Driving brain function with non-invasive rhythmic stimulation: a new way of shaping behavior?

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McGill

Lab

neurospeed lab
imaging at the speed of brain

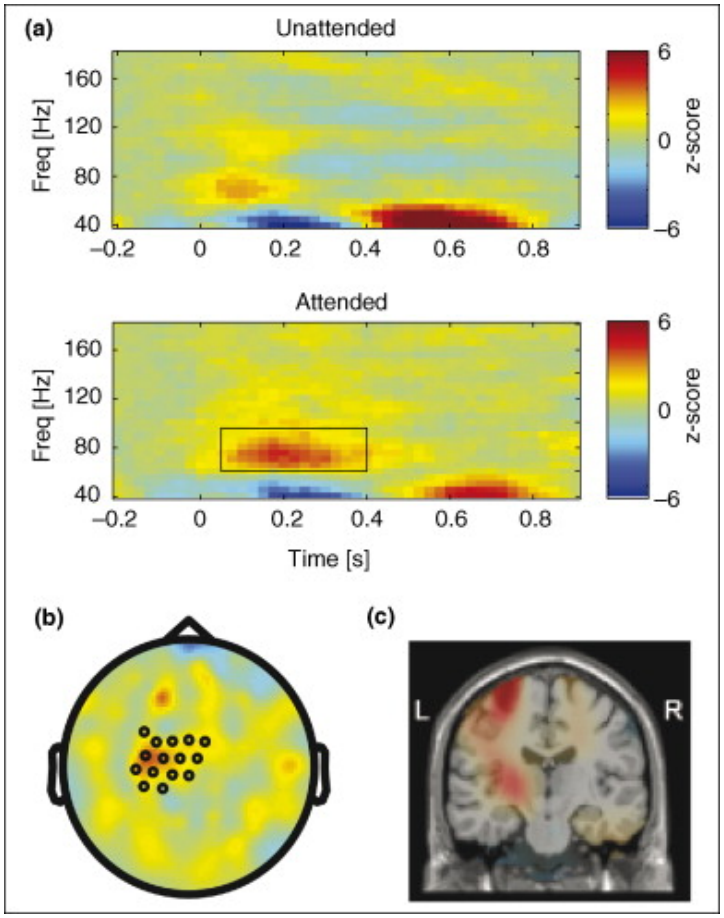
neuro

Brams
International Laboratory for
Brain, Music, and Sound Research

Introduction

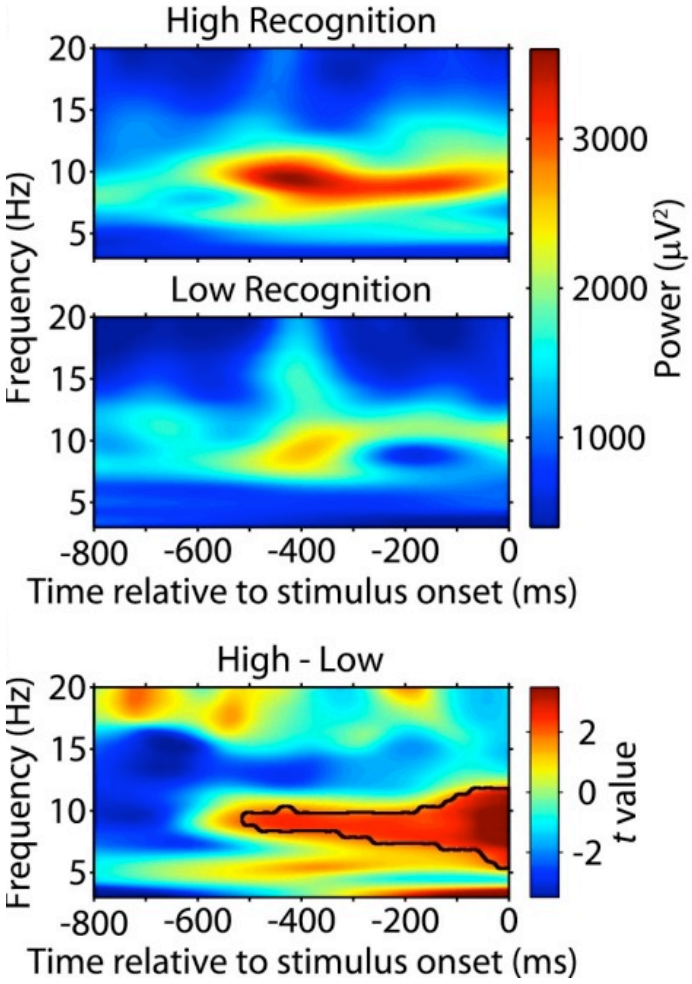
Functional role of brain oscillations

Selective attention



Jensen et al., 2007

Memory Recognition

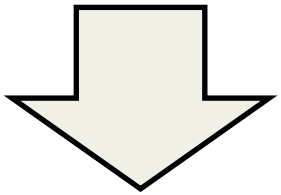


Jutras et al., 2013

Introduction

Neural oscillations can predict or correlate with participants' performance

The causal relationship brain oscillations and behavior needs to be clarified



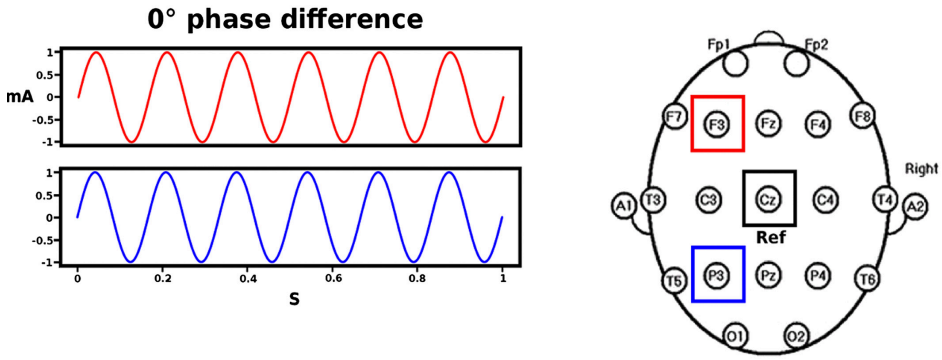
Directly modulate brain oscillations during task performance and observe the consequences on behavior

Information based Stimulation

Stimulations that match functionally relevant brain rhythms

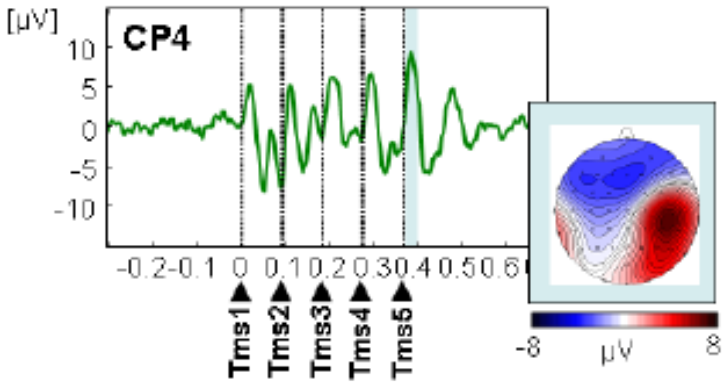
Brain oscillations

tACS



Polania et al, 2012, Current Biology

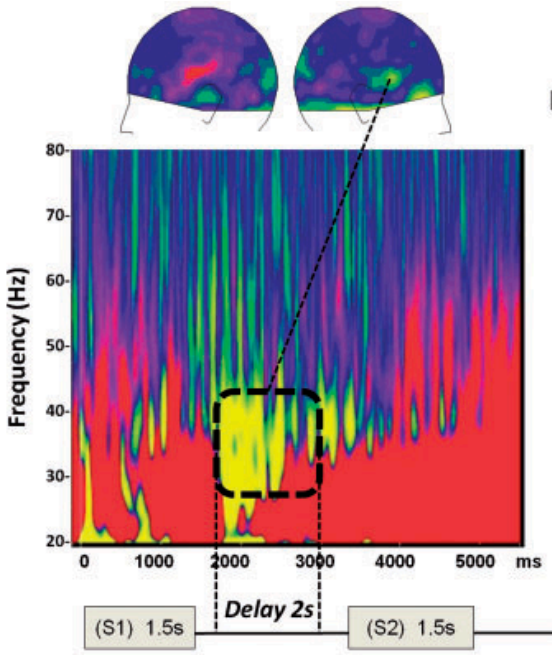
Rhythmic TMS

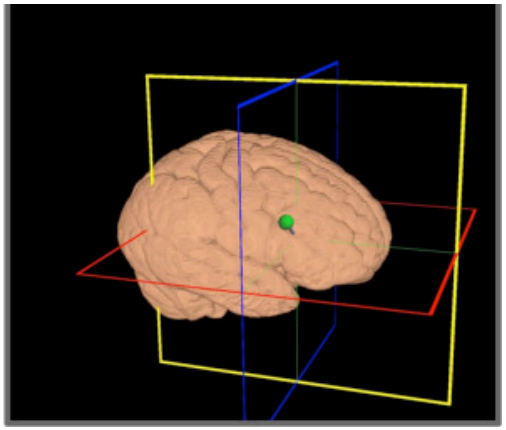


Thut et al, 2012 current Biology

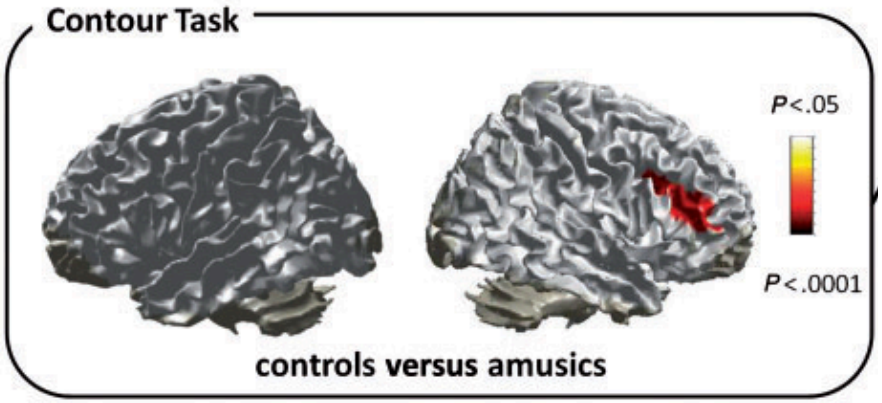
Phase resetting or entrainment of brain oscillations

tACS to boost Short-Term Memory

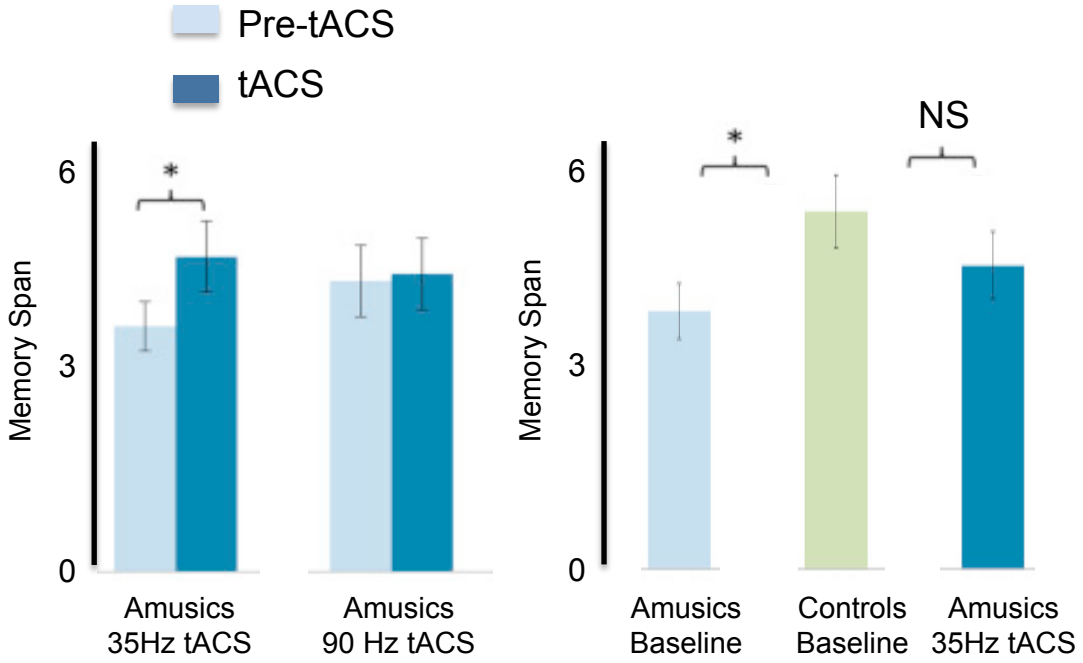




Schaal et al., 2015 Behav Brain Research



Albouy et al., 2013 Brain



Introduction

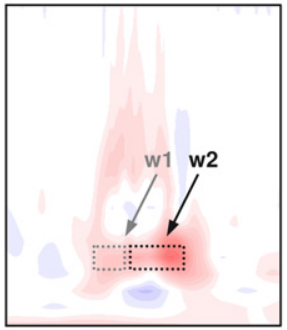
Modulate functionally relevant oscillations to modify the perceptual experience

Current Biology 21, 1176–1185, July 26, 2011

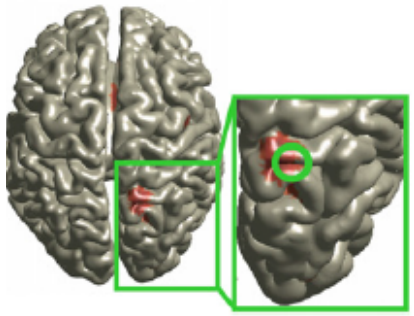
Rhythmic TMS Causes Local Entrainment of Natural Oscillatory Signatures

Gregor Thut,[1,*] Domenica Veniero,[2,3] Vincenzo Romei,[4,5] Carlo Miniussi,[2,3] Philippe Schyns,[1] and Joachim Gross[1]

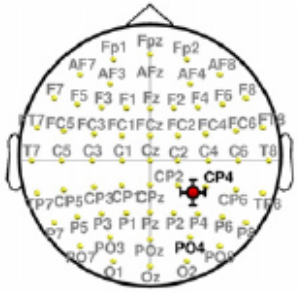
Alpha TMS vs Arrhythmic TMS



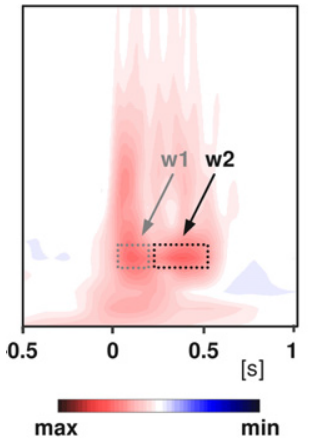
B Source estimate of α-generators in MR



C Stimulation site on electrode array



Alpha TMS vs SHAM



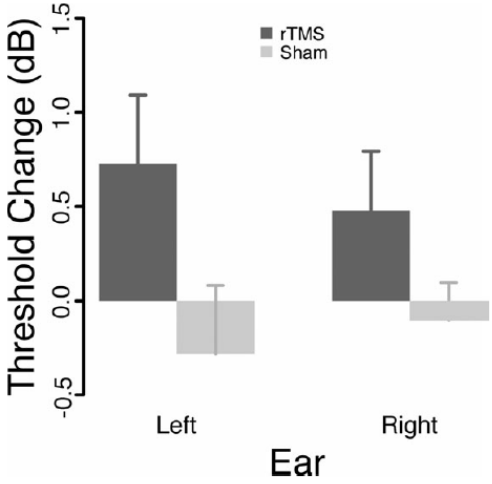
Introduction

Entraining functionally relevant oscillations to modulate the perceptual experience

