Relating individual differences in short-term memory-derived EEG to cognitive training effects

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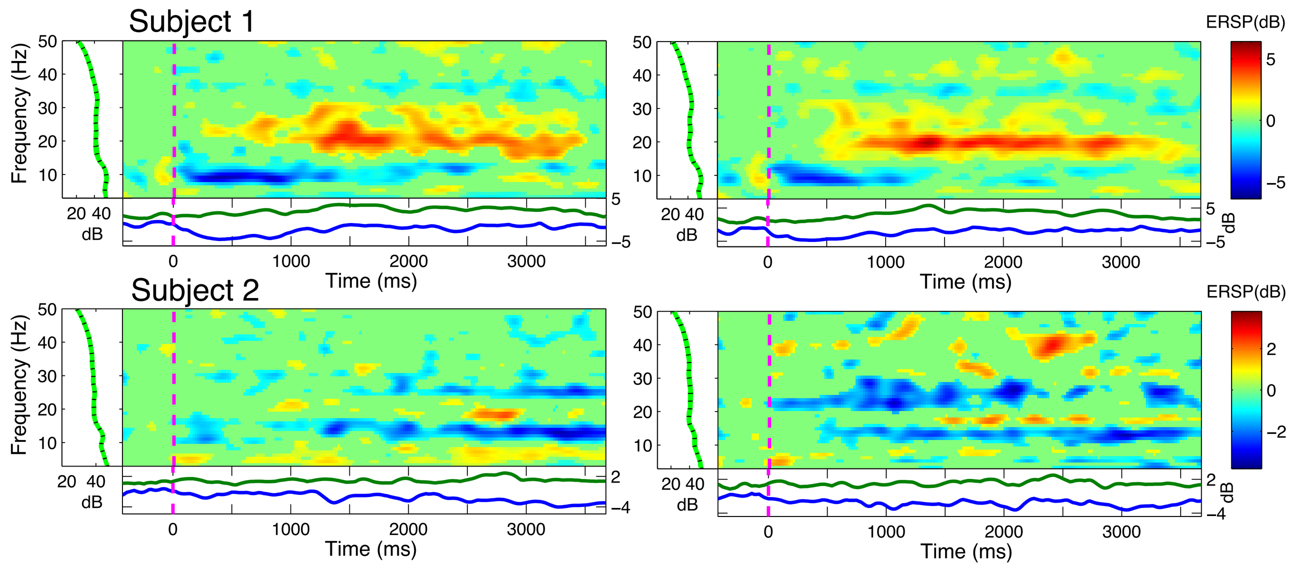
Introduction

Voltage (i.e., ERP) measures of the delay-period during a working memory task show considerable individual differences that correlate with memory span (Vogel et al., 2004)



Spectral measures of delay-period EEG activity show considerable individual differences and are also stable and trait-like (Kundu et al., SFN 2010 poster, shown above)

Training on delayed-recall tasks causes changes in BOLD and FA measures that localize to fronto-parietal brain regions (Olesen et al, 2004; Takeuchi et al., 2010)

Prolonged, adaptive training on WM tasks improves performance on the task itself, as well as on nonmnemonic tests of general fluid intelligence (gF), with the largest gains seen in low gF individuals (Jaeggi et al., 2008)

Does training on a working memory task show systematic task-related changes in an individual's delay-period activity?

Methods

2 Groups : Dual N-back training (n=3; Brain Workshop http://brainworkshop.sourceforge.net/) and **control training** (n=3 ; Tetris http://www.gosu.pl/tetris/); randomized. Both groups trained 40 minutes per day, 5 times per week, for 5 weeks. The control task does not have overt memory demands. Subjects were assessed pre- and post- training by select measures.

