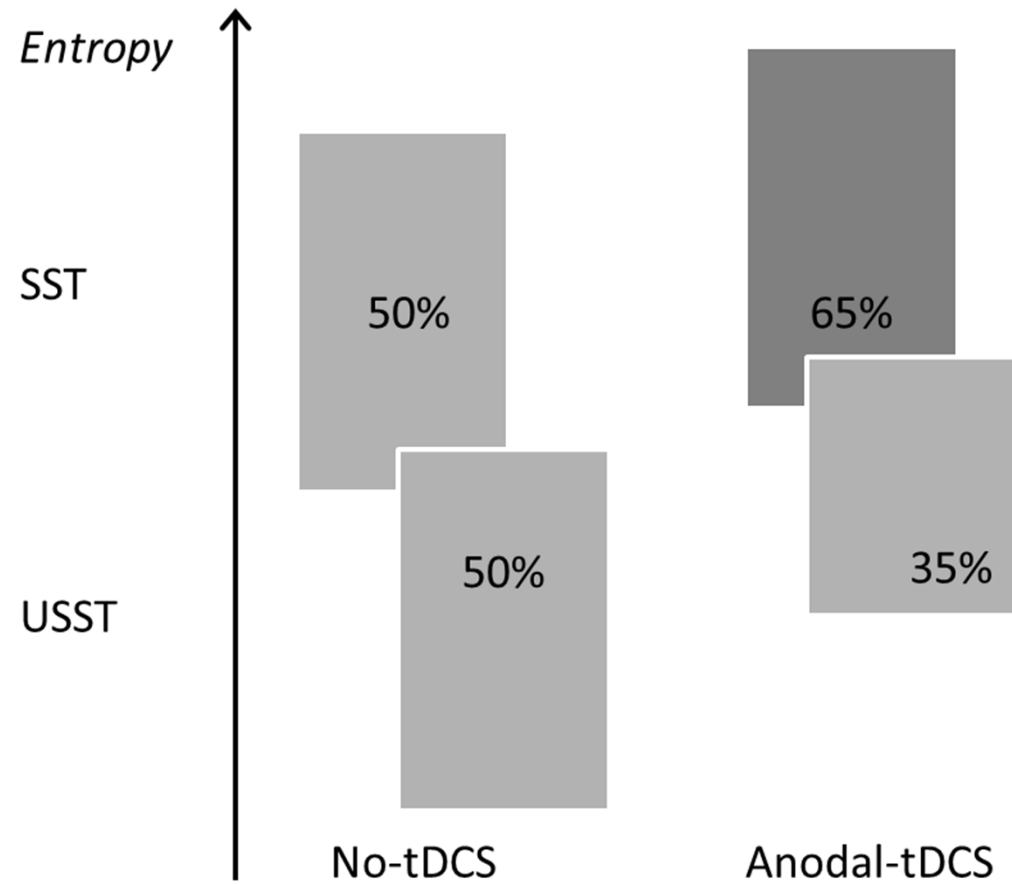
Courtesy of Duann et al., 2009

Stop-signal task and behavior result



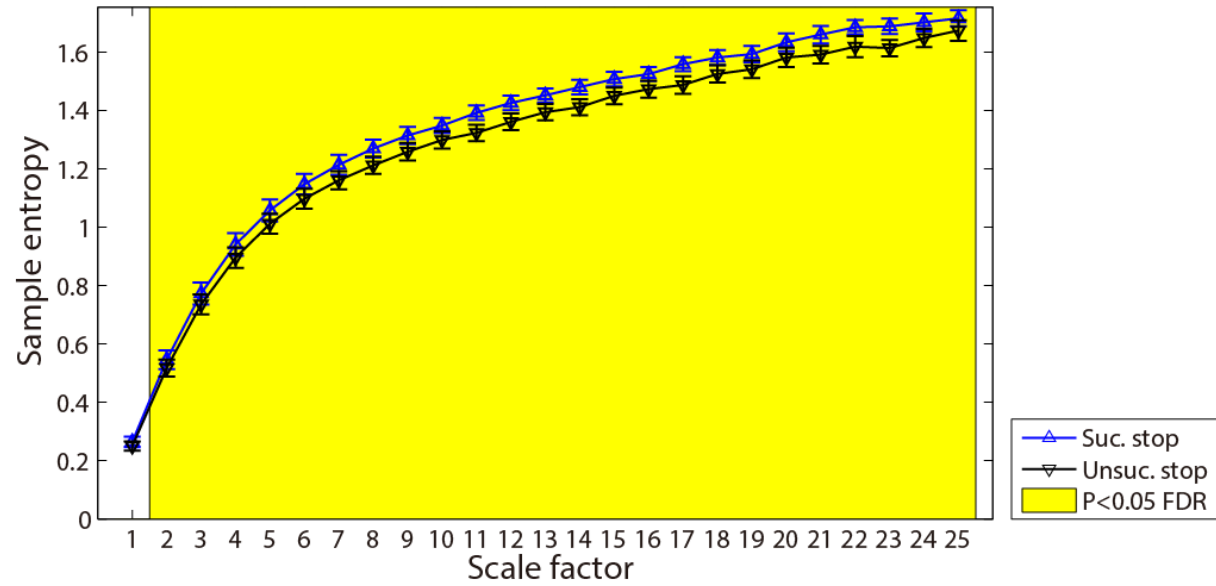
How about MSE during inhibitory control?

Hypotheses before see the results

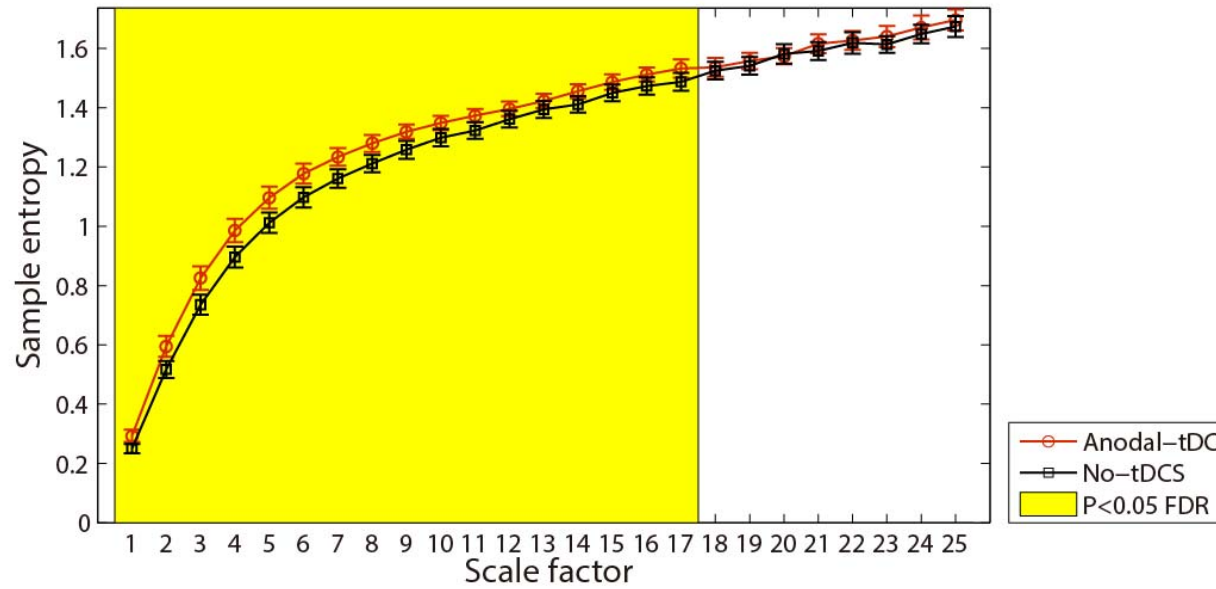


FCz

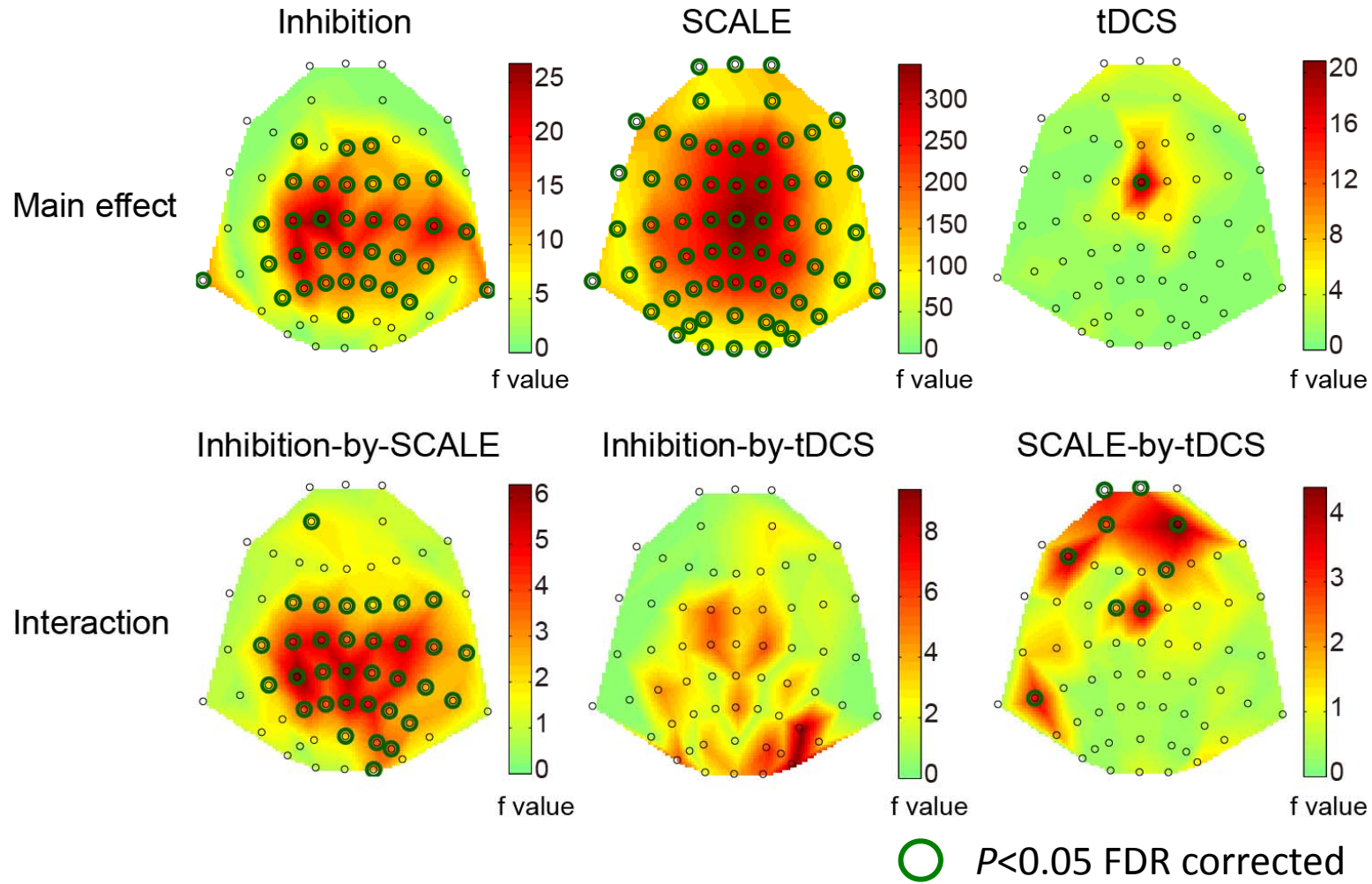
Higher MSE for Successful vs. unsuccessful stop