◆ Human Brain Mapping 35:14–29 (2014) ◆

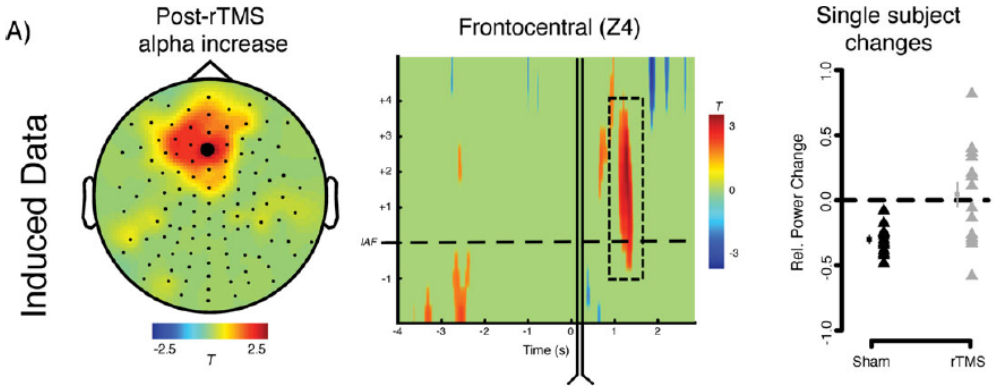
Effects of Individual Alpha rTMS Applied to the Auditory Cortex and Its Implications for the Treatment of Chronic Tinnitus

Nathan Weisz,[1]* Claudia Lüchinger,[2] Gregor Thut,[3] and Nadia Müller[2]

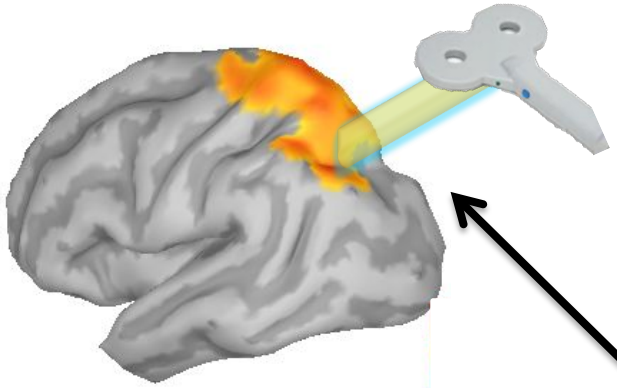


Alpha TMS over left auditory cortex

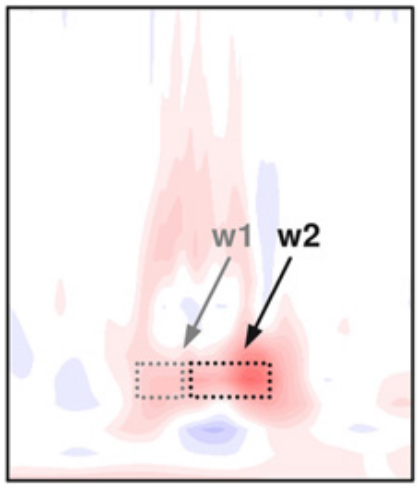
Single tone comparison – Intensity threshold



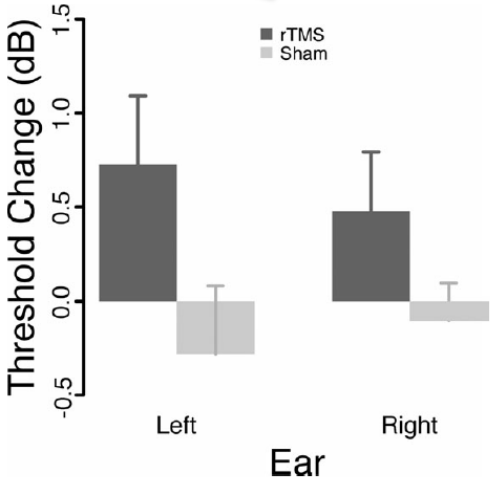
Introduction



TMS



Oscillations



Behavior

Questions

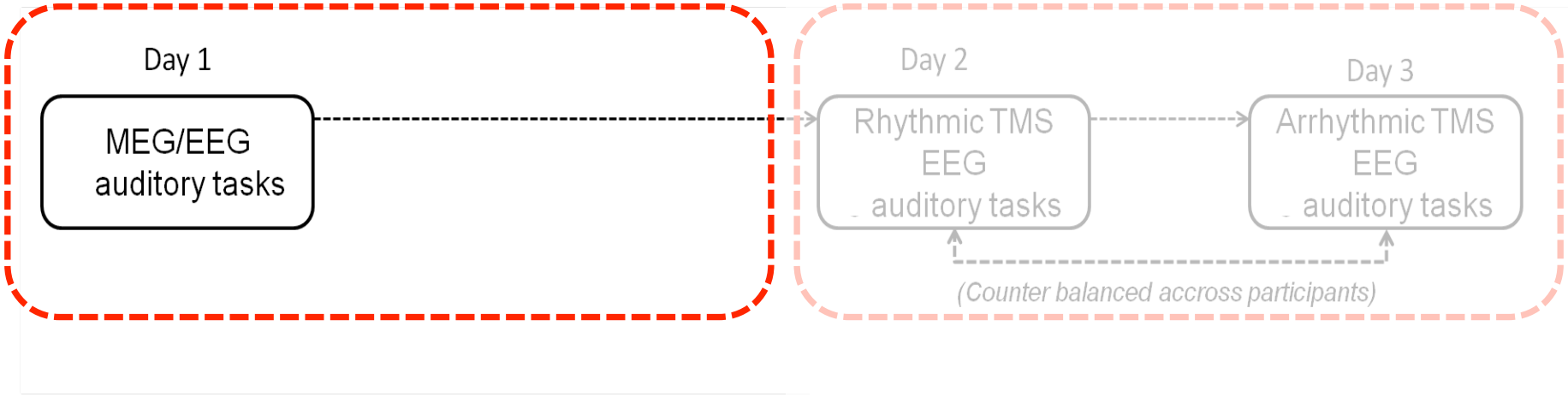
How a functionally relevant periodic stimulation applied over specific nodes of the auditory network during auditory processing can …

1) causally influence the activity of the auditory network

2) causally influence connectivity patterns of the auditory network

3) affect participants' behavioral performance (accuracy, RTs)

Protocol



Region to be targeted with rTMS

Frequency of the stimulation

Baseline behavioral performance

TMS Behavioral performance

Baseline ERFs and oscillatory markers

TMS ERFs and oscillatory markers

Baseline connectivity patterns

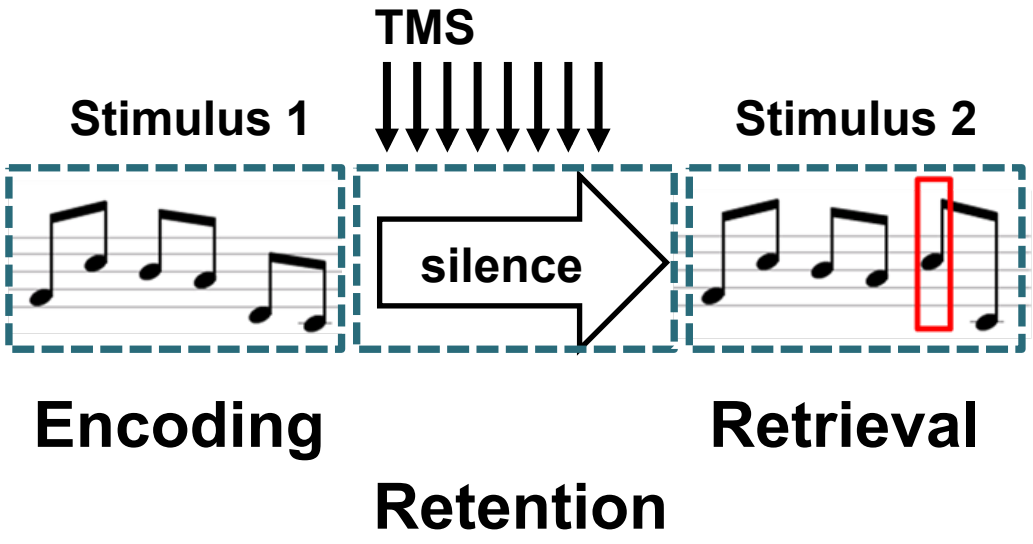
TMS connectivity patterns

Task

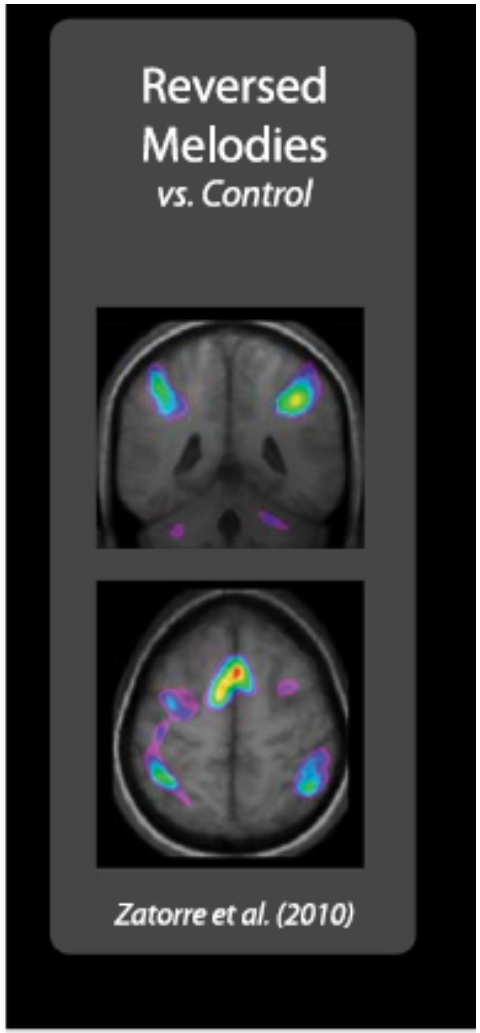
Auditory Working Memory

The mechanism that allows the retention in memory of recent auditory information
(Cowan 2008, Baddeley 2003, 2010, Schulze and Kloesh 2012)