Pre- and post- training measures

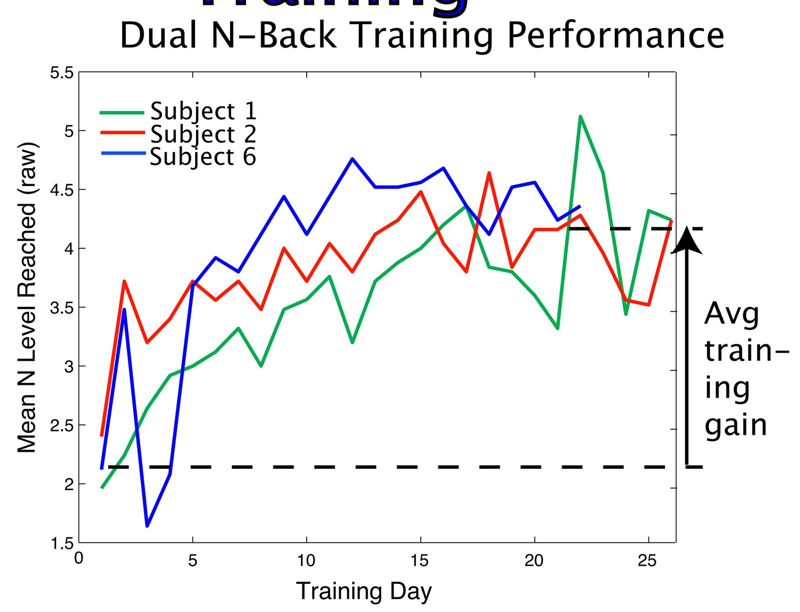
Electrophysiological measures:
1. Spatial delayed-recognition task: Serial presentation of 2 or 4 identical square stimuli in different locations with lateralized presentation (randomized). Subjects were instructed to remember the locations marked by each stimulus in the cued hemifield. 160 trials per session. TMS was delivered to left SPL for 50% of trials (randomized).
2. Change-detection task: Stimuli were presented simultaneously. Load 2, 4, and 6 were tested (randomized). Lateralized display. Subjects were instructed to remember color and location of colored square stimuli in the cued hemifield. 200 trials per condition. Task parameters replicated from Vogel et al., 2004.

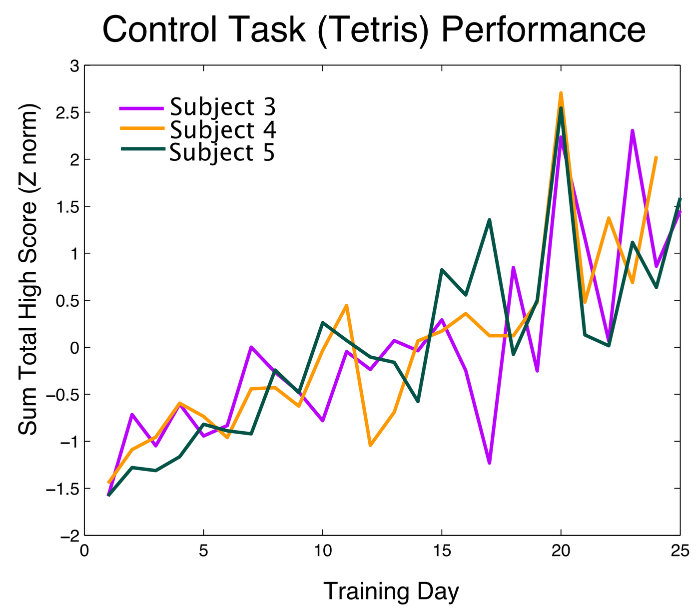
Psychometric Measures:
1. Short term memory capacity (K value) derived from change detection task.
$K = S(H-FA)$
2. Raven's Advanced Progressive Matrices (RAPM; Raven, 1990)
3. Operation Span (OPAN; Turner & Engle, 1989)