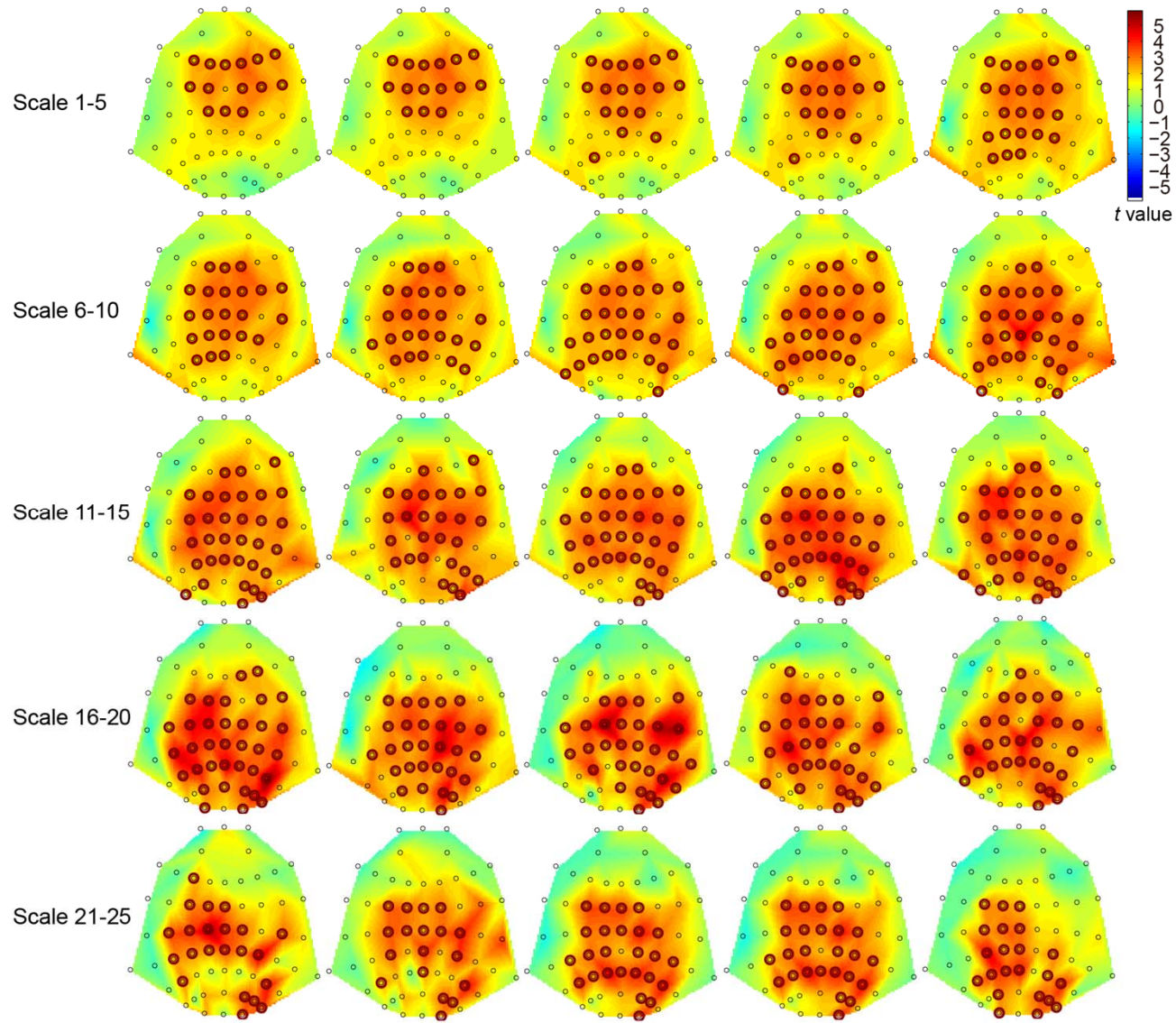
Higher MSE for Anodal-tDCS vs. No-tDCS



ANOVA of MSE: “Inhibition” (successful- vs. unsuccessful-stop) × “SCALE” (25 scales) × “tDCS” (No-tDCS vs. Anodal-tDCS)

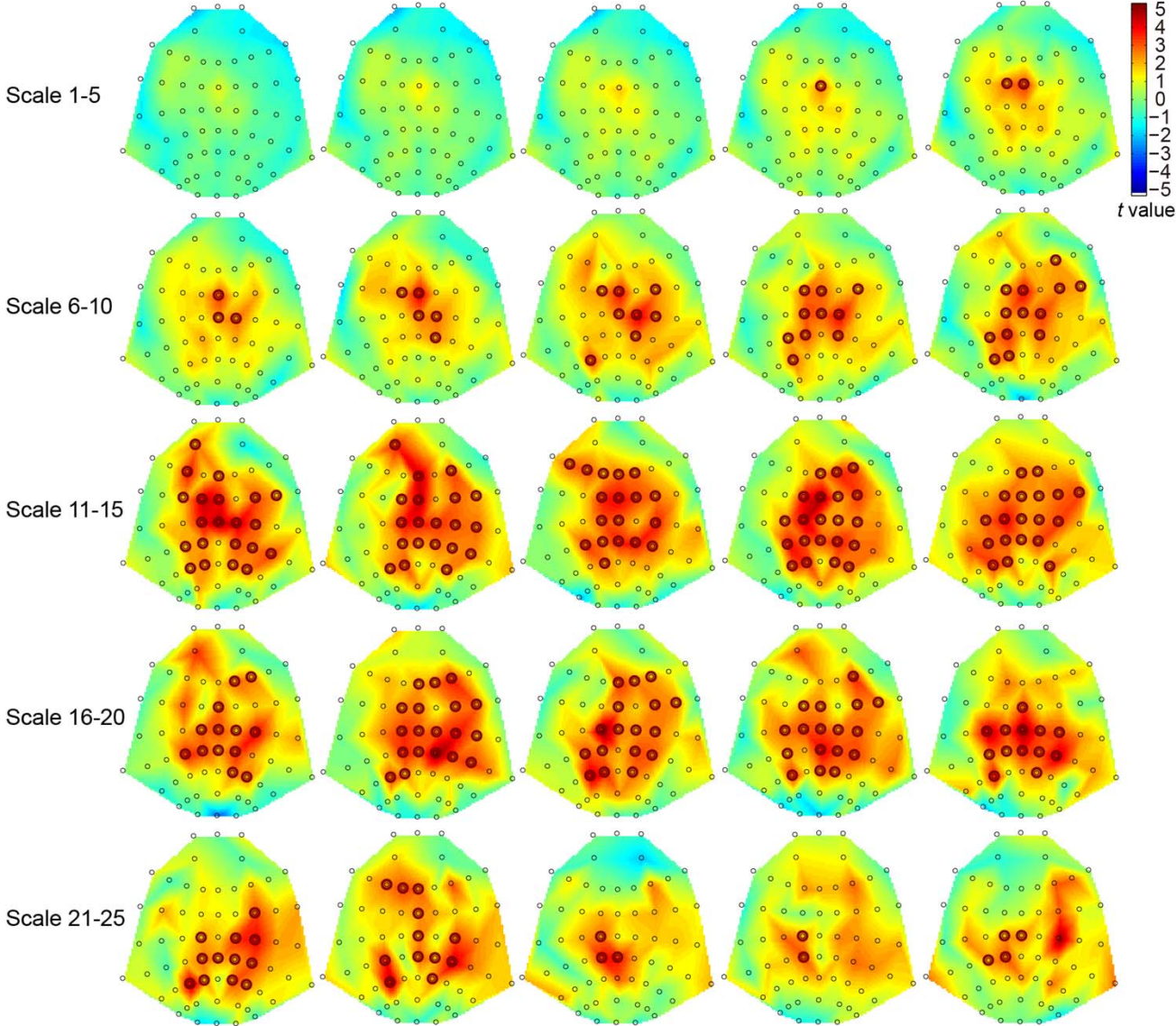


Higher MSE for Successful vs. Unsuccessful stop (No-tDCS)



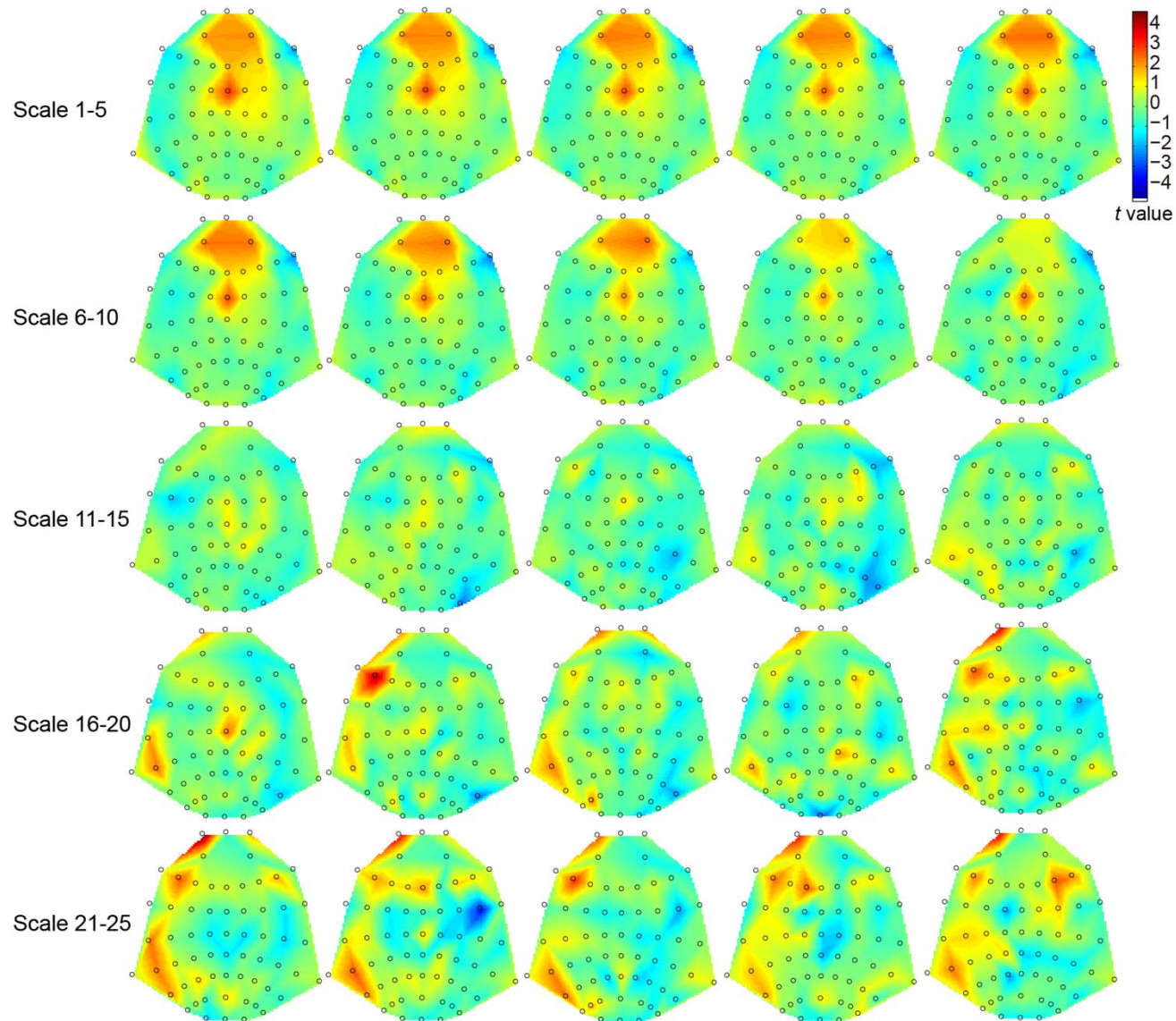
○ $P < 0.05$ under a cluster-based permutation test

Higher MSE for Successful vs. Unsuccessful stop (Anodal-tDCS)



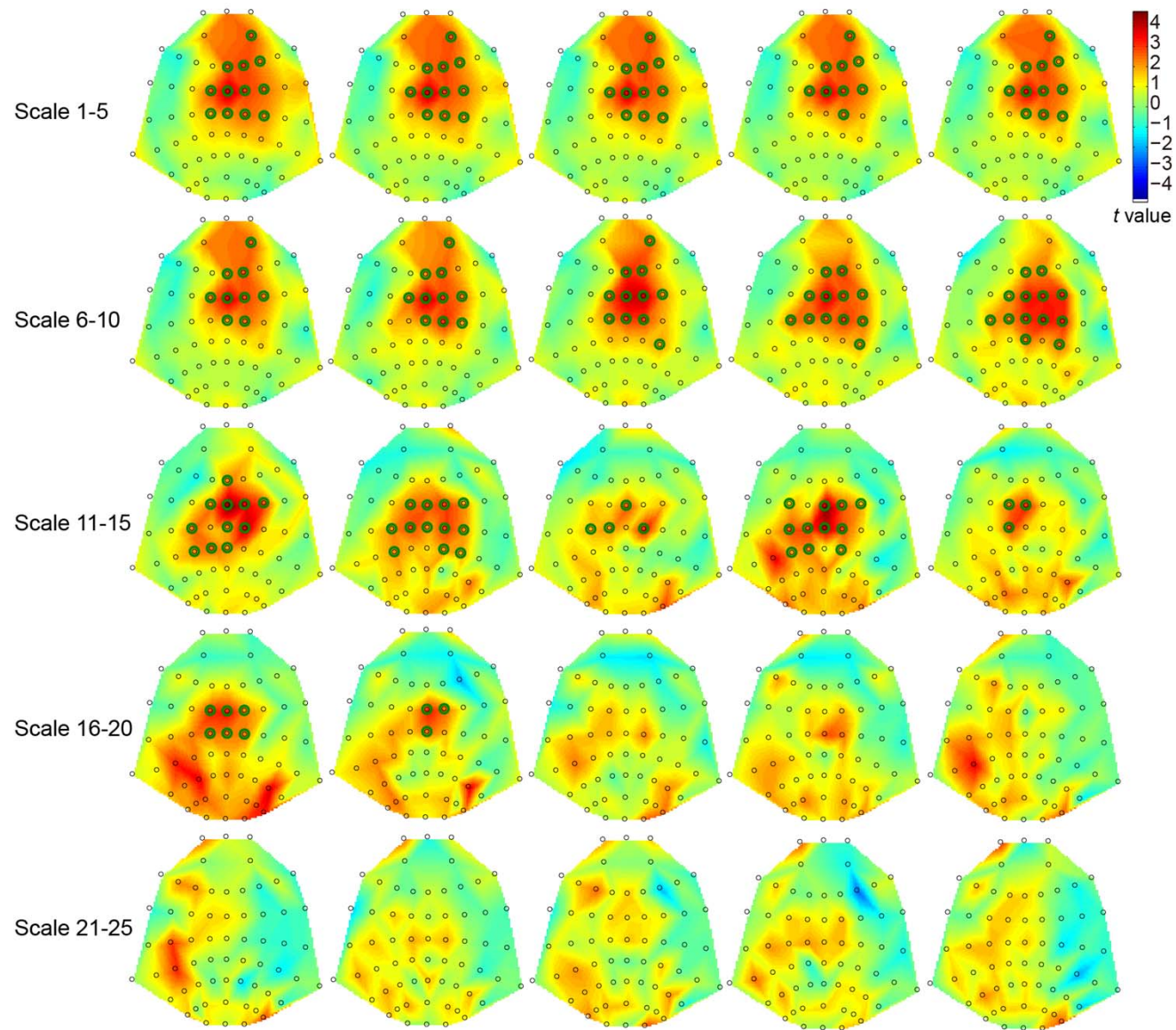
○ $P < 0.05$ under a cluster-based permutation test