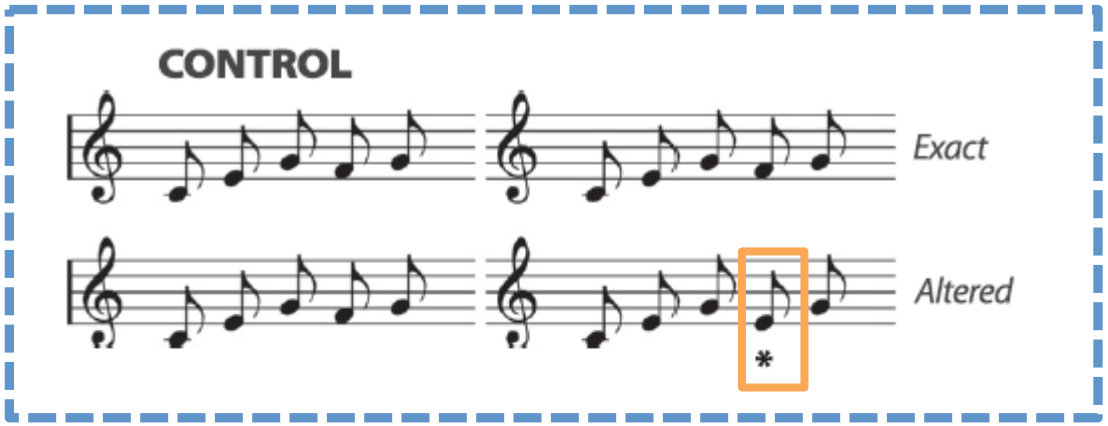
Recognition task



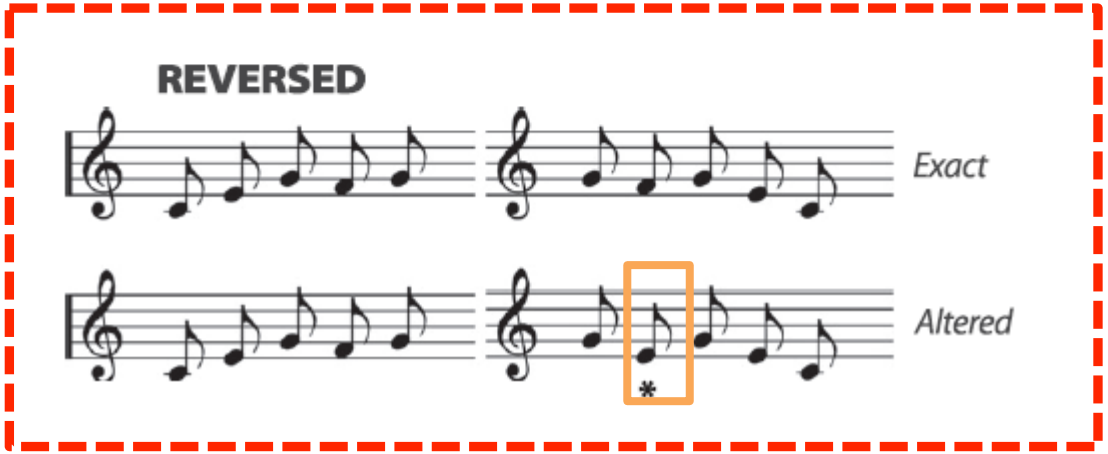
Task



Simple Memory



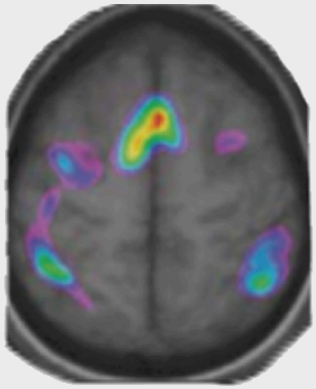
Memory + Manipulation



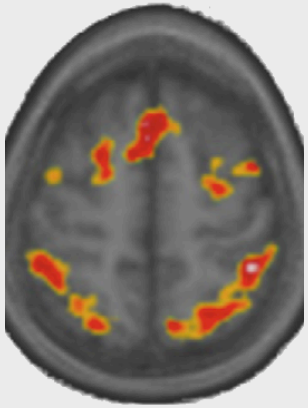
Foster , Halpern & Zatorre, 2013

Introduction

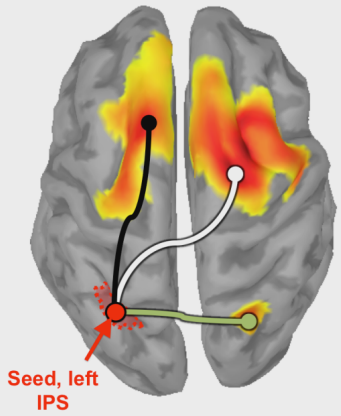
Manipulation of Melodies in Memory



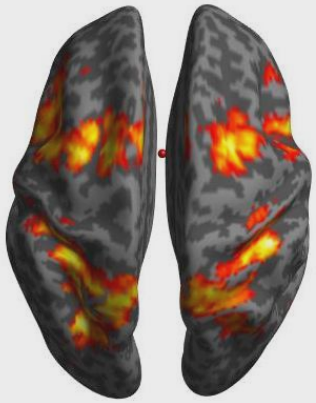
Zatorre et al., 2010



Foster et al., 2013

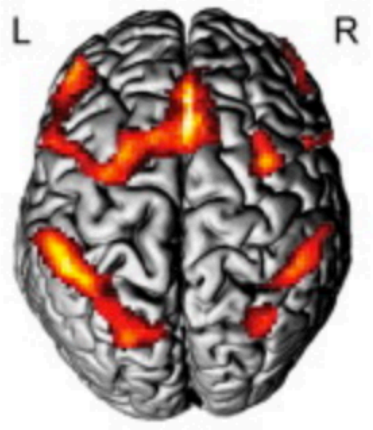


Albouy et al., 2017



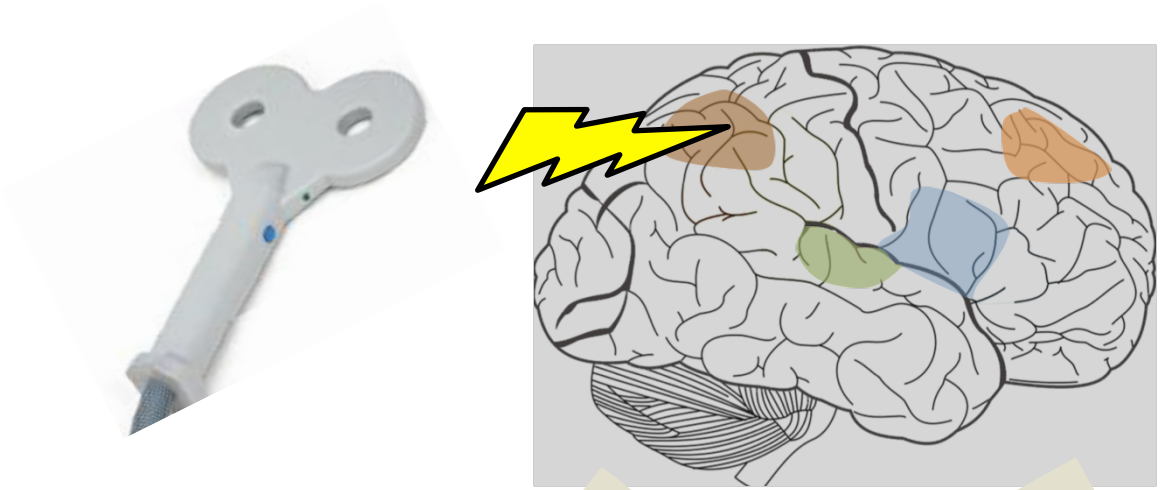
Malinovitch et al, in preparation

Quantitative calculation, Visual mental rotation …



Zago et al., 2008

Objectives

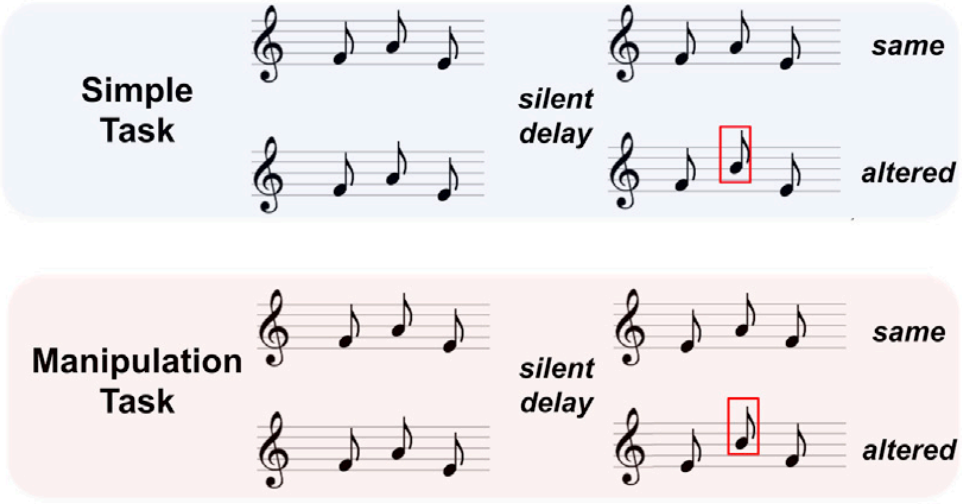


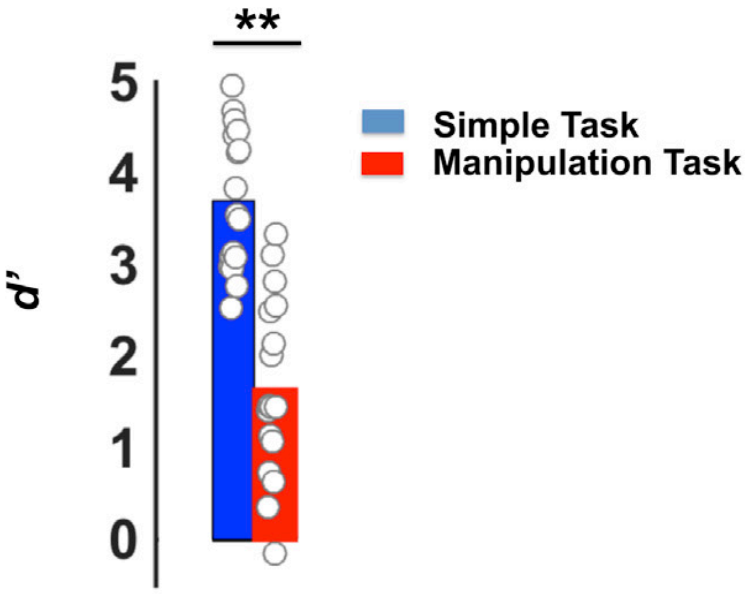
+/-

Memory + Manipulation

Memory

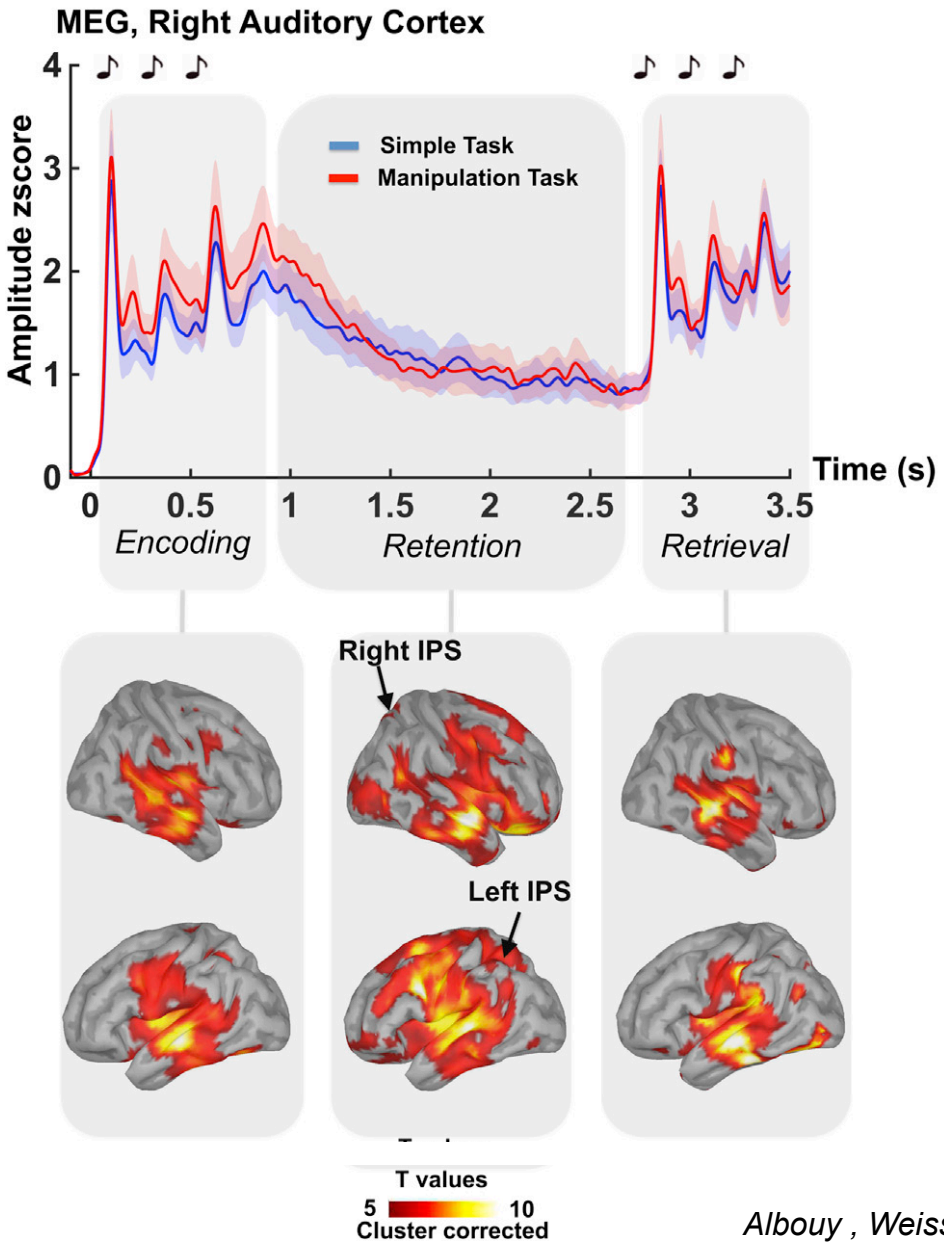
Task and behavioral performance





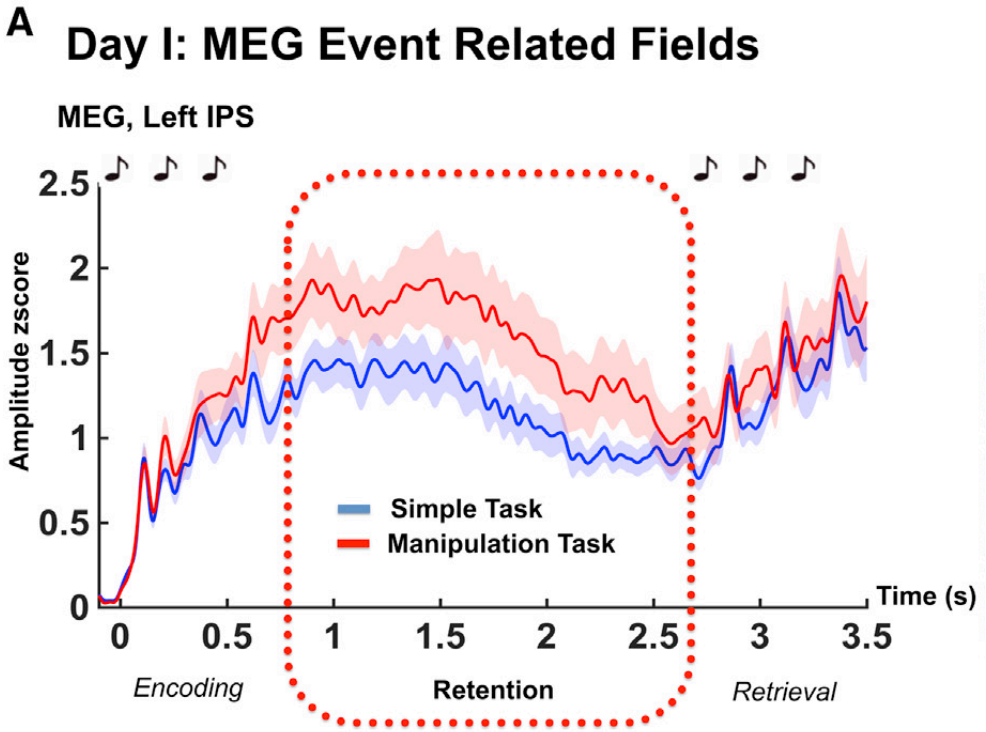
Albouy , Weiss, Baillet and Zatorre., 2017 Neuron

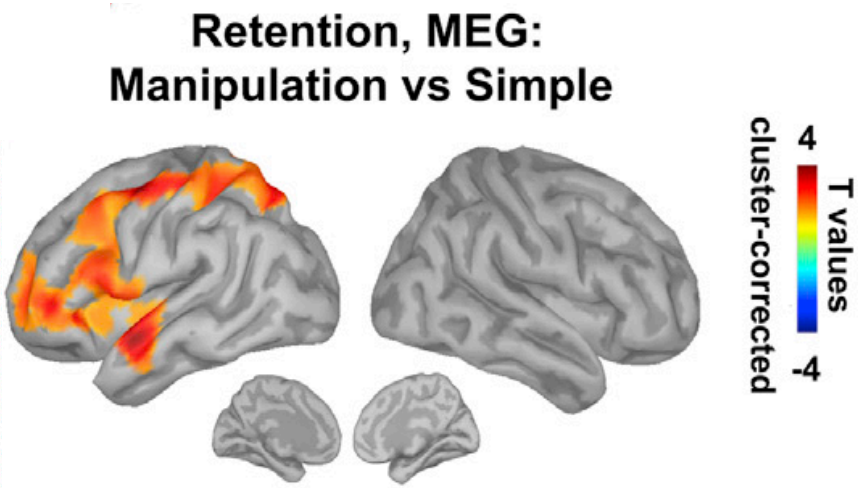
Event Related Fields



Albouy , Weiss, Baillet and Zatorre., 2017 Neuron

Task Comparison, MEG/EEG



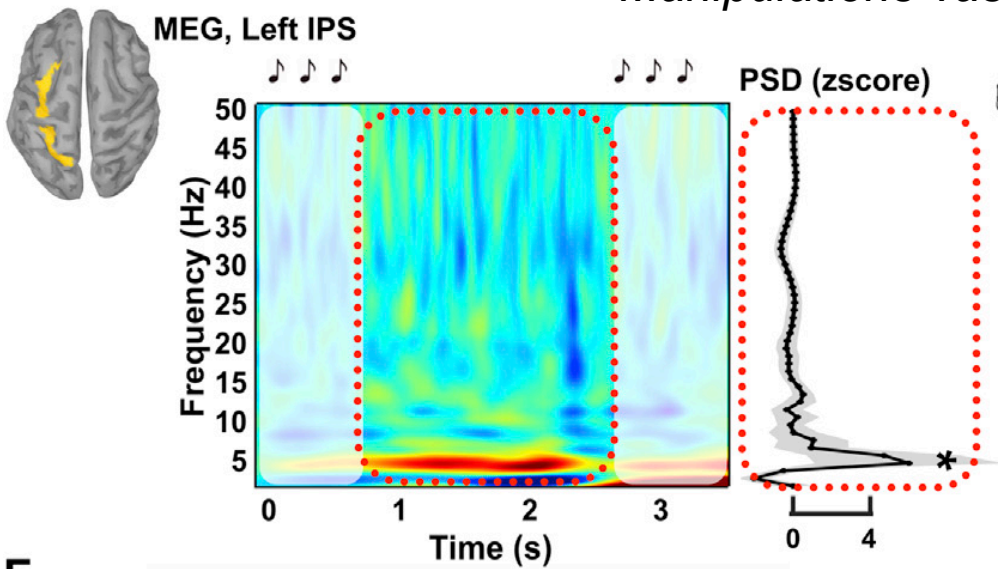


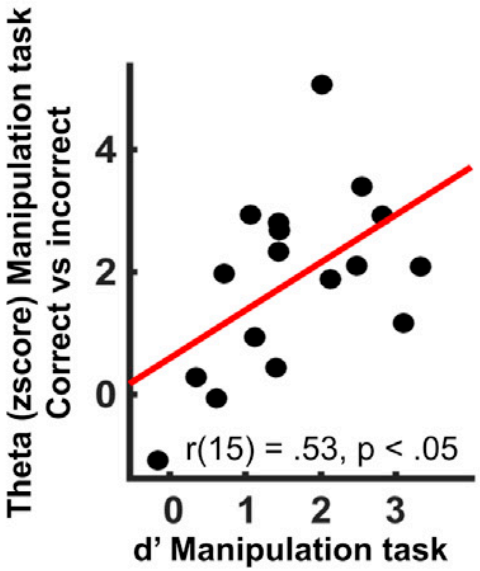
Left Fronto Parietal Pathway involved in the Manipulation of Auditory Information

rTMS to boost Working Memory specifically

Manipulation vs Simple

Correct vs Incorrect trials
Manipulations Task

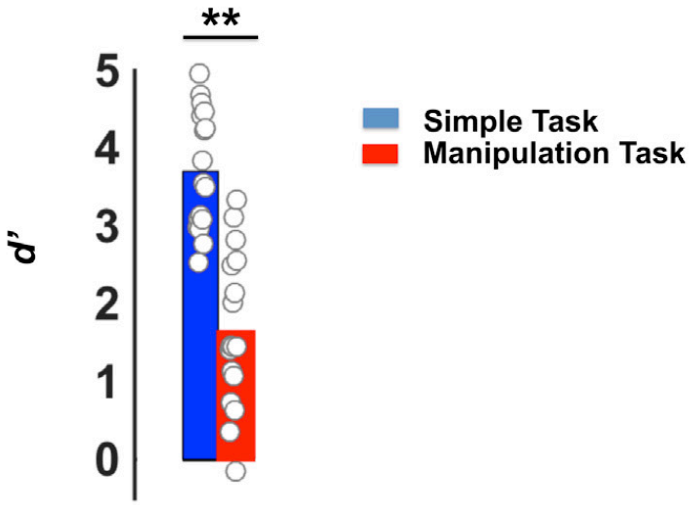




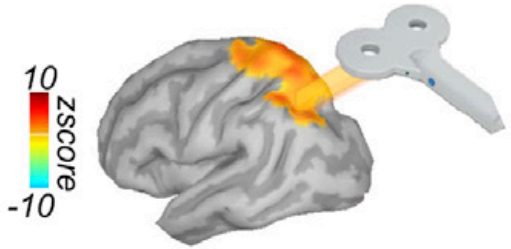
Theta power in the dorsal pathway during the retention period predicts participants manipulation abilities