MSE for Anodal-tDCS vs. No-tDCS (Successful-stop)



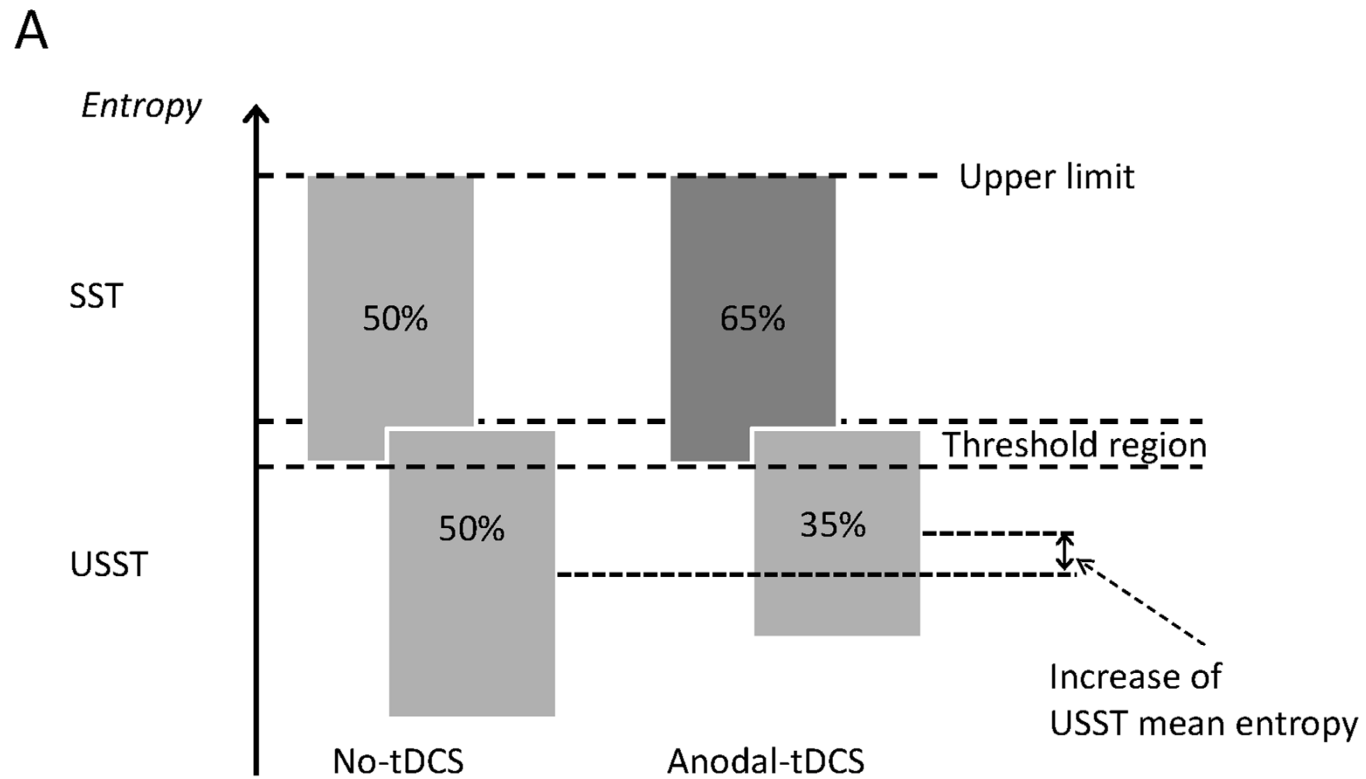
○ $P < 0.05$ under a cluster-based permutation test

Higher MSE for Anodal-tDCS vs. No-tDCS (Unsuccessful-stop)



○ $P < 0.05$ under a cluster-based permutation test

Scheme for the MSE results



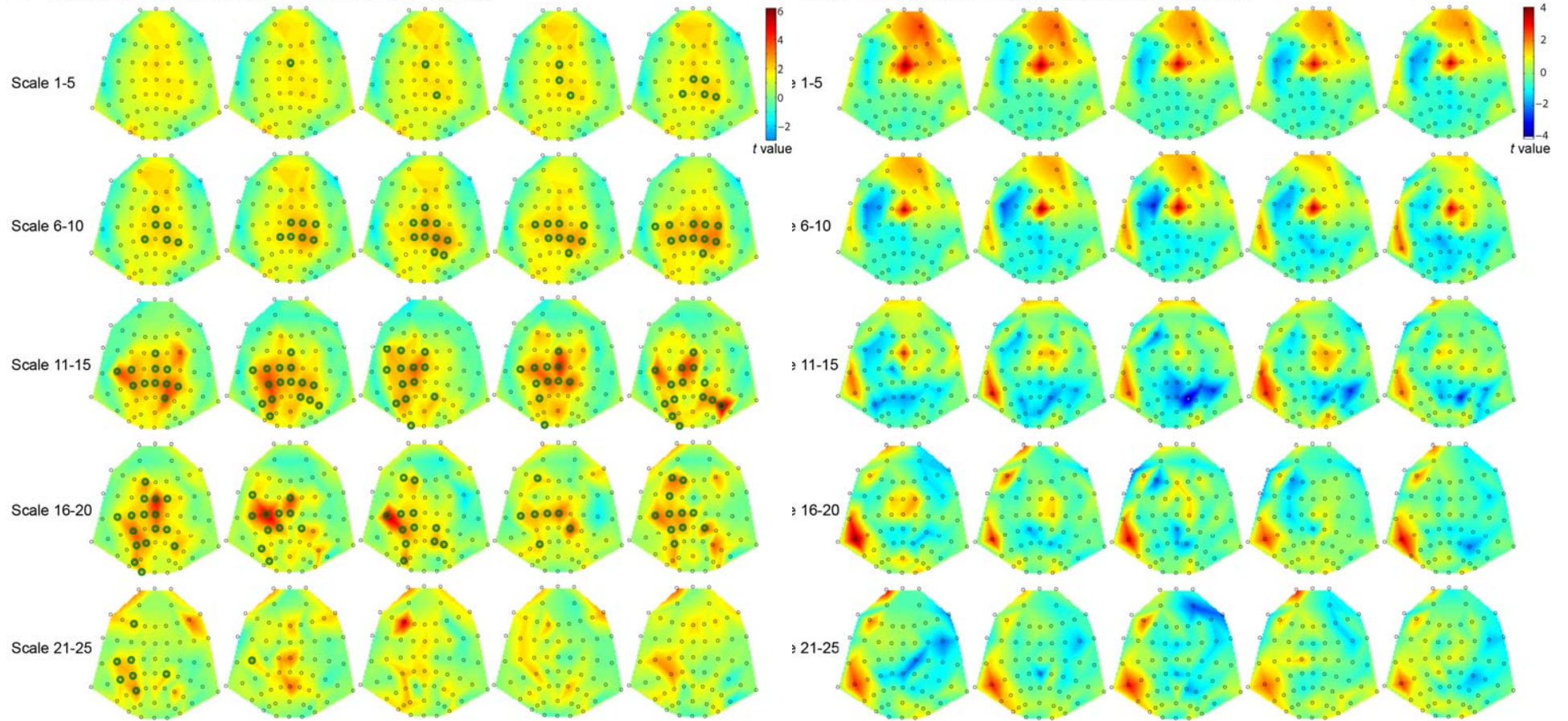
Anodal-tDCS vs. No-tDCS within Low/High performers

Within low performers

Within high performers

E Anodal-tDCS vs. No-tDCS (within Low-performing group)

Anodal-tDCS vs. No-tDCS (within High-performing group)



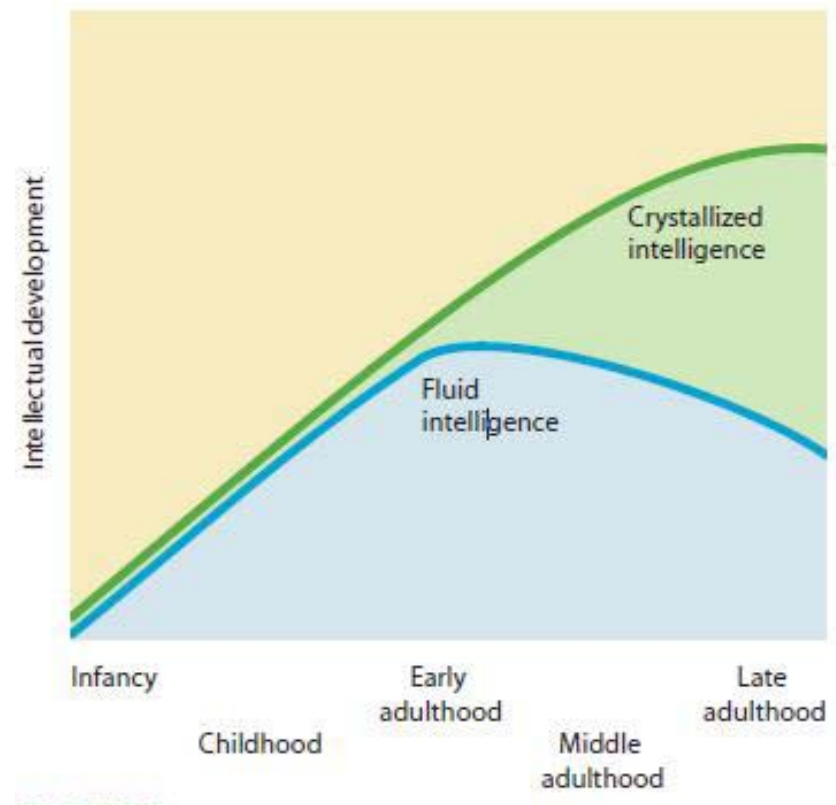
Conclusions

- In stop-signal task, MSE is higher for successful vs. unsuccessful stop trials.
- Anodal tDCS over pre-SMA can efficiently improve the performance of inhibitory control.
- From the perspective of MSE, Anodal tDCS can improve brain's adaptability to a fast environmental change.
- The anodal tDCS effect on MSE can provide a theoretical basis for clinical intervention via tDCS.
- MSE of EEG can be related to behavioral performance, because MSE reflects the adaptability of the brain in each trial.

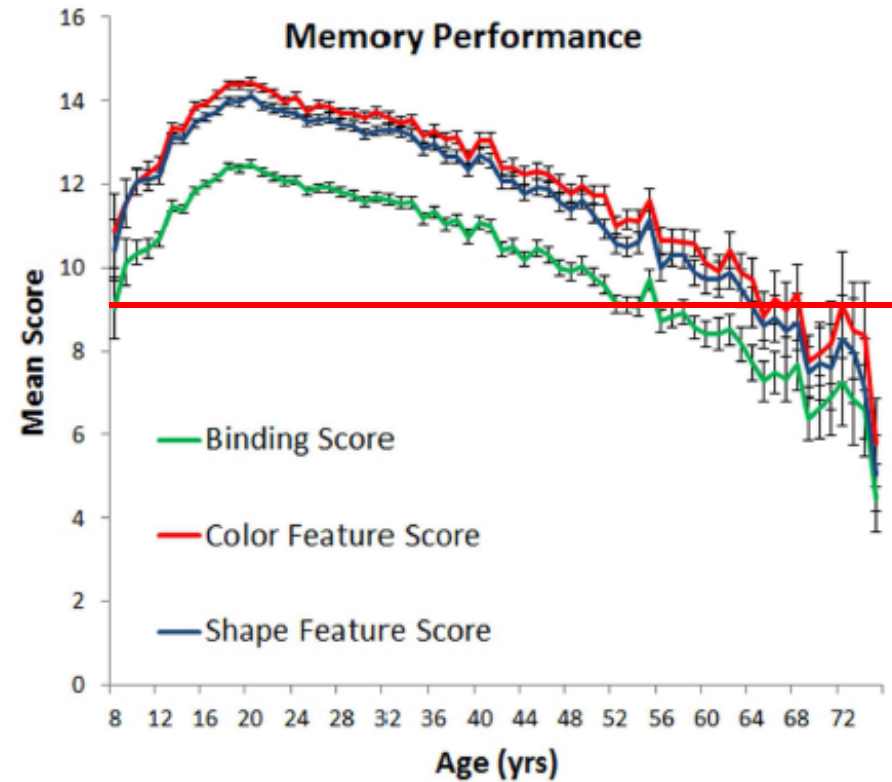
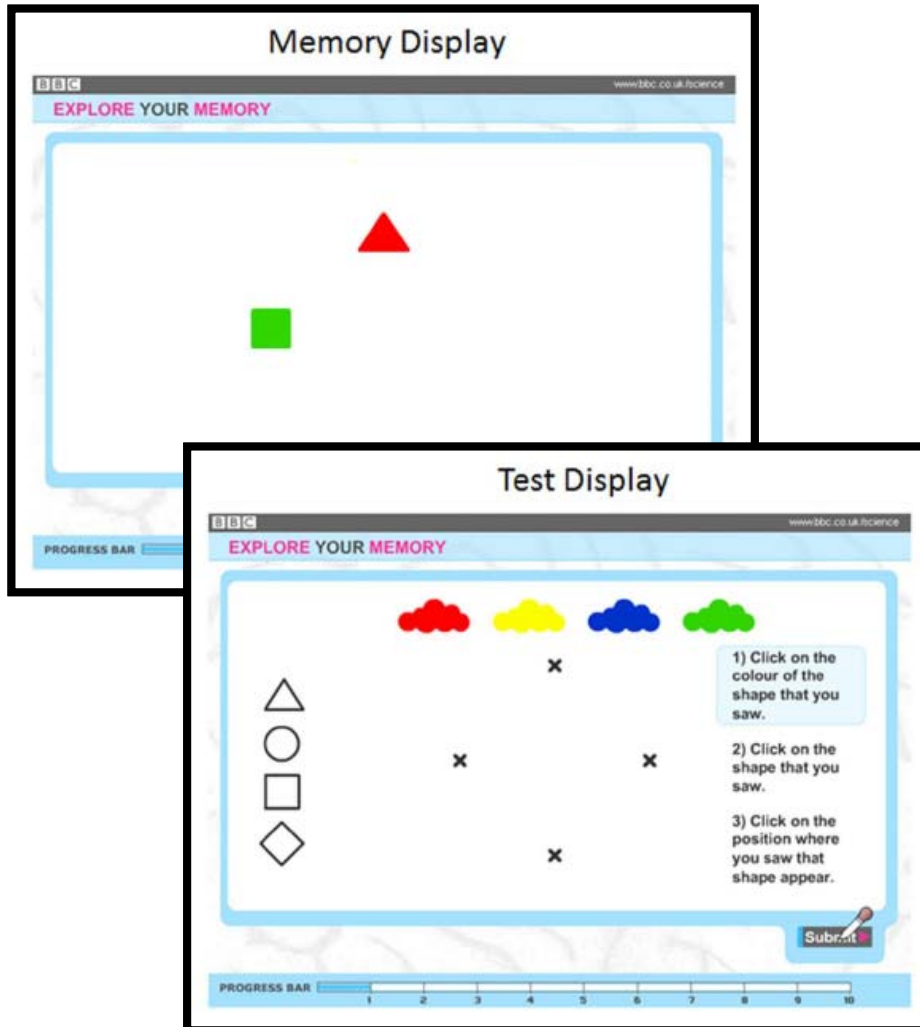
MSE, Applied to Aging Study

Cognitive Aging

- Anatomical
 - Normal: PFC and backward
 - Pathological: MTL and outward
- Behavioral
 - Intact crystalized knowledge, but declined fluid intelligence
 - Intact verbal WM
 - Poor visual WM



VWM and Cognitive Aging

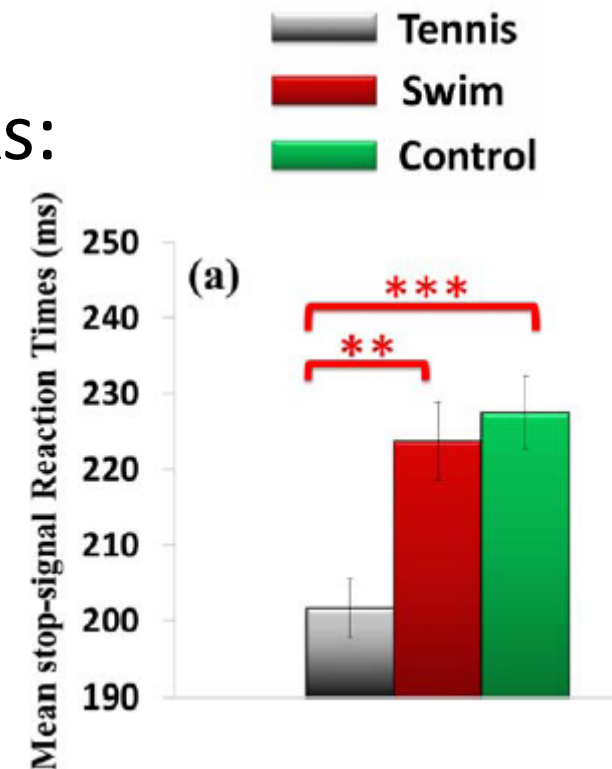


Exercise for the elderly

- Aerobic exercise (close-skill) increases brain volume and improves processing speed

(Colcombe et al., 2003, 2004, 2006; Kramer et al., 1999; Stroth et al., 2009)

- What the current literature lacks:
 - Open-skill vs. Close-skill vs. Cognitive training
 - Can exercise improve VWM?



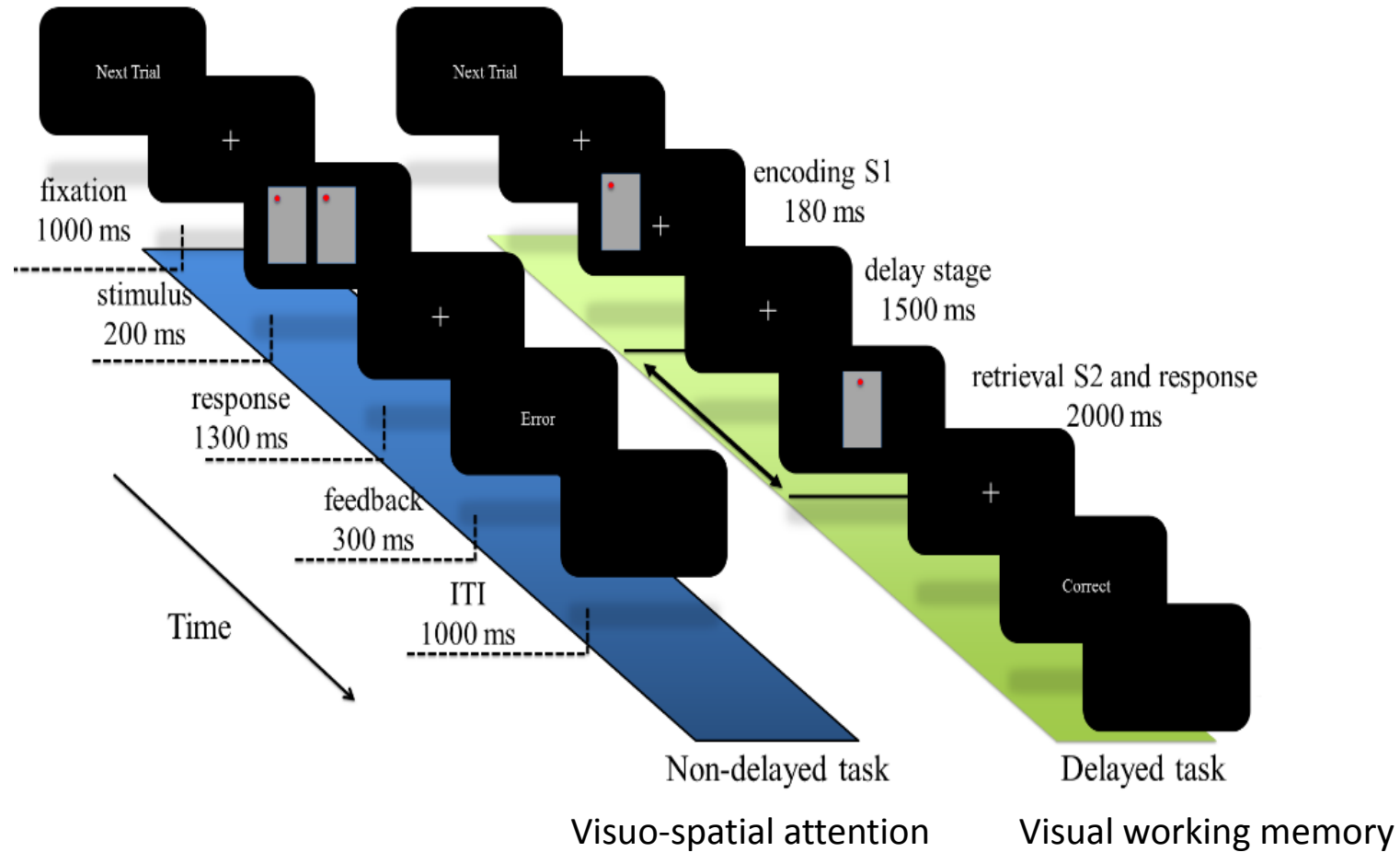
Participants

- 48 Participants
 - 24 male and 24 female
 - 66-70 years of age
 - 24 physically active elderly in ping-pong club (physical activity >5 hours per week)
 - 24 physically inactive elderly from the photography and chess club (physical activity <2 hours per week)
 - No signs of dementia, depression