Conclusion phase 1

Performance

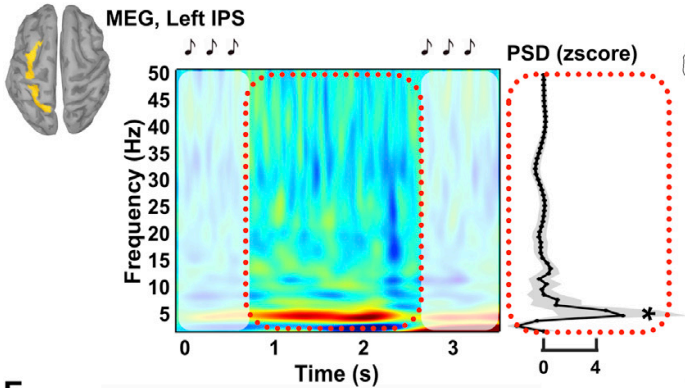


Target region

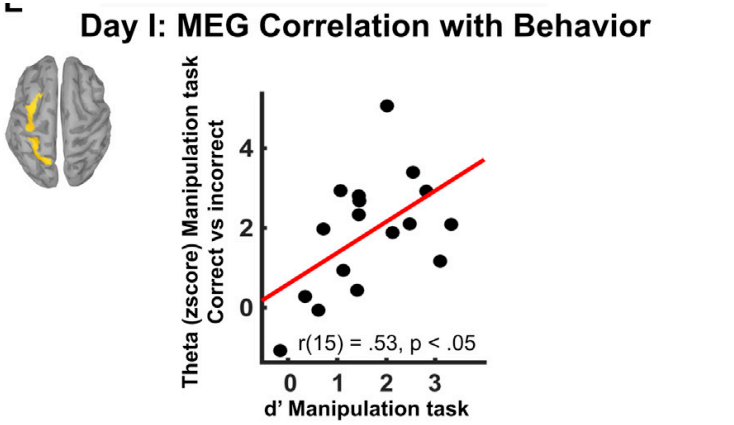


TMS at Theta Frequency

Frequency of stimulation



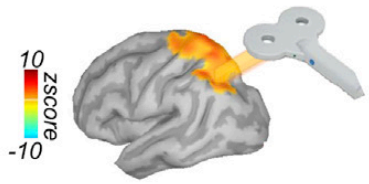
Link with behavior



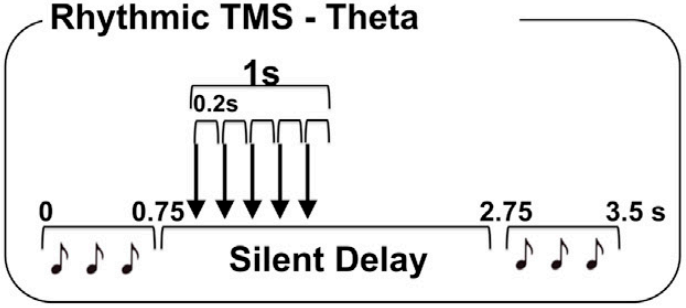
rTMS boosts Manipulation specifically

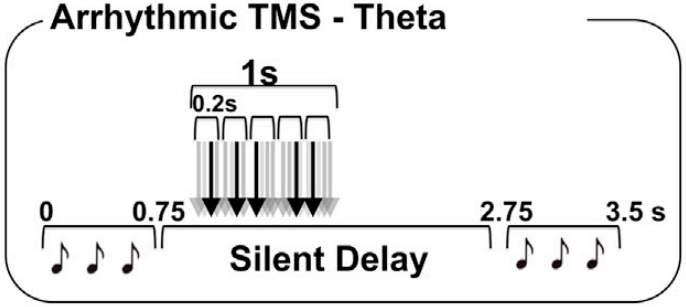
A

TMS Protocol

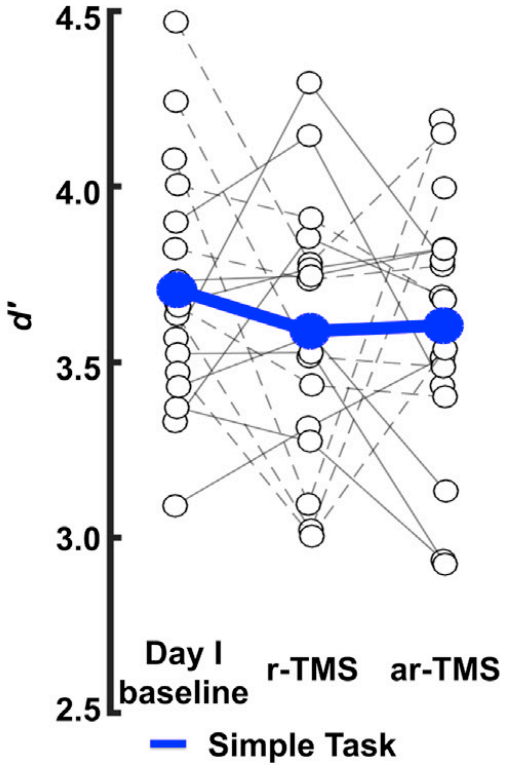


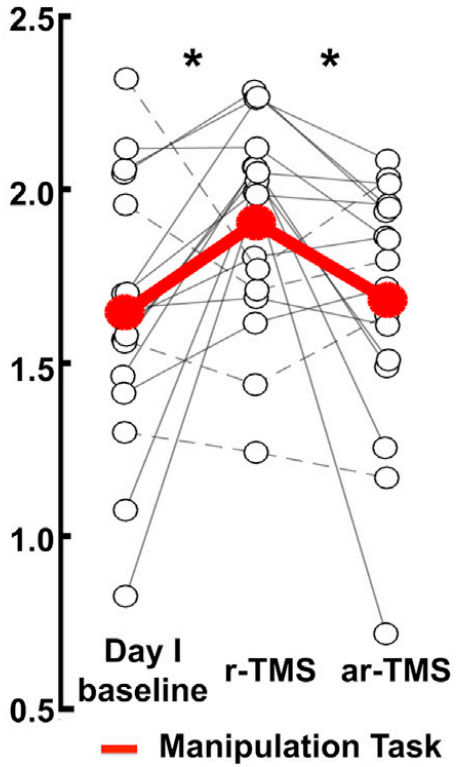
TMS at Theta Frequency



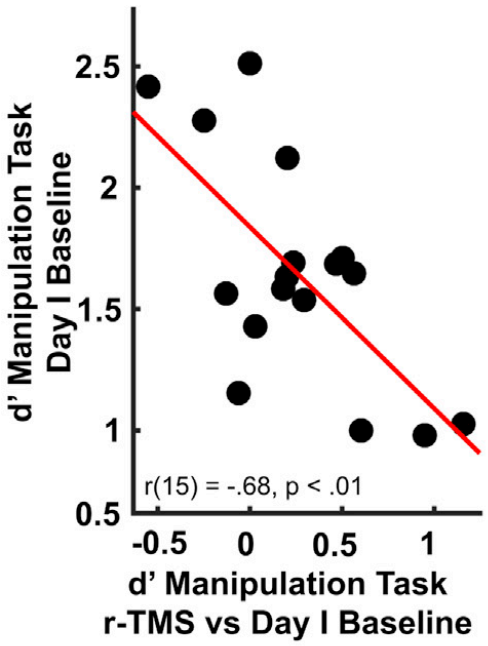


Behavioral Performance

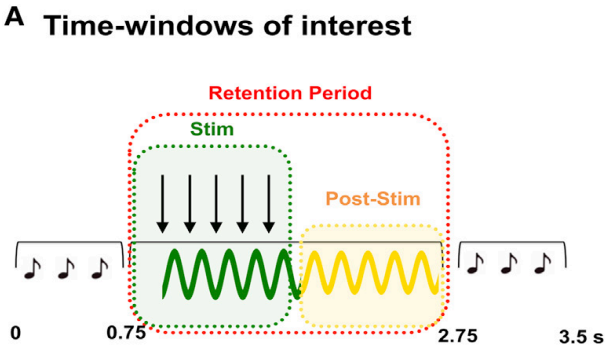




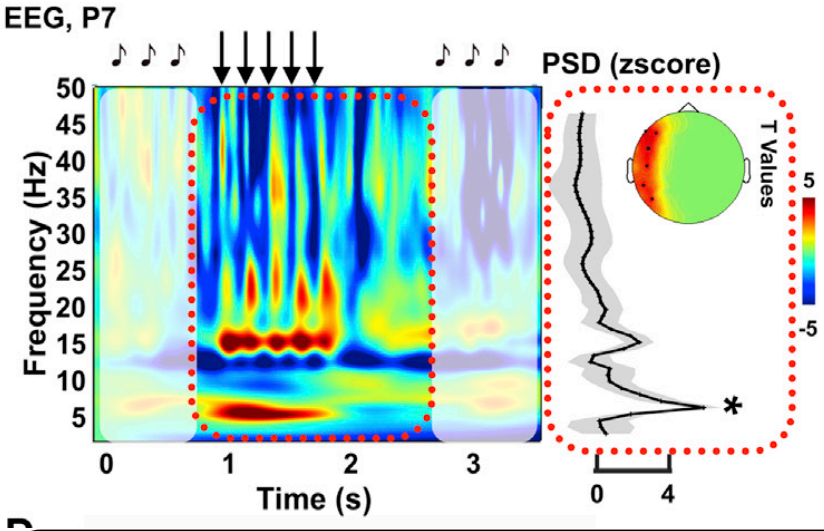
Correlation with Enhancement

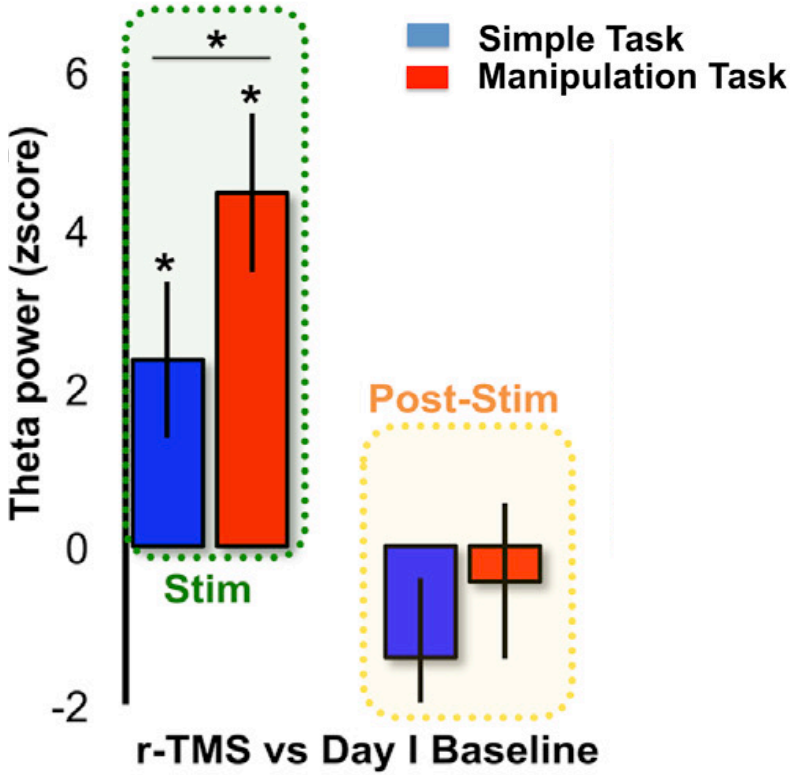


rTMS boosts ongoing oscillations



rTMS vs Baseline *rTMS vs ar-TMS*

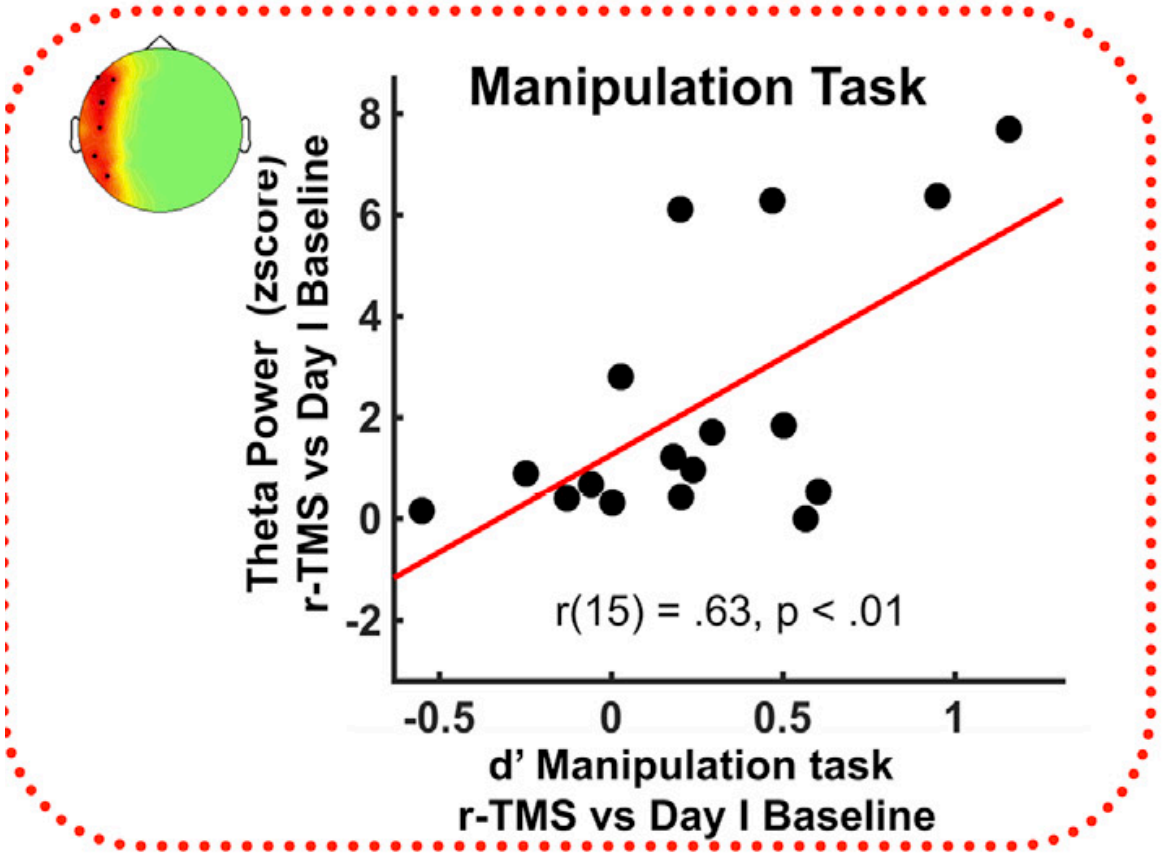




Entrainment is Task specific, but is efficient only during the stimulation time period