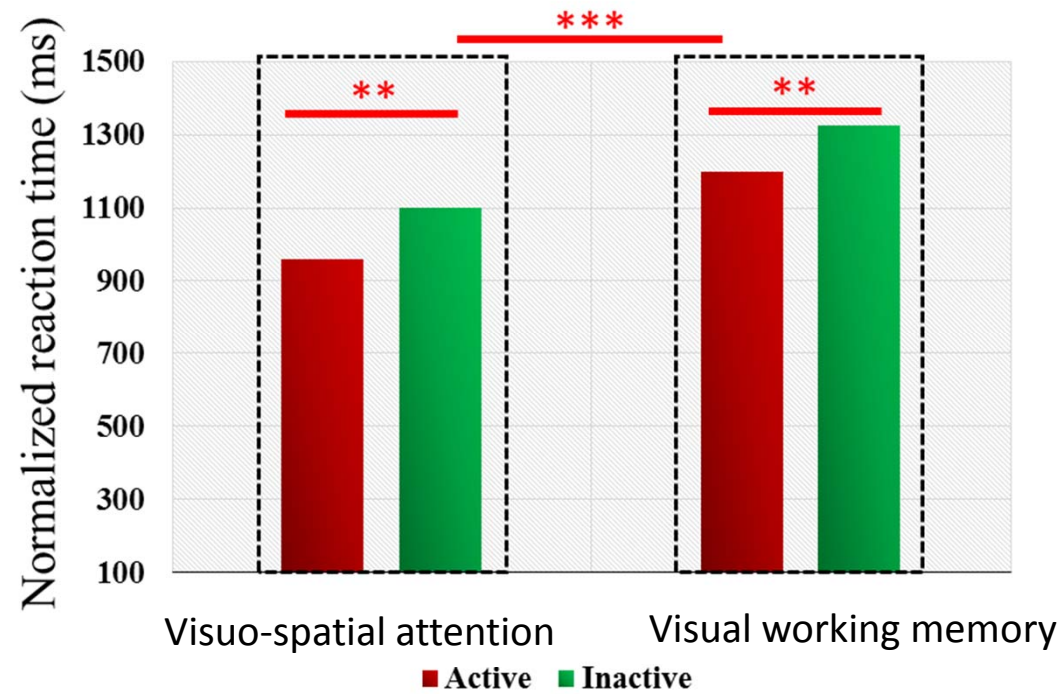


Physically active vs. inactive elderly adults

Visuo-spatial attention & Visual working memory

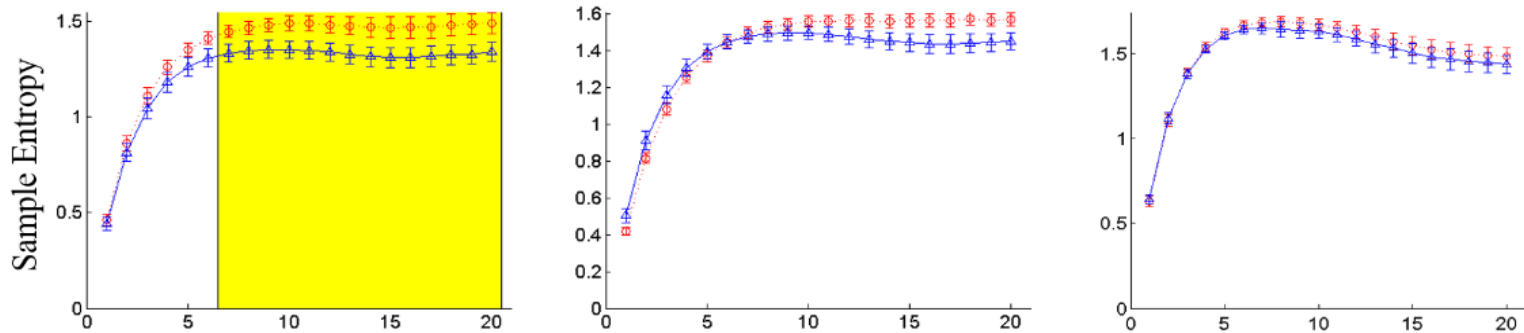


Behavioral result

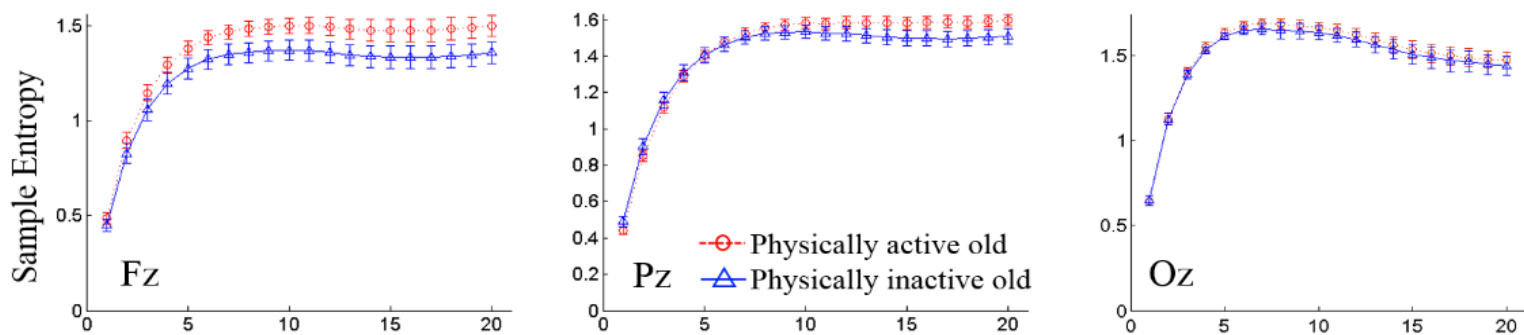


Normalized reaction time: RT/accuracy

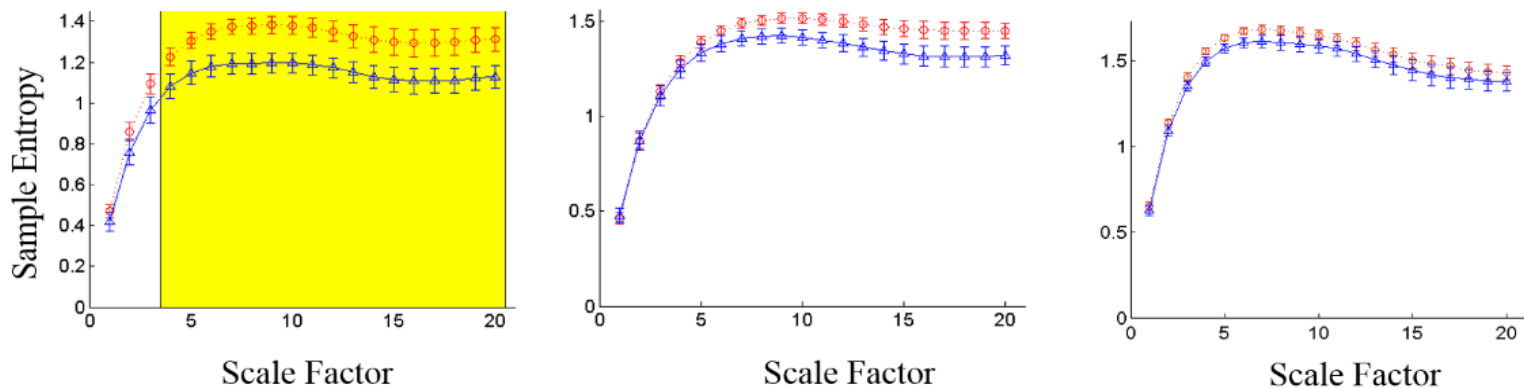
(a) Attention condition

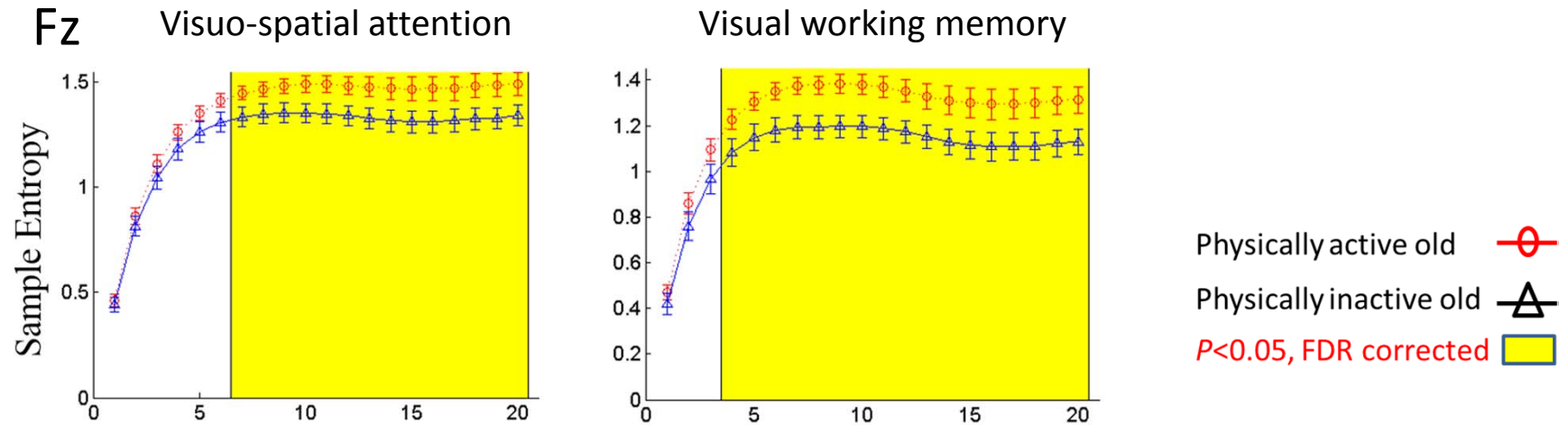


(b) Memory encoding



(c) Memory retrieval





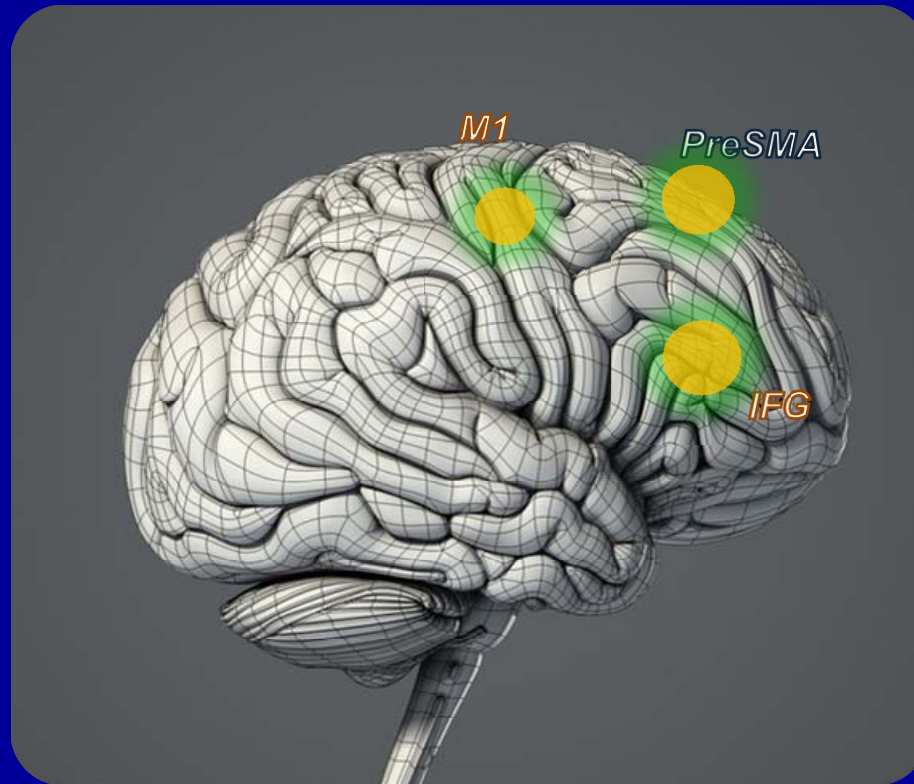
- Although VWM declines w/ age, open-skill physical exercise has positive effects on elderly adults' VWM
- Behavioral improvement is accompanied by higher complexity (MSE) in signals from frontal areas
- To battle frontal decline, open-skill sports are better choice for elderly

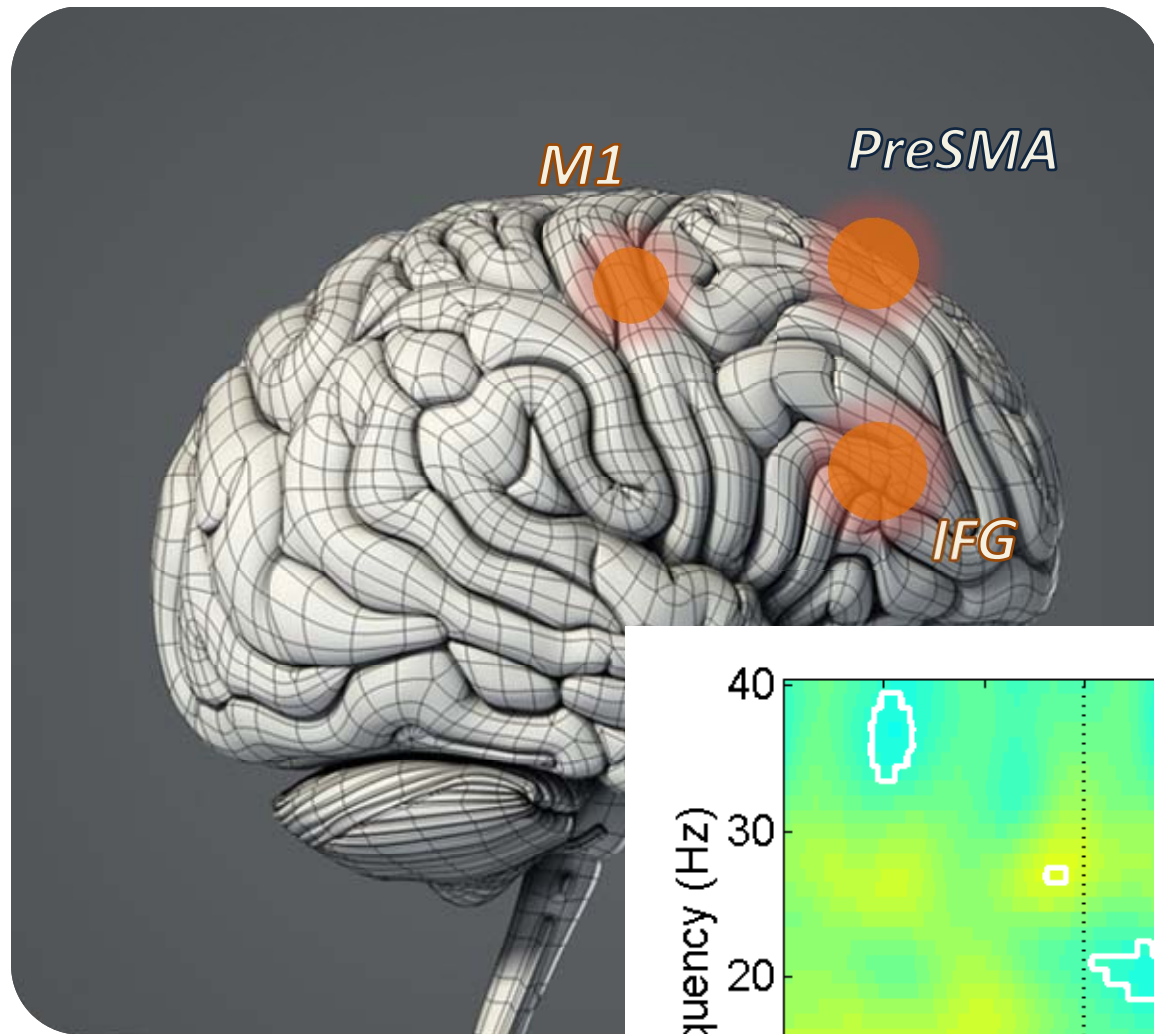
Take home messages

- Variability is important for a biological system, but not all kinds of variability is good.
- The good variability can be revealed by MSE, which indicates adaptability of a biological system.
- Inhibitory control is a cognitive process requires our brain to adapt fast, higher MSE *result in* a successful inhibitory process.
- Anodal tDCS is a protocol of brain stimulation that can elevate the brain's MSE.
- Open-skill exercise is good for our brain, revealed by MSE.