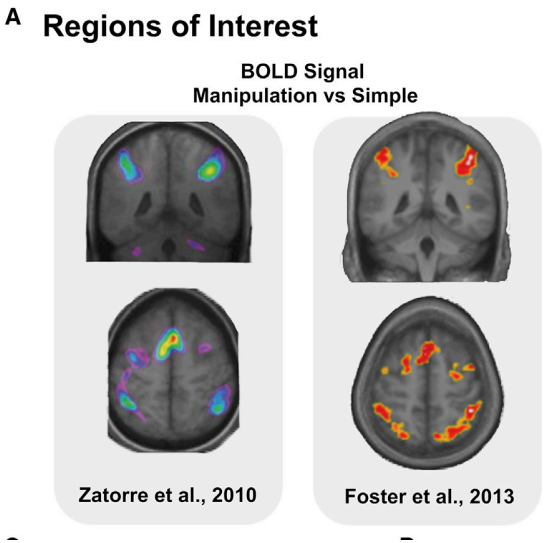
rTMS boosts ongoing oscillations

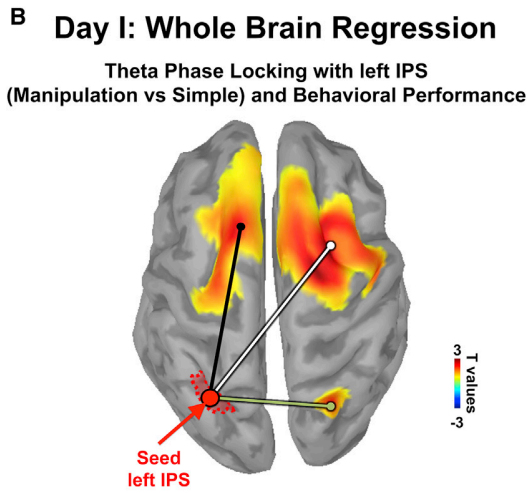
Correlation with Behavioral Enhancement

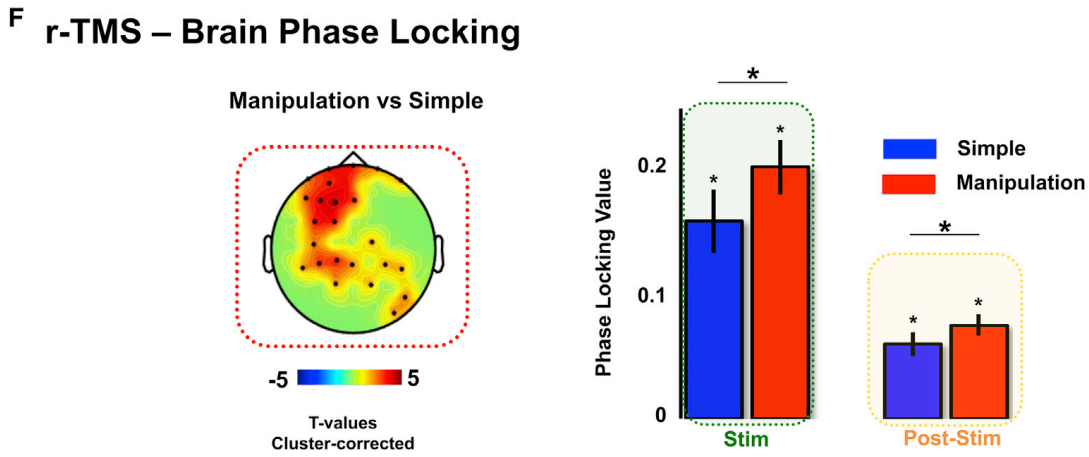


TMS-induced behavioral enhancement is causally related to theta entrainment

Functional connectivity patterns







Phase locking is Task specific, and is efficient during both stimulation and post stimulation time periods

Conclusions

Rhythmic TMS at theta boosts specifically participants performance on the inverted task

No behavioral modulation for the control task or arrhythmic stimulation

Rhythmic TMS boosts ongoing oscillations

Theta power entrained with TMS predicts behavioral benefits

Perspectives

Long term effects of the stimulation

Impact of non information based stimulation on behavioral training *(Venerio et al., 2015)*

Impact of such tools on cognitive disabilities impacting memory

Aging
(Kirova et al., 2015)

Schizophrenia
(Li et al., 2015)

Depression
(Soraggi-Frez et al., 2017)

Developmental Disorders
(Tillmann et al.,2016)

Alzheimer's disease
(Kirova et al., 2015)

Thank you !

Philippe Albouy, Aurélien Weiss, Sylvain Baillet & Robert J. Zatorre

McGill

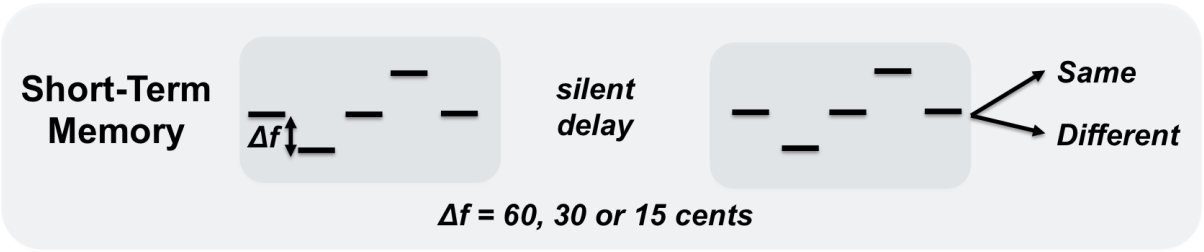
Z Lab

neurospeed lab
imaging at the speed of brain

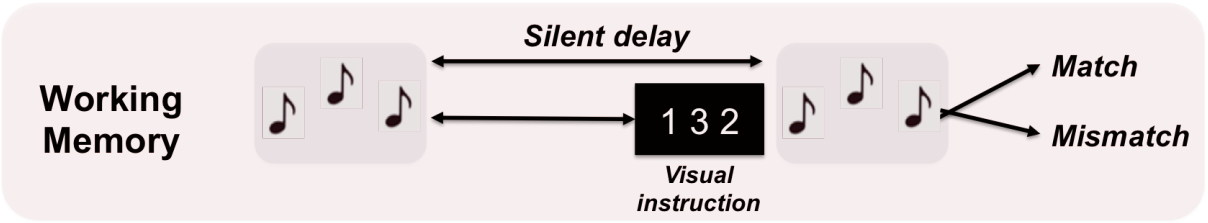
neuro

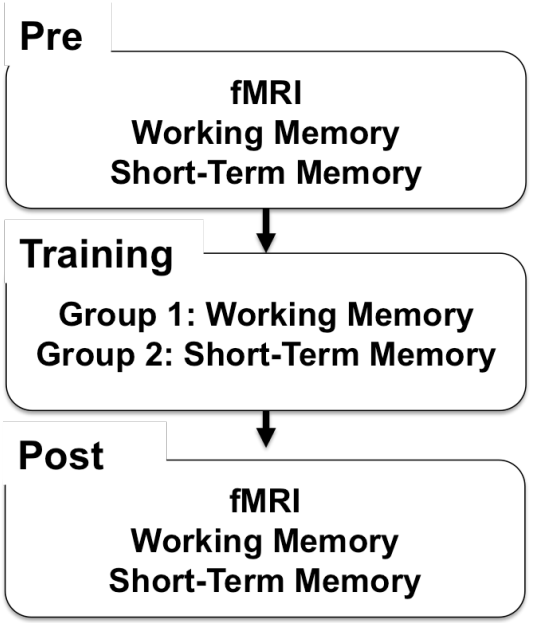
Brams
International Laboratory for
Brain, Music, and Sound Research

Behavioral training: Working vs Short-term memory

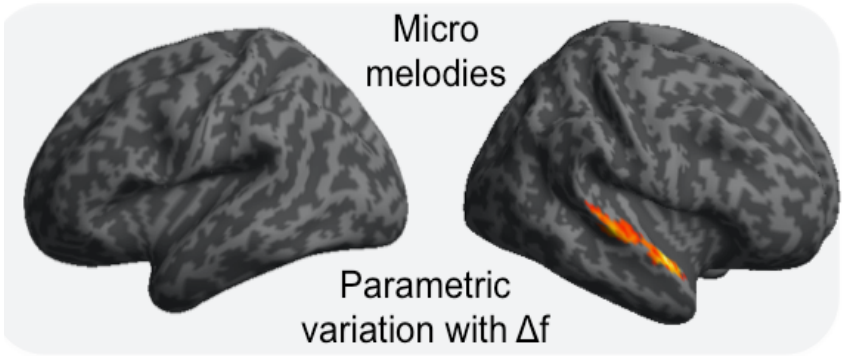


Micromelodies: Zatorre et al., 2012

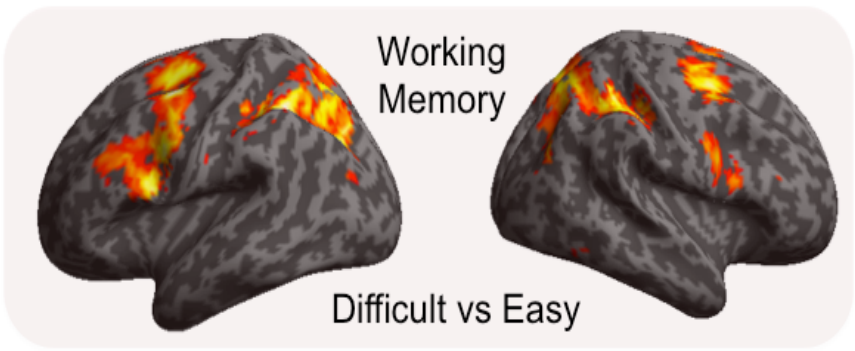




Short-Term Memory

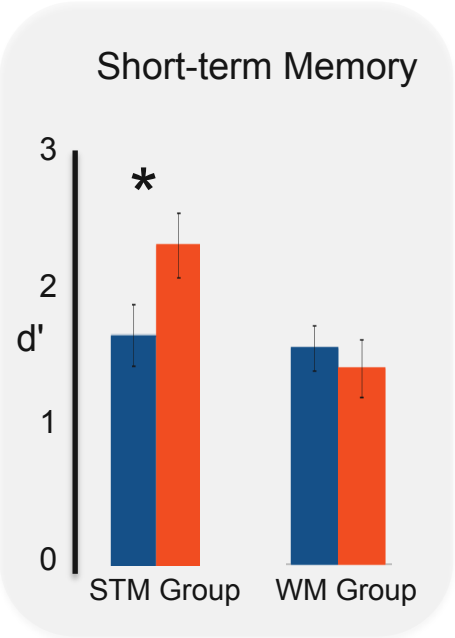


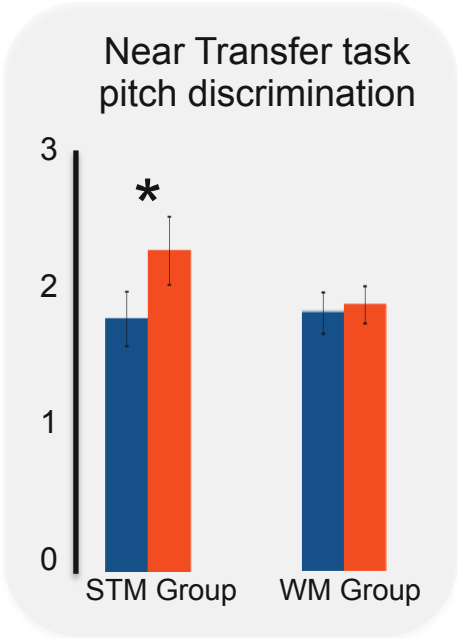
Working Memory

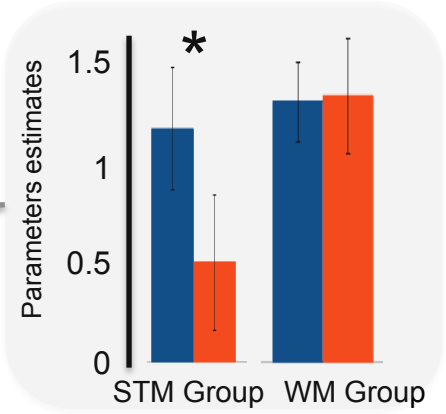


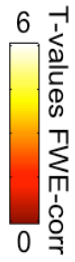
Collaboration with Ahissar Lab, Hebrew University of Jerusalem

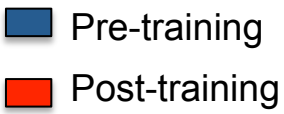
Behavioral training: Working vs Short-term memory

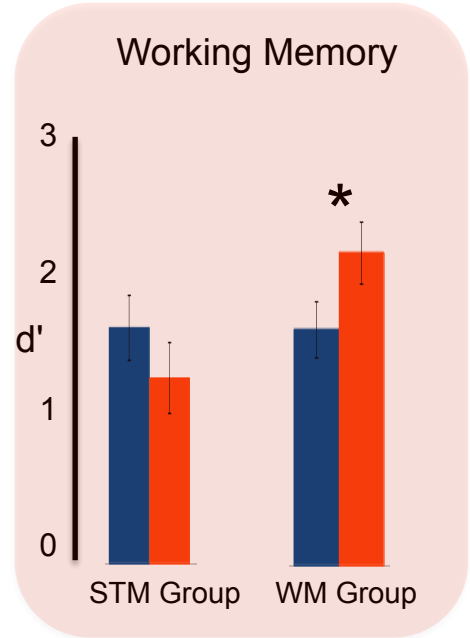


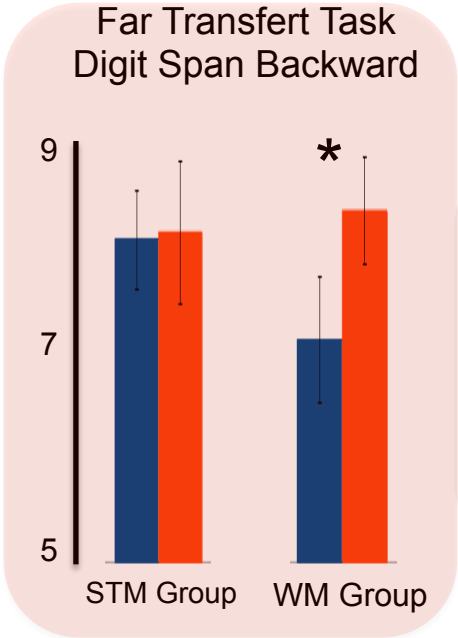


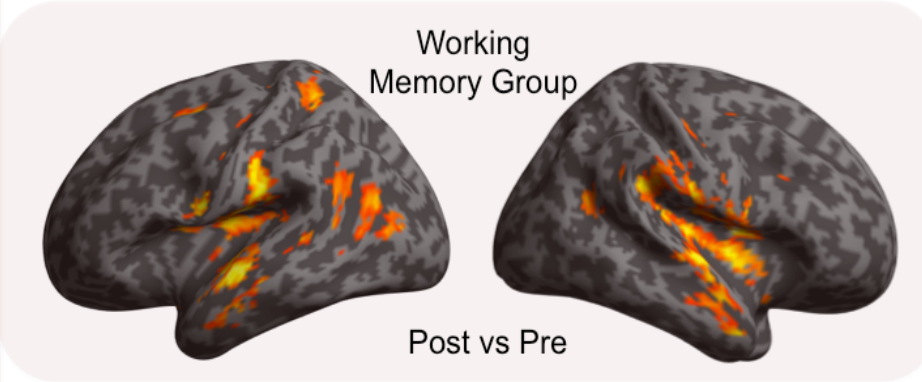












Discussion

Training Task is specific

Near transfer only for STM, far transfer for WM

STM: see Zatorre et al, (2012) decreased activity post training in the auditory cortex

WM task post –training effects in low level sensory regions

WM: Reverse Hierarchy theory (Ahissar and Hochstein 1997): Dorsal pathway sending backward signals to sensory areas to optimize stimulus representation (connectivity)

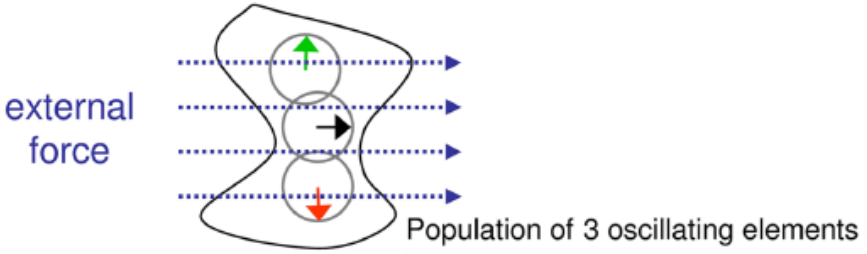
Can behavioral performance be boosted without training, via external non-invasive intervention ?