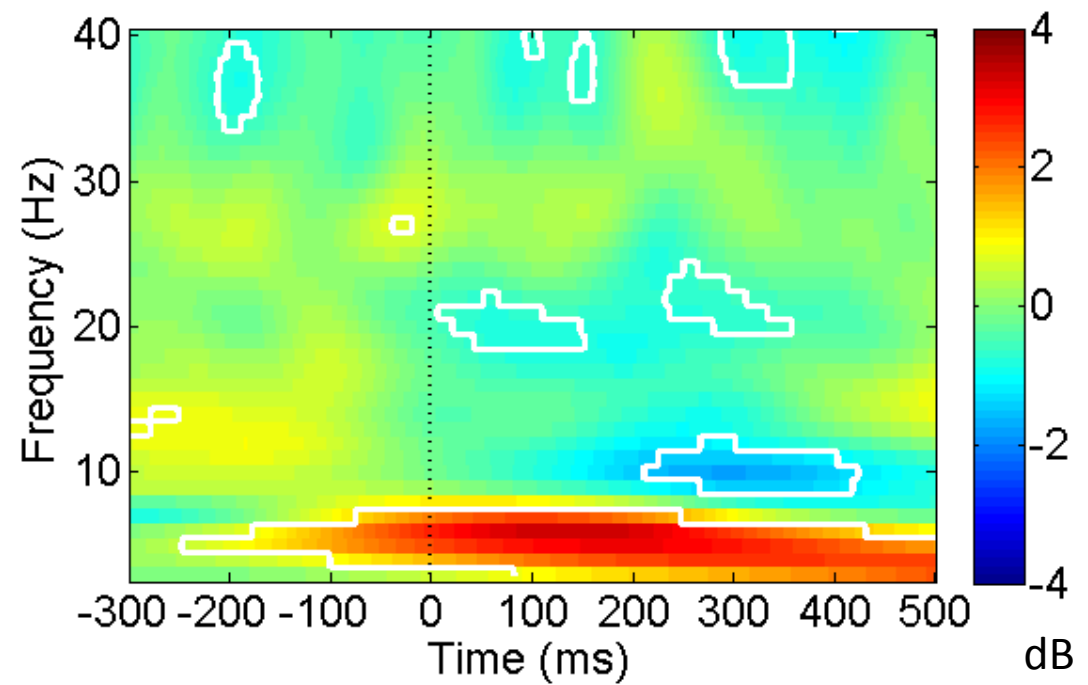
Impulsive behavior is controlled by effective large-scale coordination

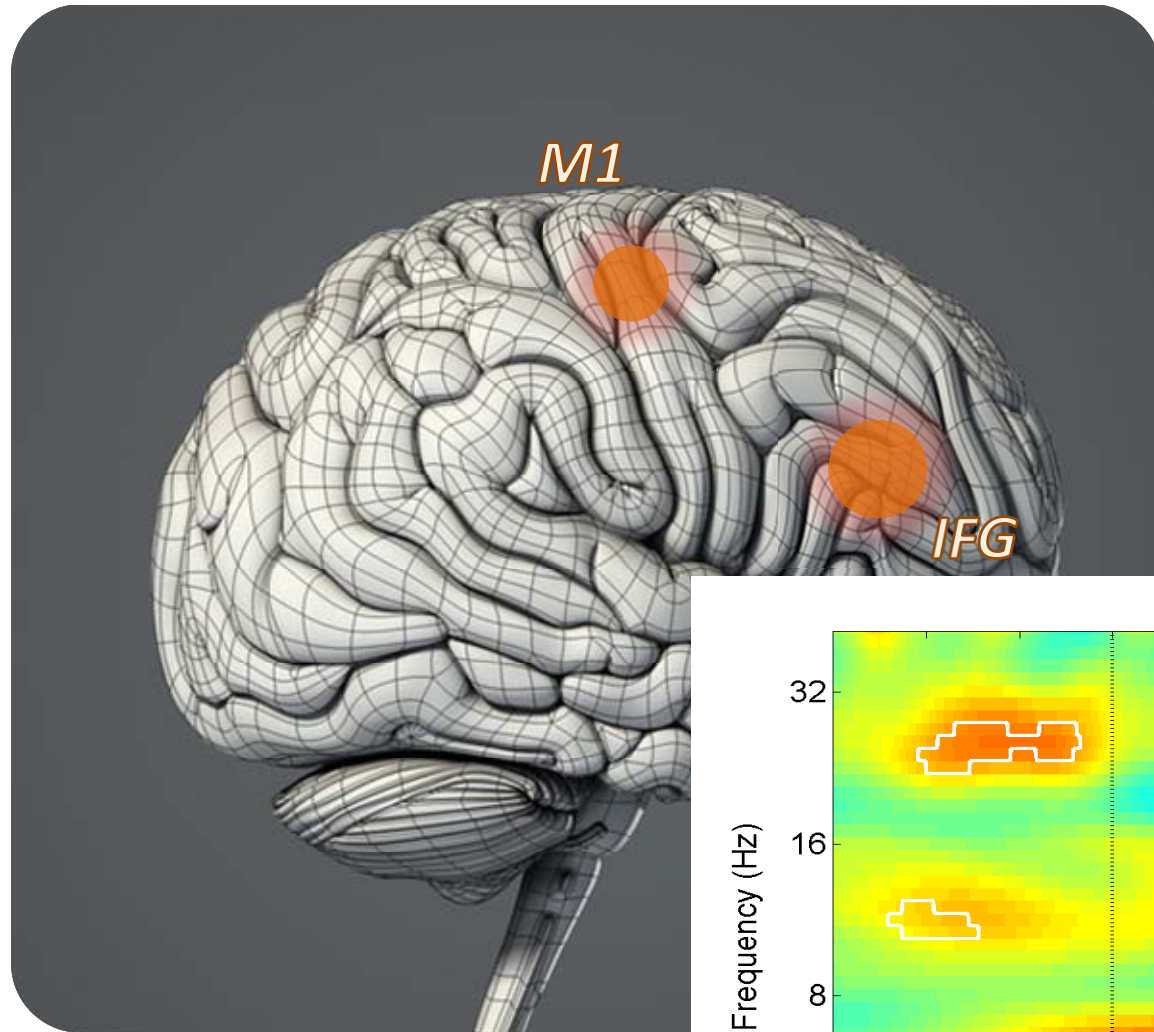
Wei-Kuang Liang, Jiaxin Yu, Yu-Hui Lo, Chi-Hung Juan



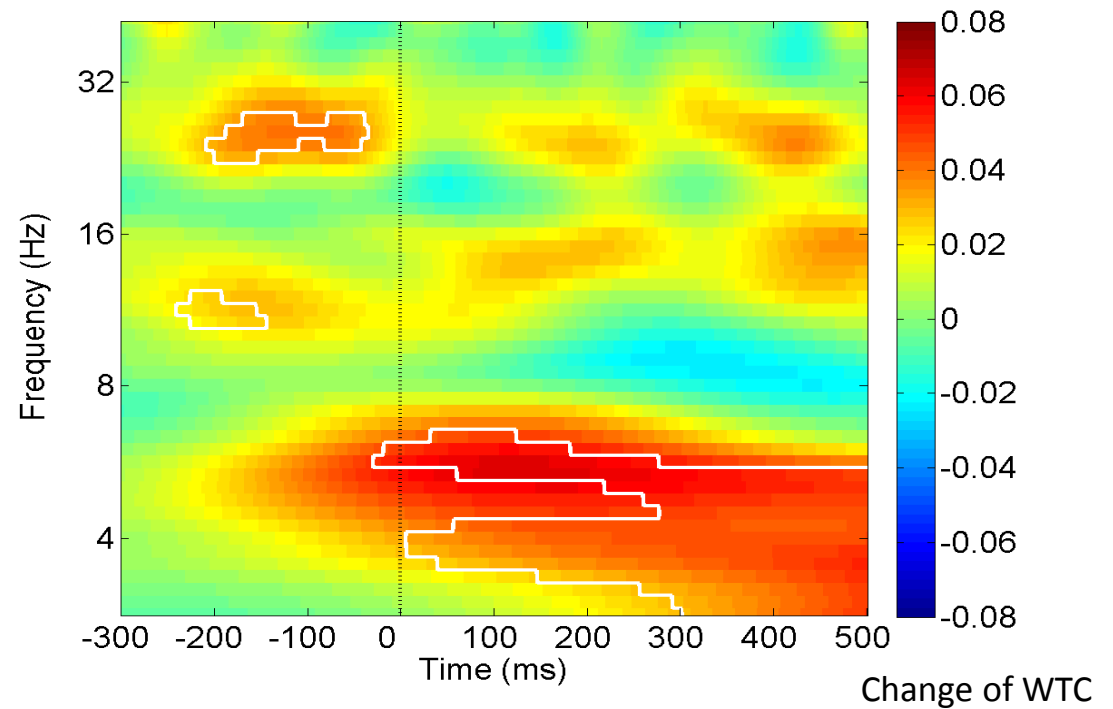


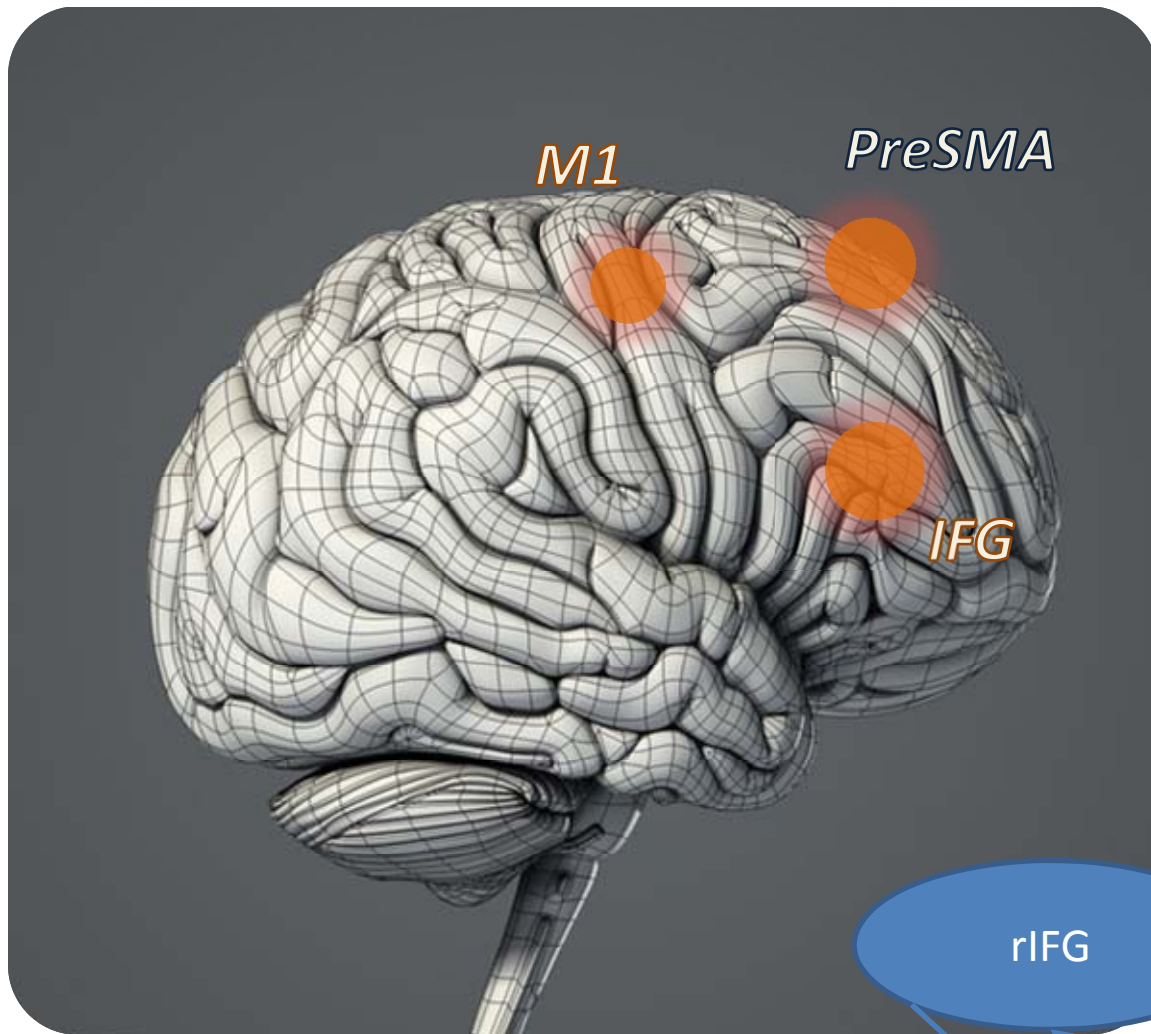
Local synchronization
(Local integration),
measured by *rescaled*
power