Additional Material

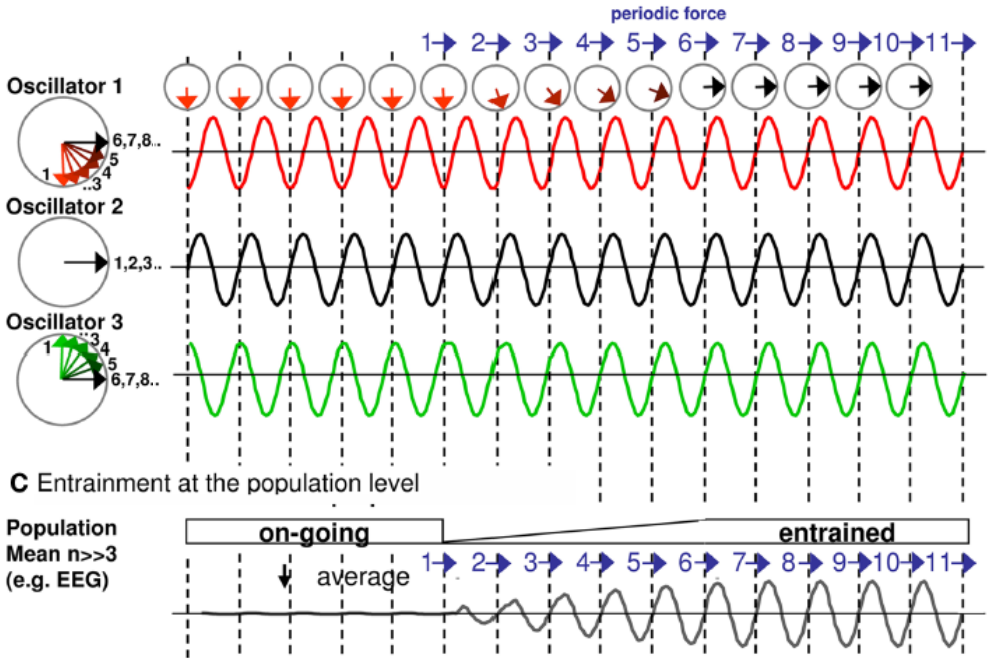
Boosting working memory with Behavioral Training

Introduction

Rhythmic TMS

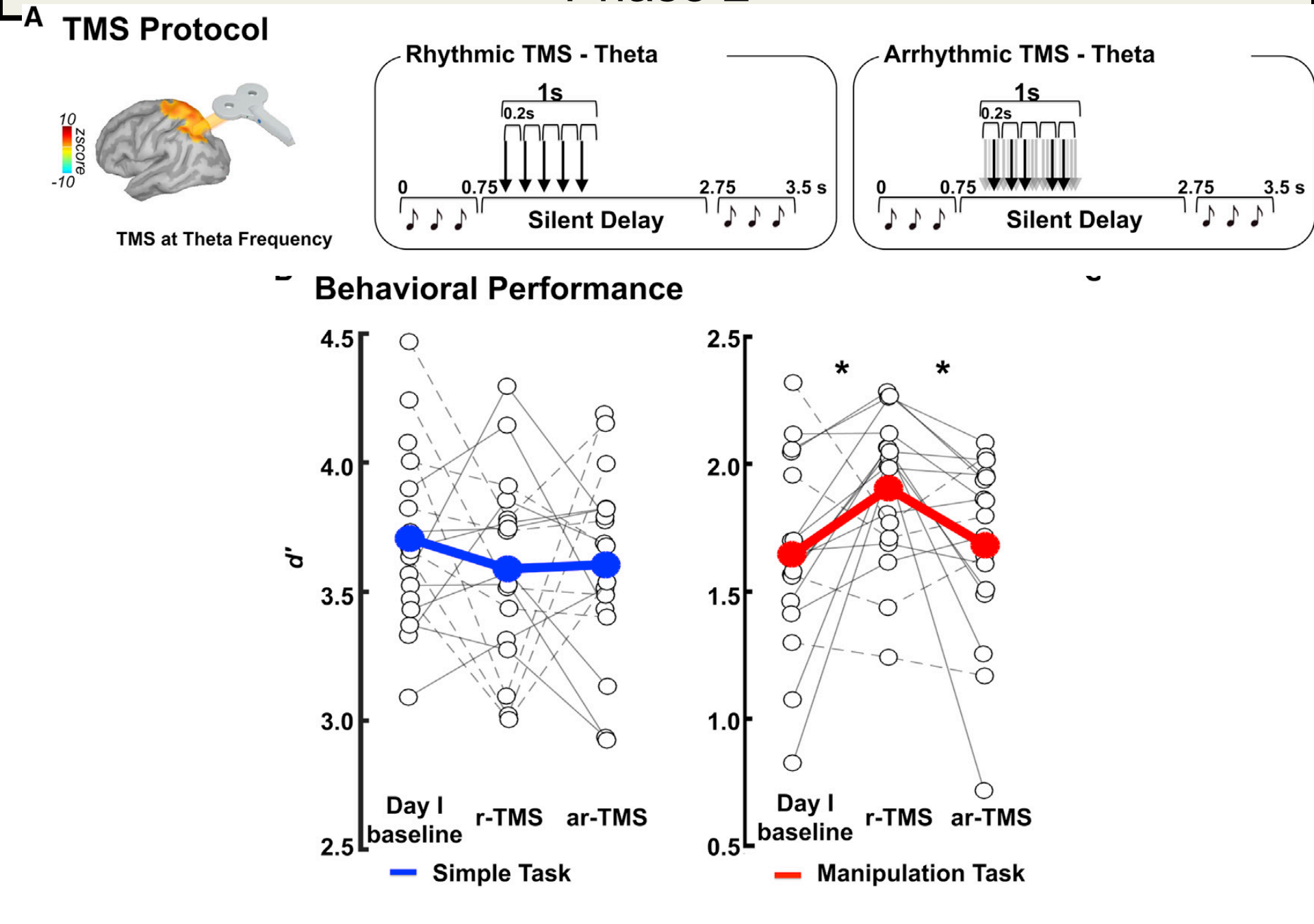


Phase resetting of ongoing oscillations

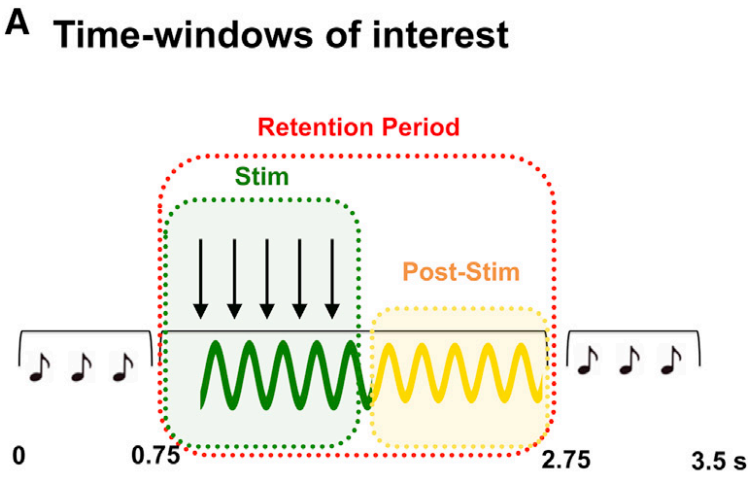


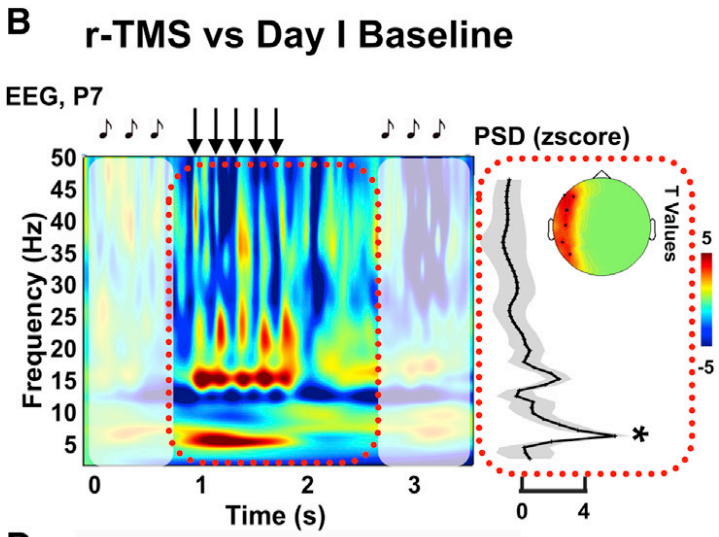
Thut et al, 2012

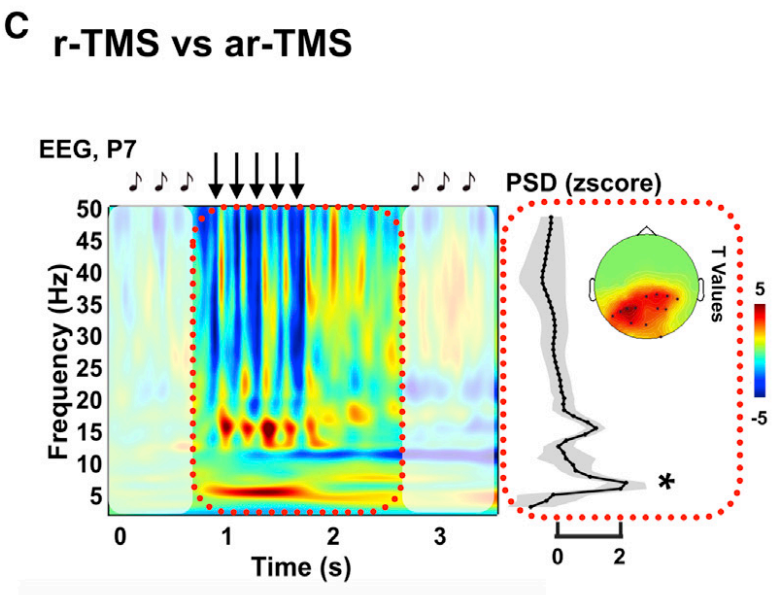
Phase 2

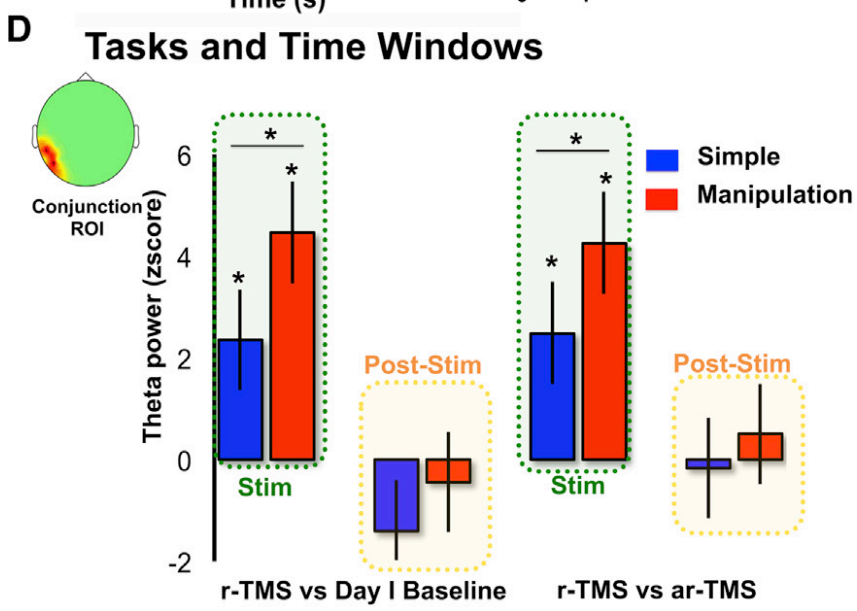

A
TMS Protocol
10
zscore
-10
TMS at Theta Frequency
Rhythmic TMS - Theta
1s
0.2s
0
0.75
2.75
3.5 s
Silent Delay
Arrhythmic TMS - Theta
1s
0.2s
0
0.75
2.75
3.5 s
Silent Delay
Behavioral Performance
d'
4.5
4.0
3.5
3.0
2.5
Day I
baseline
r-TMS
ar-TMS
Simple Task
2.5
2.0
1.5
1.0
0.5
*
*
Day I
baseline
r-TMS
ar-TMS
Manipulation Task

EEG data : Entrainment



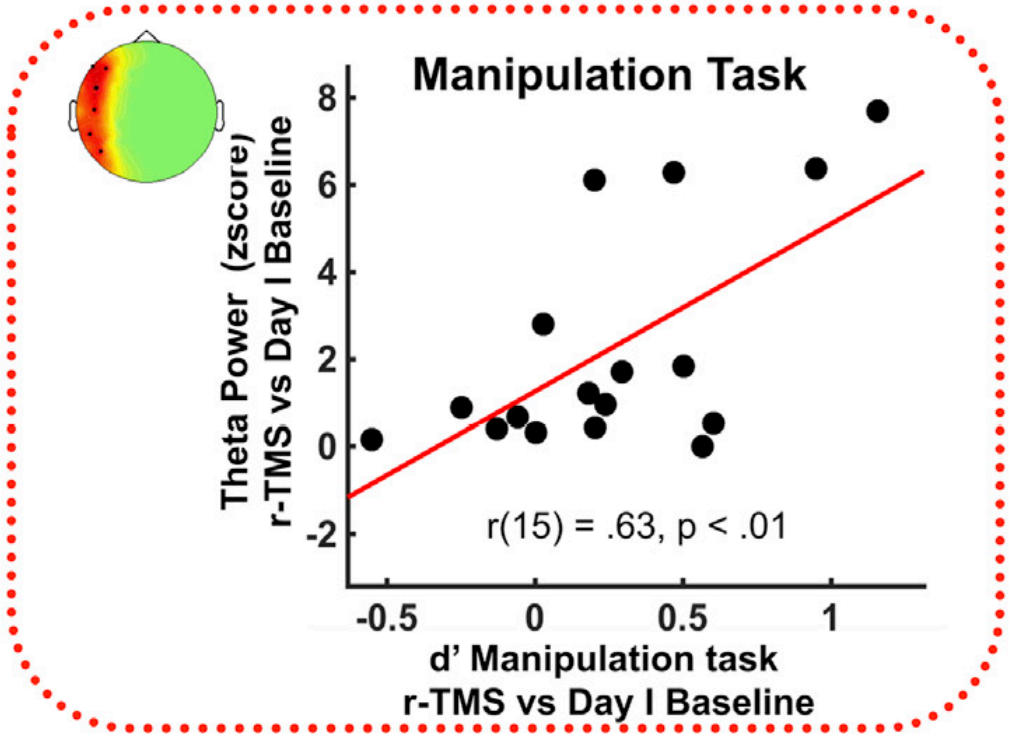


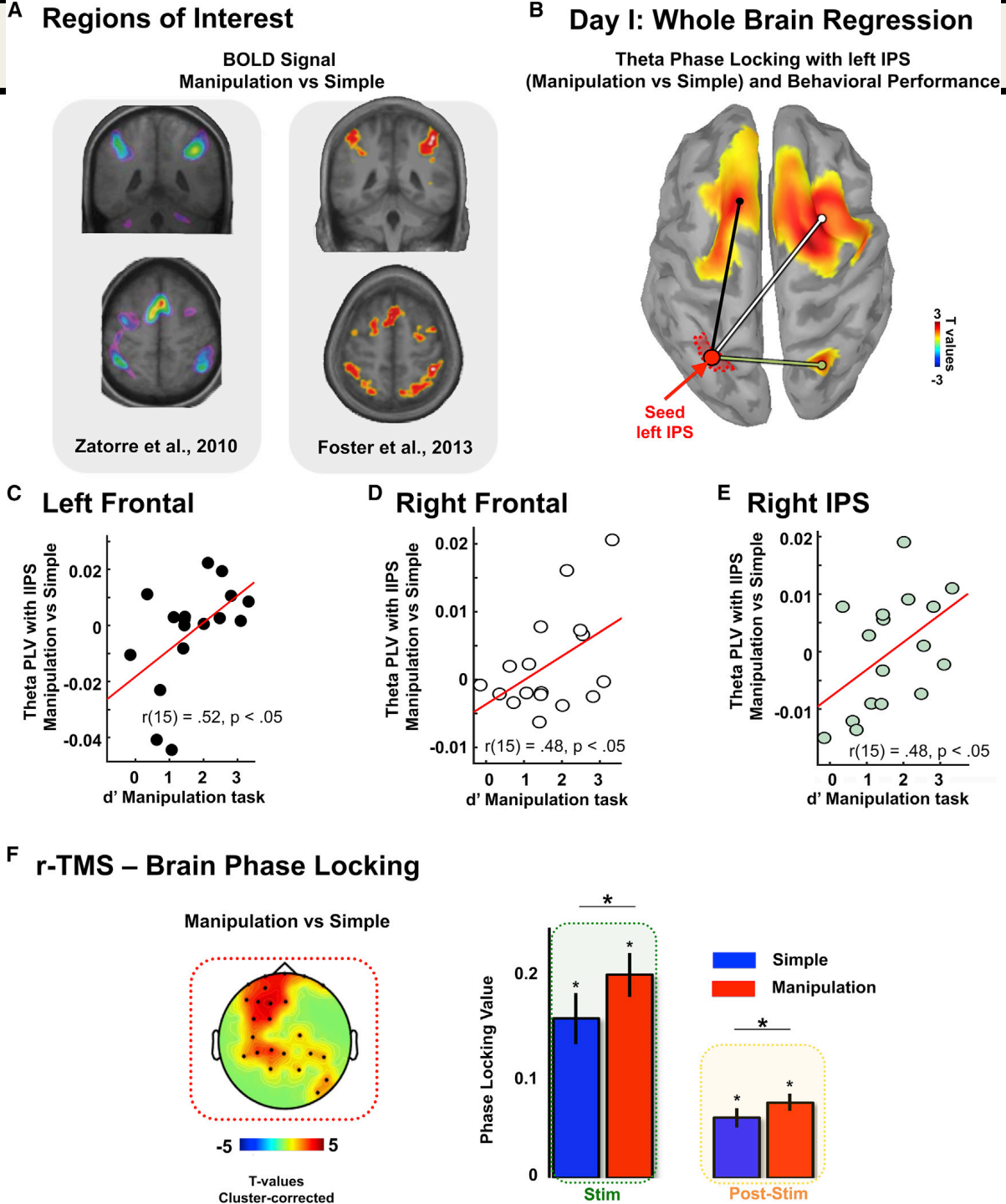




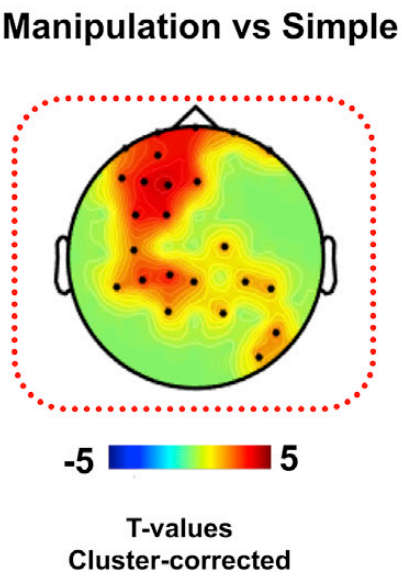
E

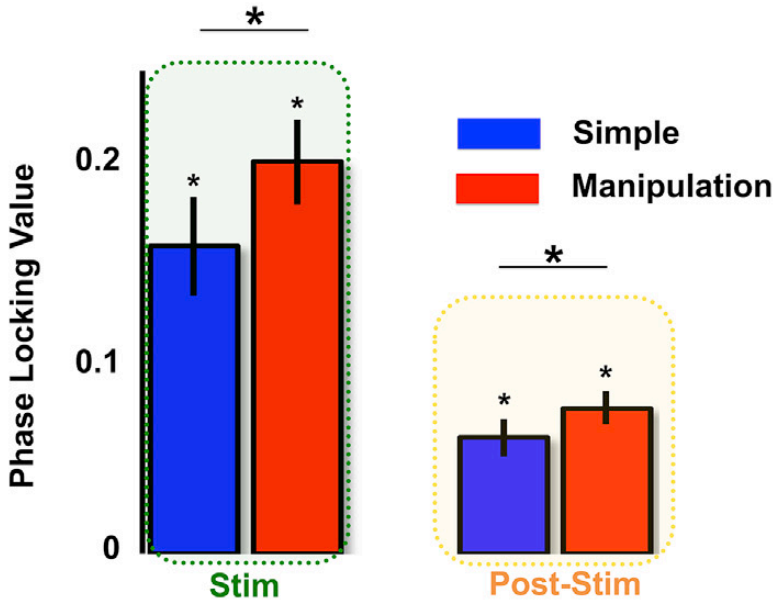
Correlation with Behavioral Enhancement



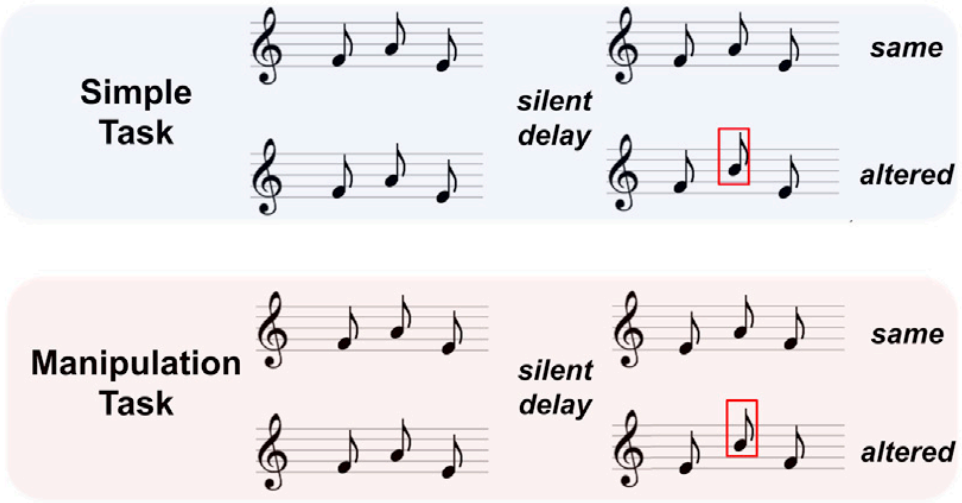

A
Regions of Interest
BOLD Signal
Manipulation vs Simple
Zatorre et al., 2010
Foster et al., 2013
B
Day I: Whole Brain Regression
Theta Phase Locking with left IPS
(Manipulation vs Simple) and Behavioral Performance
T values
3
-3
Seed
left IPS
C
Left Frontal
Theta PLV with lIPS
Manipulation vs Simple
0.02
0
-0.02
-0.04
r(15) = .52, p < .05
0 1 2 3
d' Manipulation task
D
Right Frontal
Theta PLV with lIPS
Manipulation vs Simple
0.02
0.01
0
-0.01
r(15) = .48, p < .05
0 1 2 3
d' Manipulation task
E
Right IPS
Theta PLV with lIPS
Manipulation vs Simple
0.02
0.01
0
-0.01
r(15) = .48, p < .05
0 1 2 3
d' Manipulation task
F
r-TMS – Brain Phase Locking
Manipulation vs Simple
-5
5
T-values
Cluster-corrected
Phase Locking Value
0.2
0.1
0
*
Simple
Manipulation
Stim
Post-Stim

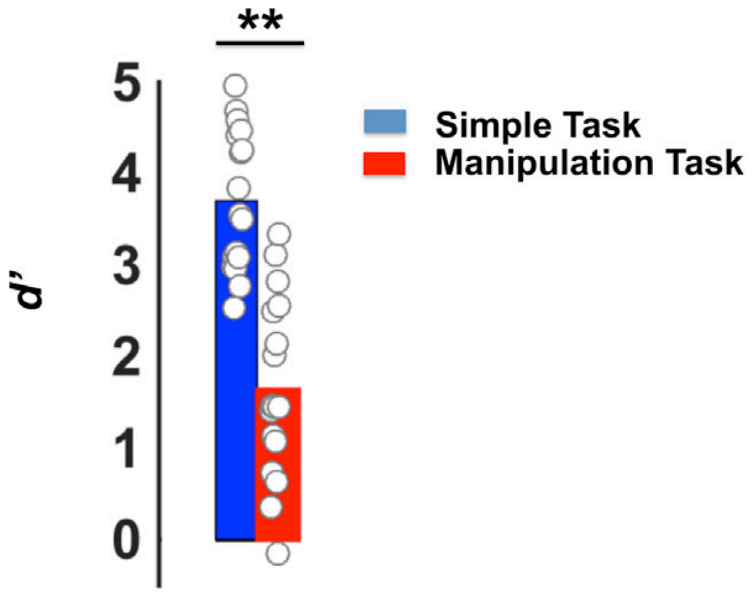
r-TMS – Brain Phase Locking





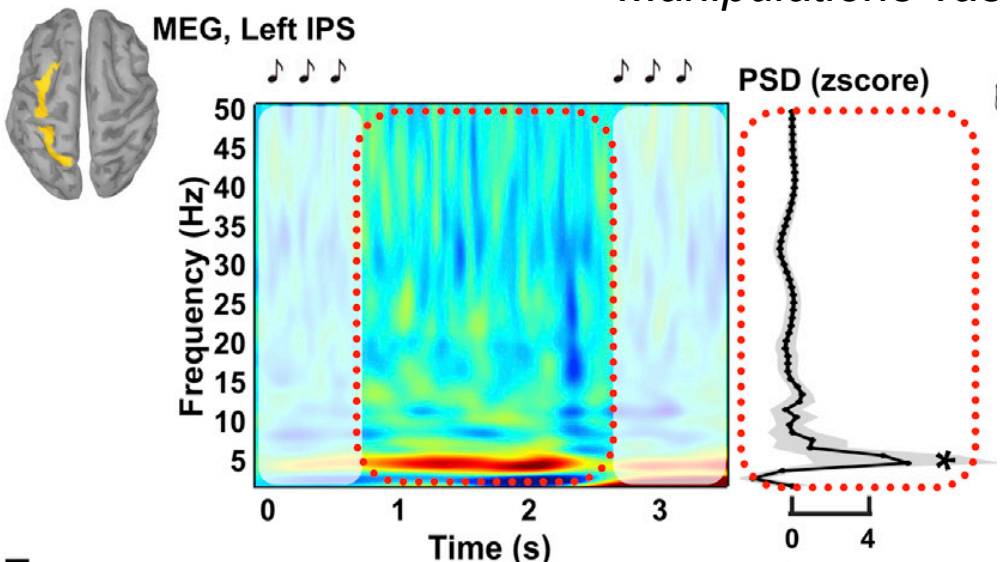
rTMS to boost Working Memory specifically

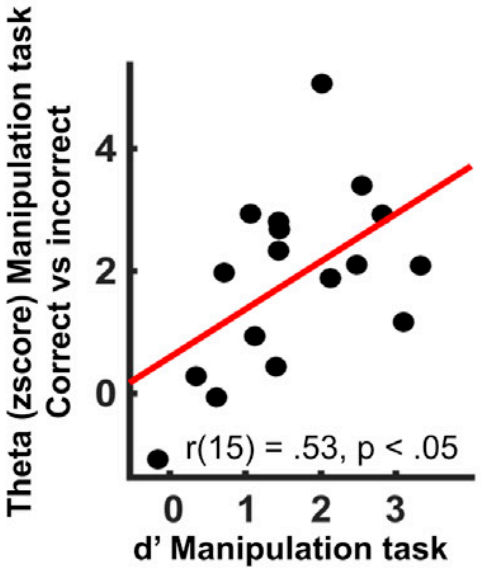




Manipulation vs Simple

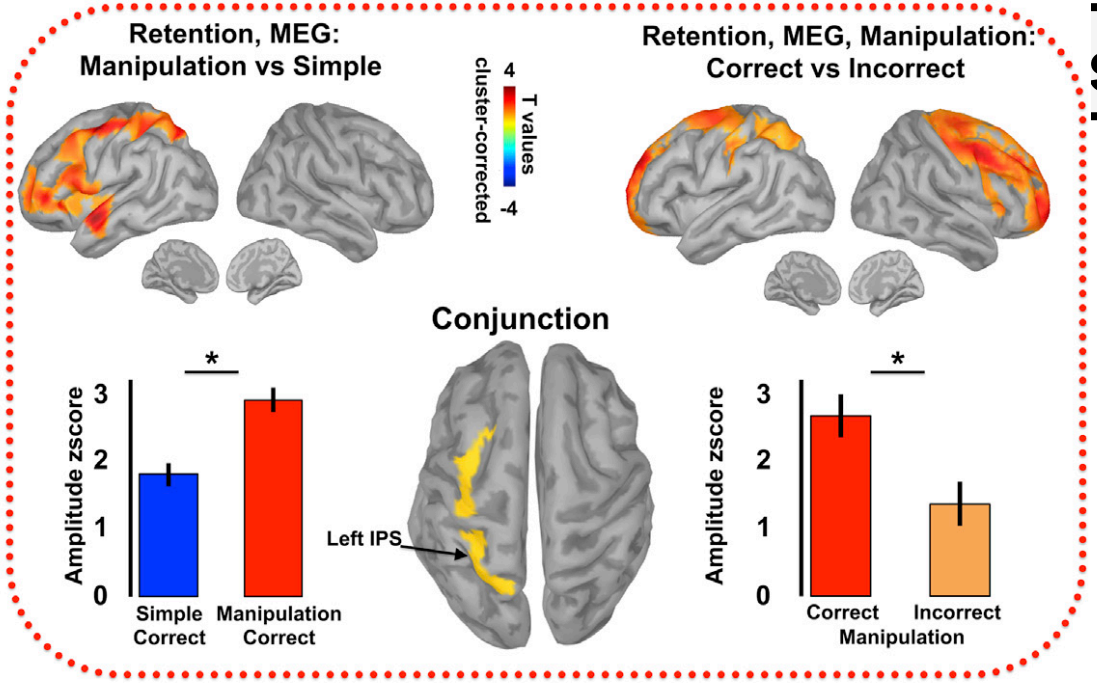
Correct vs Incorrect trials Manipulations Task

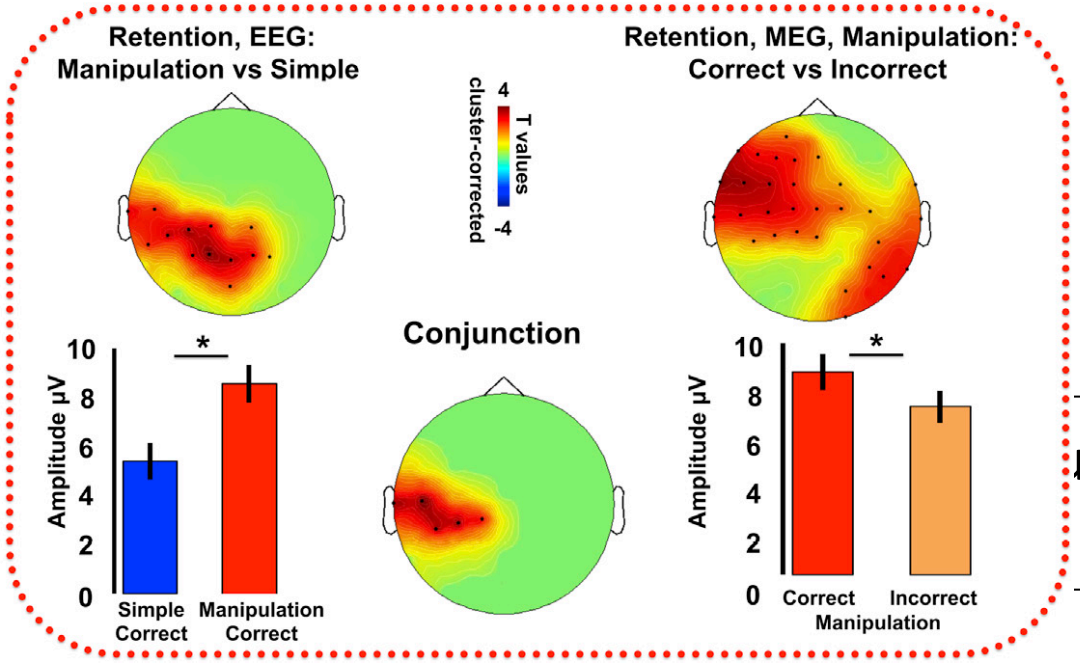




Albouy , Weiss, Baillet and Zatorre., 2017 Neuron

D st





Left Front ulation of

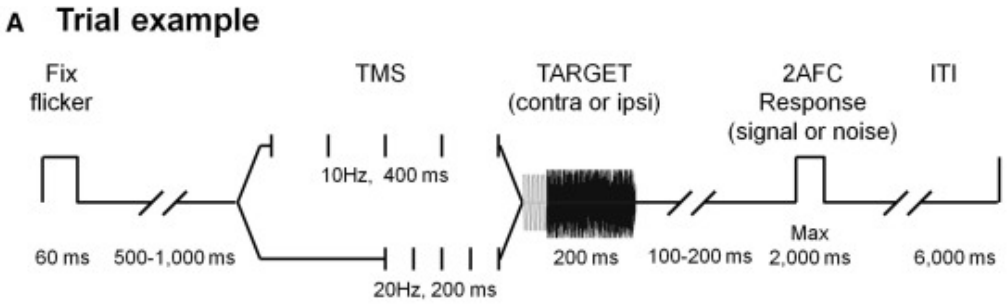
Introduction

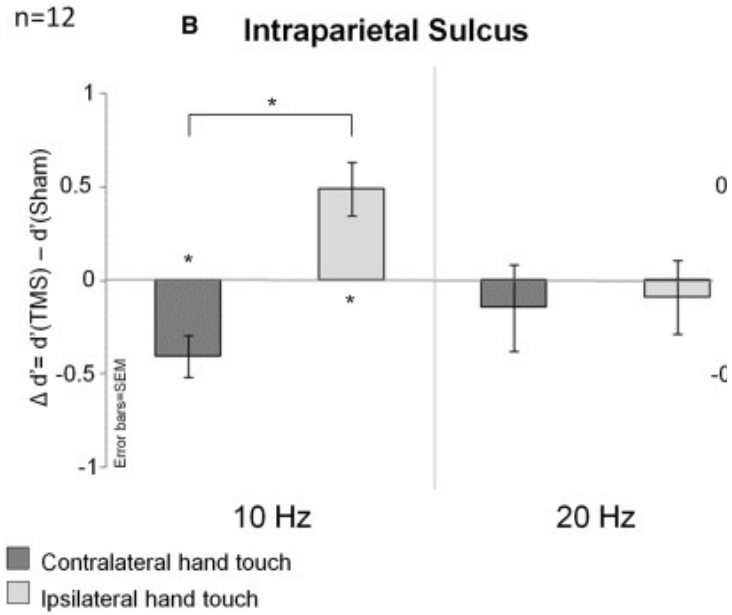
Entraining functionally relevant oscillations to modulate the perceptual experience