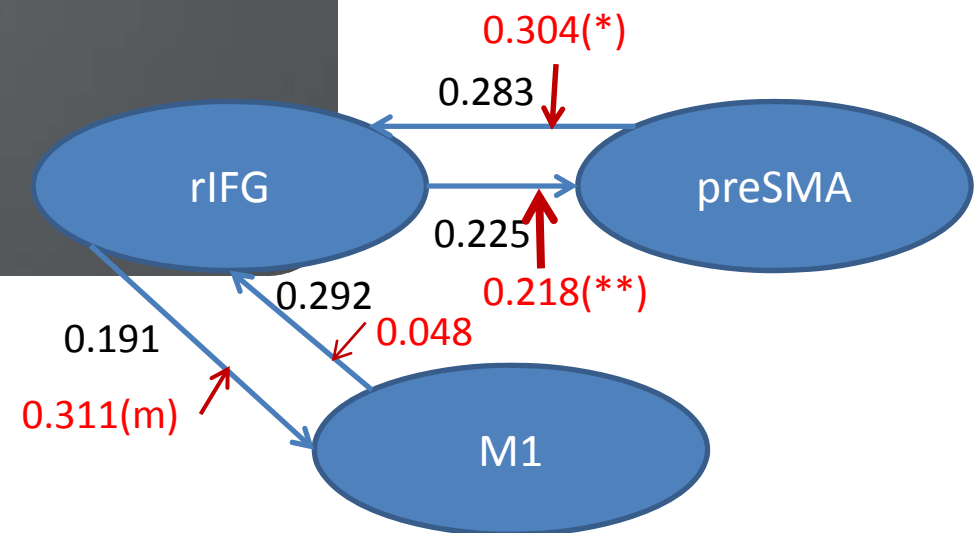


Large-scale synchronization
(Large-scale integration),
between two regions, measured
by *Wavelet Coherence*.
(Grinsted et al. 2004)

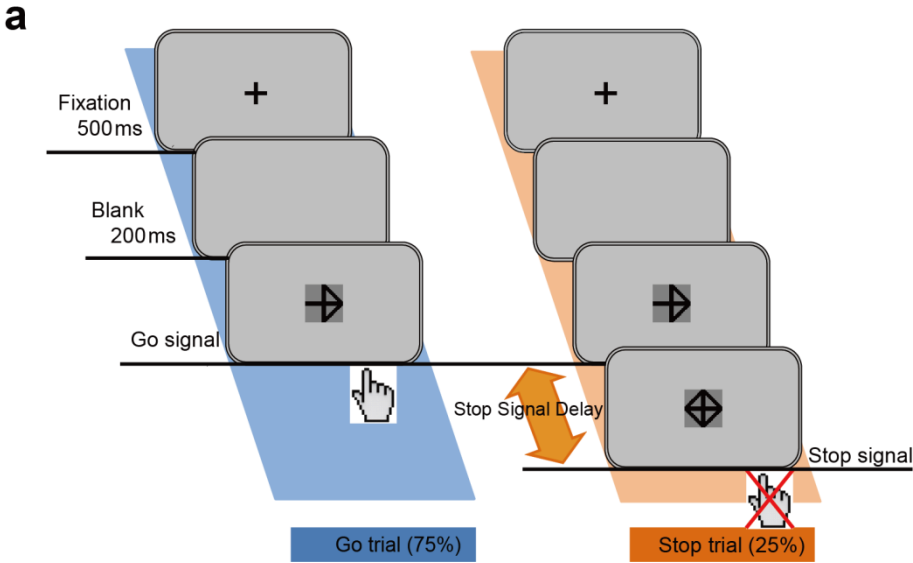




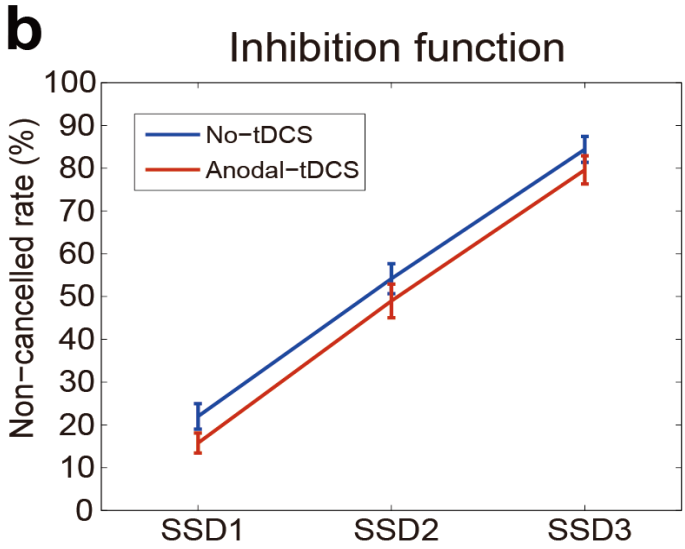
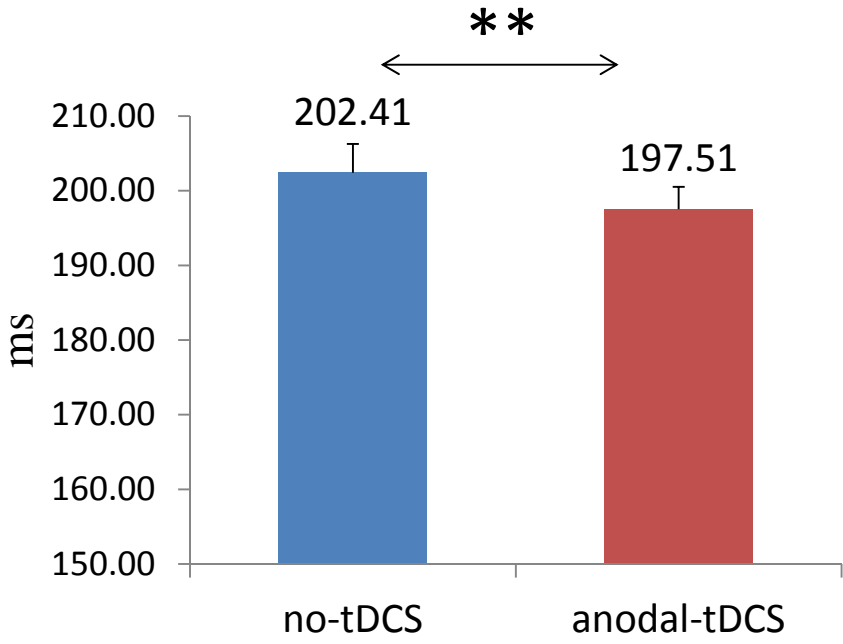
For large-scale integration among three or more regions, a model of phase-coupling is required



Stop-signal task and behavior result



The ability of inhibitory control (SSRT) was improved by anodal tDCS over preSMA

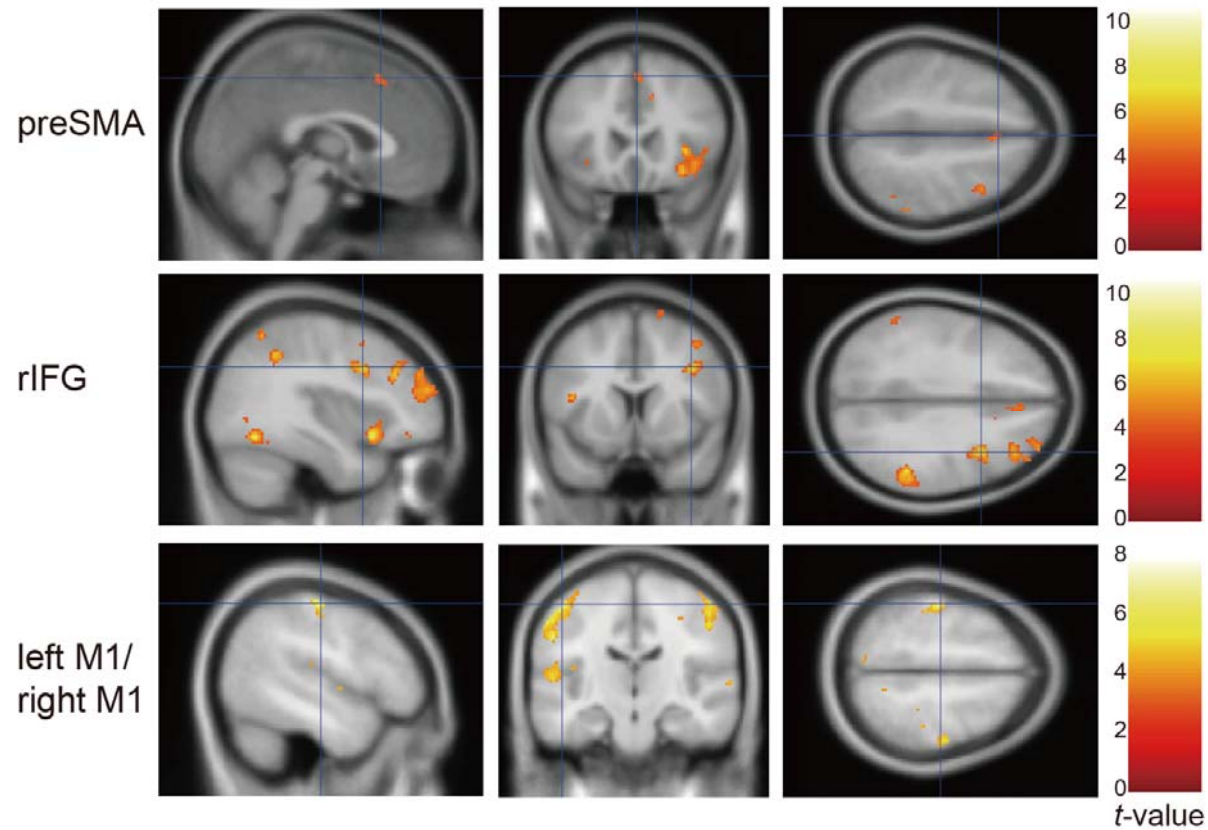


** : $P=0.01$

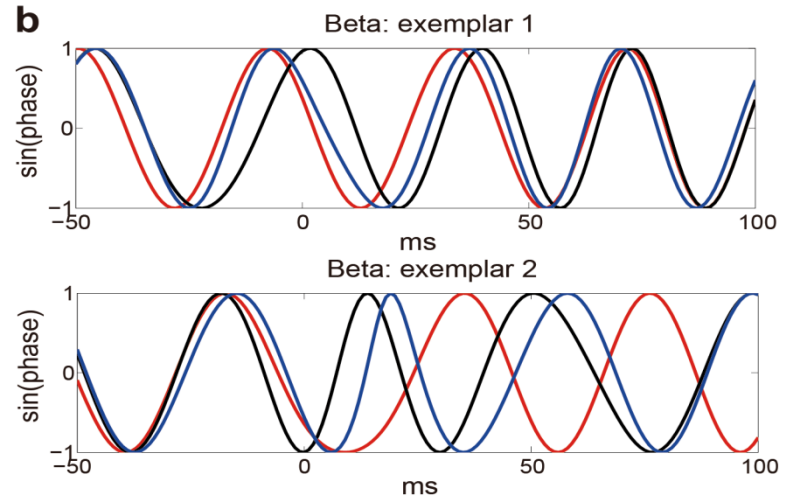
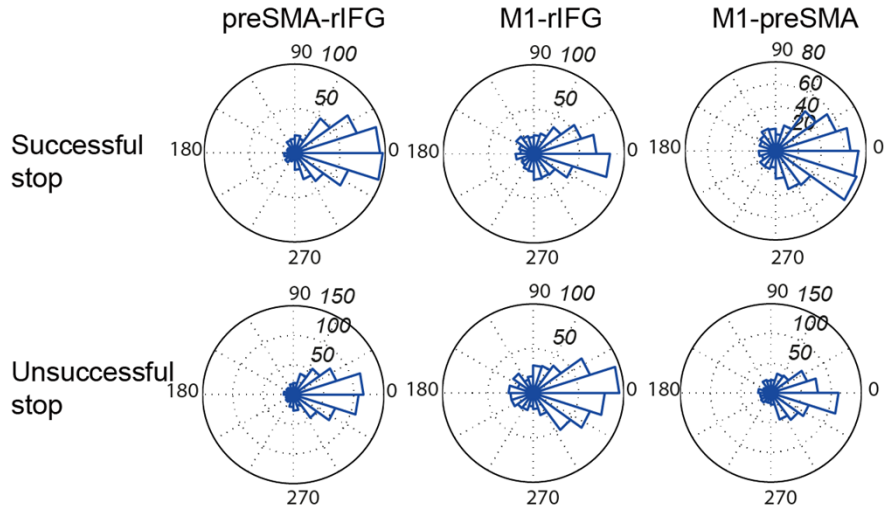
How about the phase coupling during inhibitory control?