Current Biology 24, 329–332, February 3, 2014

Alpha Stimulation of the Human Parietal Cortex Attunes Tactile Perception to External Space

Manuela Ruzzoli[1,3,*] and Salvador Soto-Faraco[1,2,3]

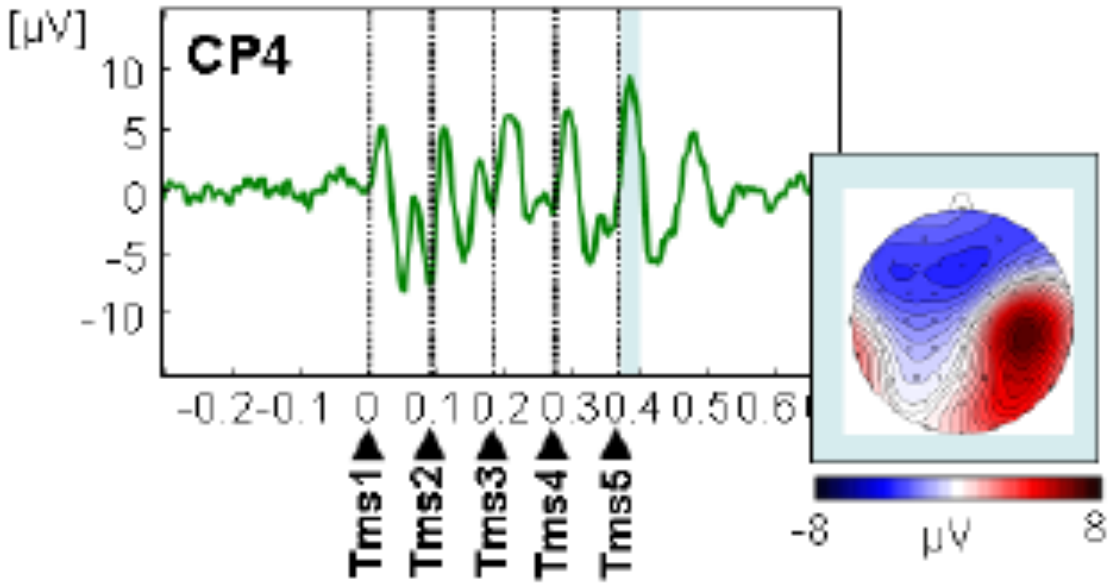




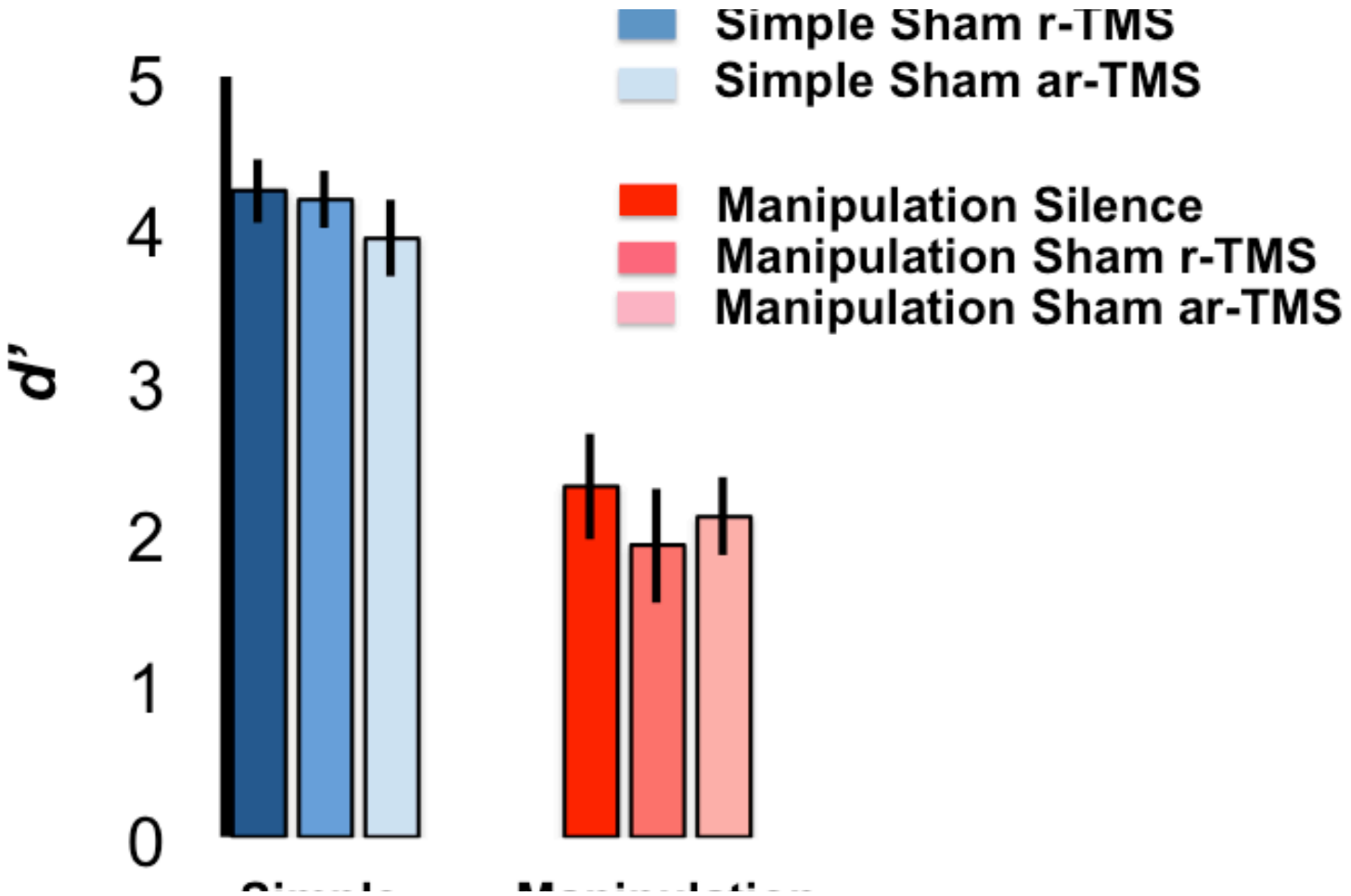
Introduction

Rhythmic TMS

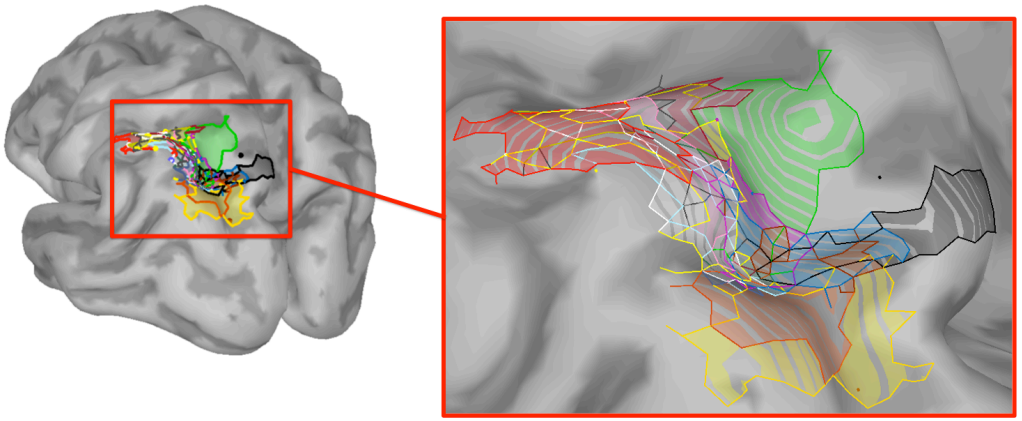
Phase resetting of ongoing oscillations



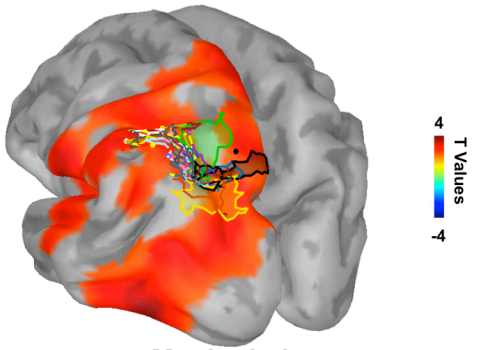
Thut et al, 2012


Simple Sham r-TMS
Simple Sham ar-TMS
Manipulation Silence
Manipulation Sham r-TMS
Manipulation Sham ar-TMS
d'
5
4
3
2
1
0

A. Region of interest (Event Related Fields)

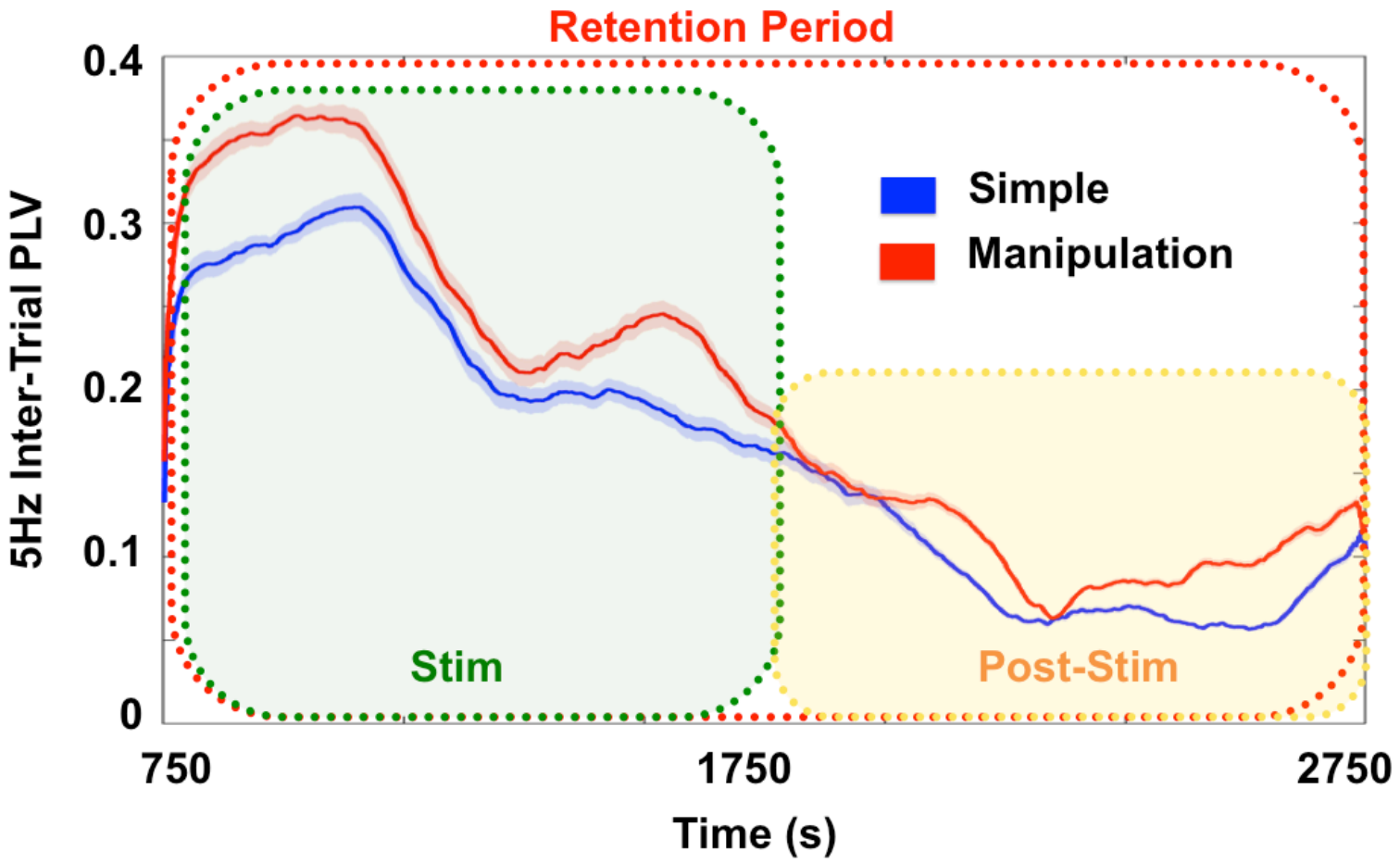


B. Convergence with Theta Generators

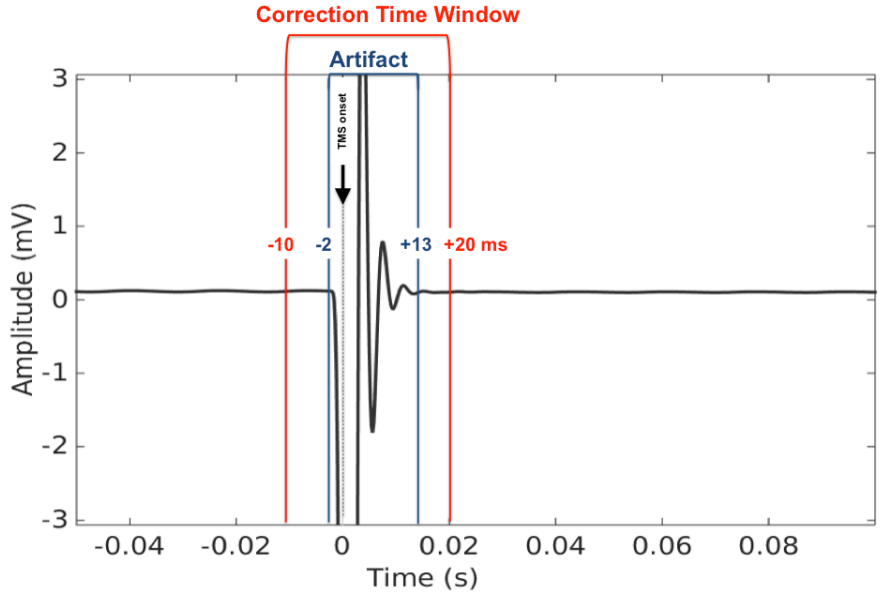


Manipulation
Correct vs Incorrect

Inter-Trial Phase Locking Value - r-TMS



A. Artefact Time Window



B. Artefact correction – Time Frequency