Source waveforms and their phase data in *theta* and *beta* band

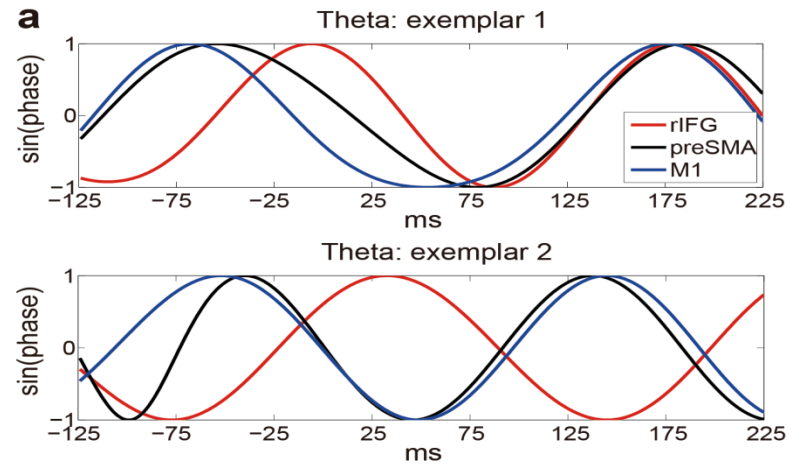
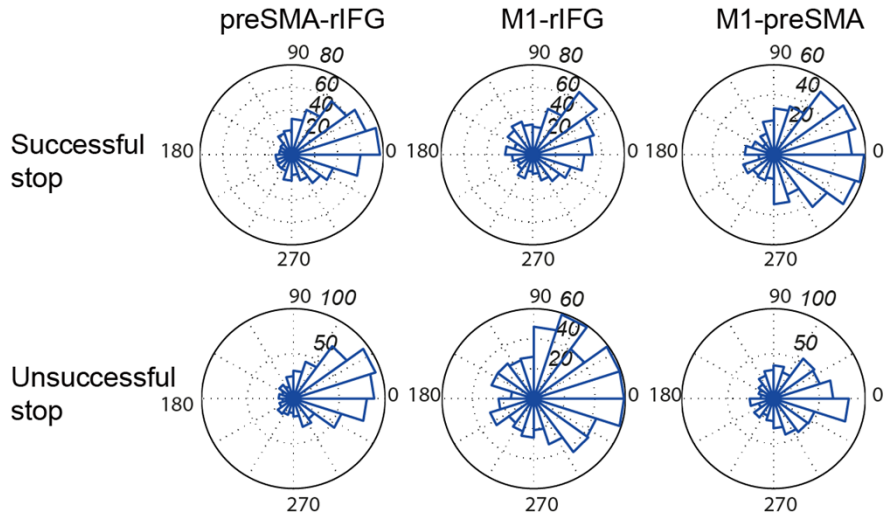
- 16 participants, EEG signals were projected to *rIFG*, *preSMA* and *contralateral M1* (Maximum Likelihood Projection).



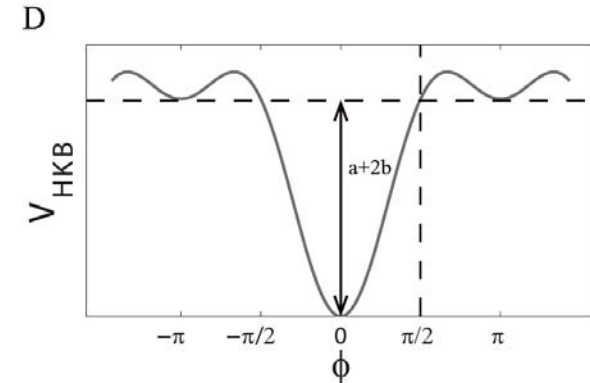
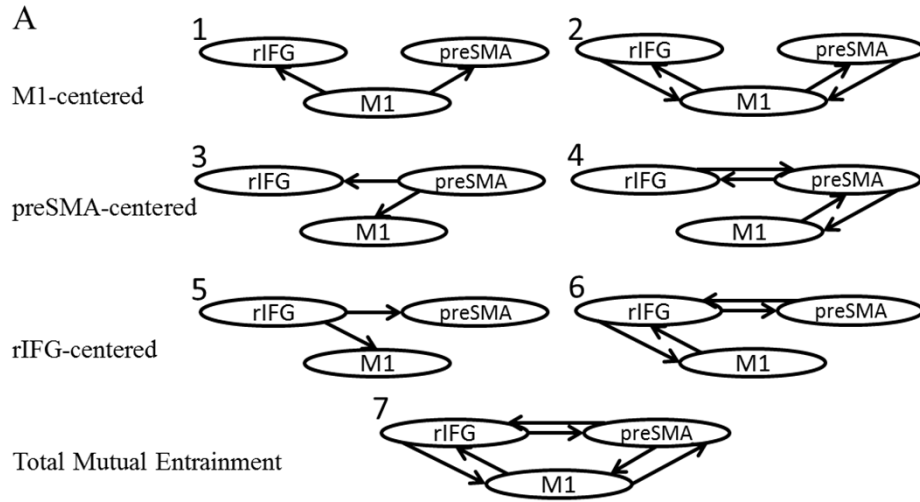
Beta: phase difference (No-tDCS)



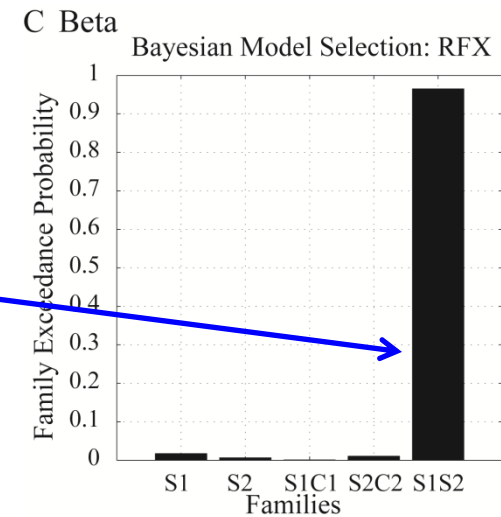
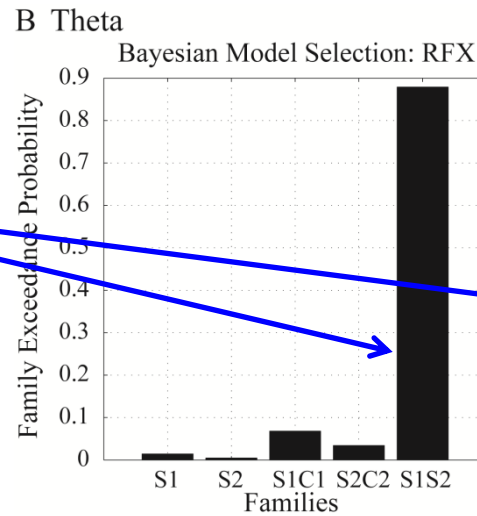
Theta: phase difference (No-tDCS)



DCM for phase coupling (Penny et al. 2009)



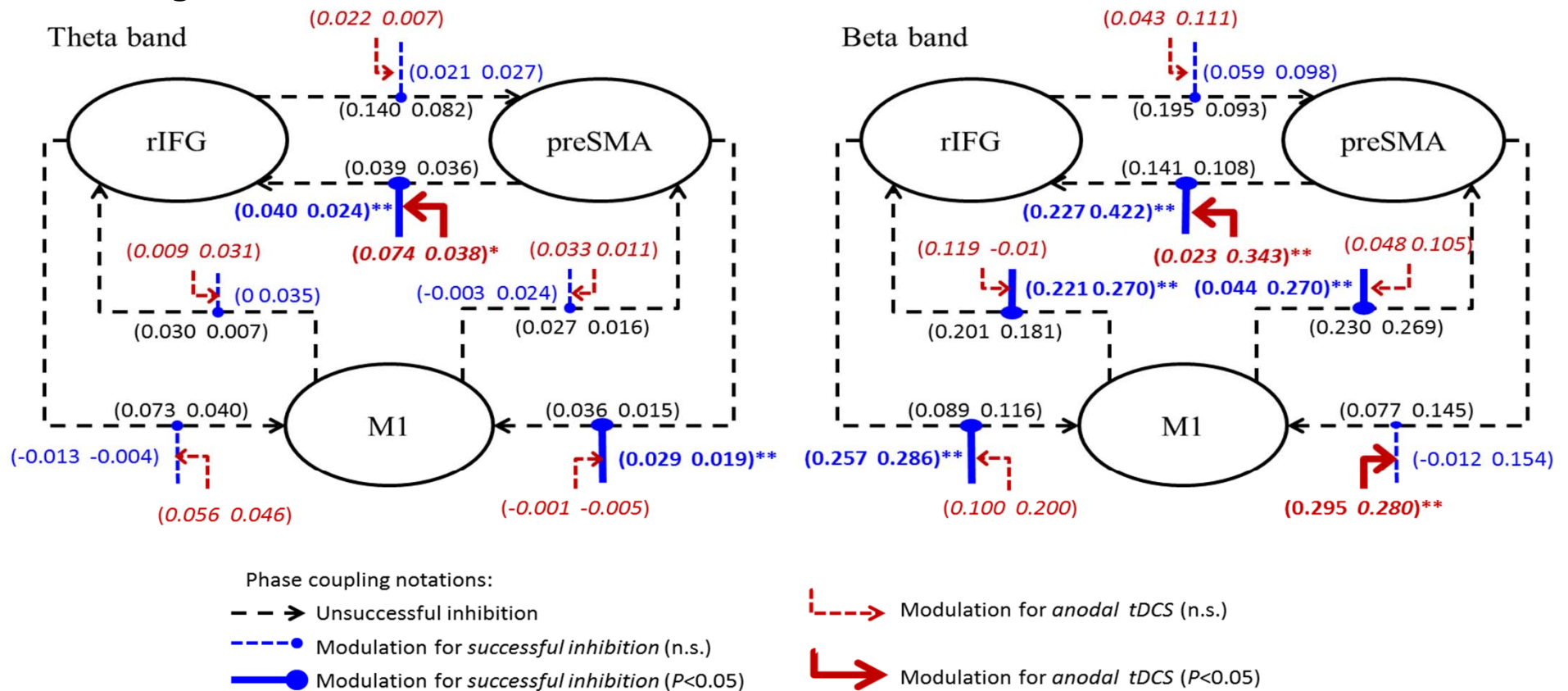
Phase *dynamics* amongst preSMA, rIFG, and M1 follows the *HKB* (Haken-Kelso-Bunz) phase interaction function



Connection parameters.

Two modulations: (1) for successful stop; (2) for anodal tDCS application.

Results: (1) preSMA is the source site to modulate M1 in theta band; (2) rIFG is the source to mediate M1 in beta band; (3) Anodal tDCS over preSMA can strengthen these connection in both the theta and beta bands.



Interim conclusions

- Anodal-tDCS over preSMA 促進抑制控制(inhibitory control)的機制，可以反映在不同腦區間相位同步(phase coupling)的速度上
- 對於*theta* oscillations, DCM for phase-coupled response推斷:抑制控制成功或不成功與由preSMA往rIFG,以及由preSMA到M1 phase coupling 的強度有關
- 對於*beta* oscillations, DCM for phase-coupled response推斷:抑制控制成功或不成功與由rIFG往M1, 以及由preSMA到rIFG phase coupling 的強度有關
- Anodal-tDCS over preSMA 可以進一步加強在*theta*及*beta* band上由preSMA往rIFG phase coupling 的強度，因此增加抑制控制成功的可能

Conclusions

- 在認知的歷程中，大腦的運作是既複雜又和諧的
- MSE是目前用來量化大腦運作過程複雜度最 powerful 的指標
- Large-scale integration (Dynamics of phase-coupling) 可以用來表達個腦區間和諧的程度，這種跨腦區的耦合，如同交響樂一般

Acknowledgements

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游家鑫(Jiaxin Yu)

人類記憶實驗室

鄭仕坤教授(Shih-kuen Cheng)

Thank you for your attention.