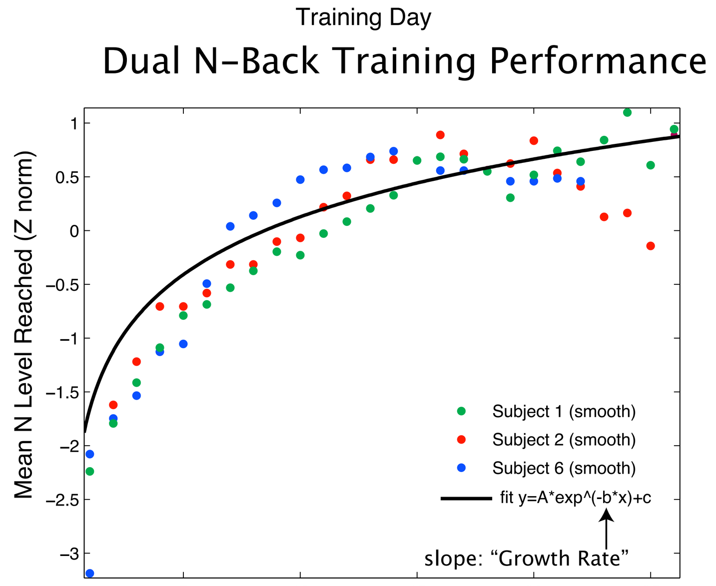
TMS/EEG:
Recorded with a 60-channel TMS-compatible amplifier (Nexstim, Helenski, Finland). Sample-and-hold circuit holds amplifier output constant from 100 us to 2 ms post-stimulus. Data were acquired at 1450 Hz, downsampled to 500 Hż and filtered (0.1-80 Hz) offline. All data processing was done with a combination of MATLAB (Mathworks, Inc), EEGLAB and ERPtoolbox (USCD) and, Fieldtrip (Donders Institute, Nijmegen).
Effective connectivity analysis methods follow Casali et al. 2010. Data-driven measures include Significant Current Density (SCD; local regional measure); Significant Current Scatter (SCS; long range distance measure), and broadband phase locking (bPL; temporal measure). Mathematically orthogonal.

Results

Training





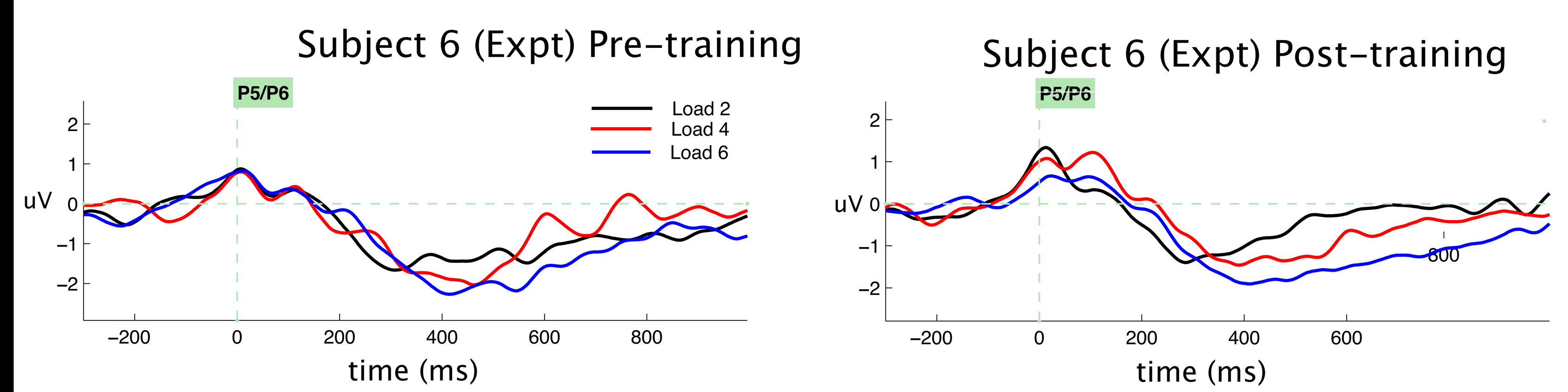


Learning on both tasks well fit by power law. Data were smoothed with moving average window over 5 day span. Comparable growth rates for both tasks implies effective learning. Mean **b(nback)**=0.0012, adj R^2=0.89; mean **b(tetris)** = 0.0011, adj R^2=0.747. Experimental group showed positive correlation between training gains and delay period power in the theta (4-7 Hz) and alpha (8-14 Hz) bands. Negative correlation found between gains and gamma (26-50 Hz) band power. Control group showed positive correlations between training gain and alpha band power. No relationship was apparent between gains and beta (15-25 Hz) band power for either group.

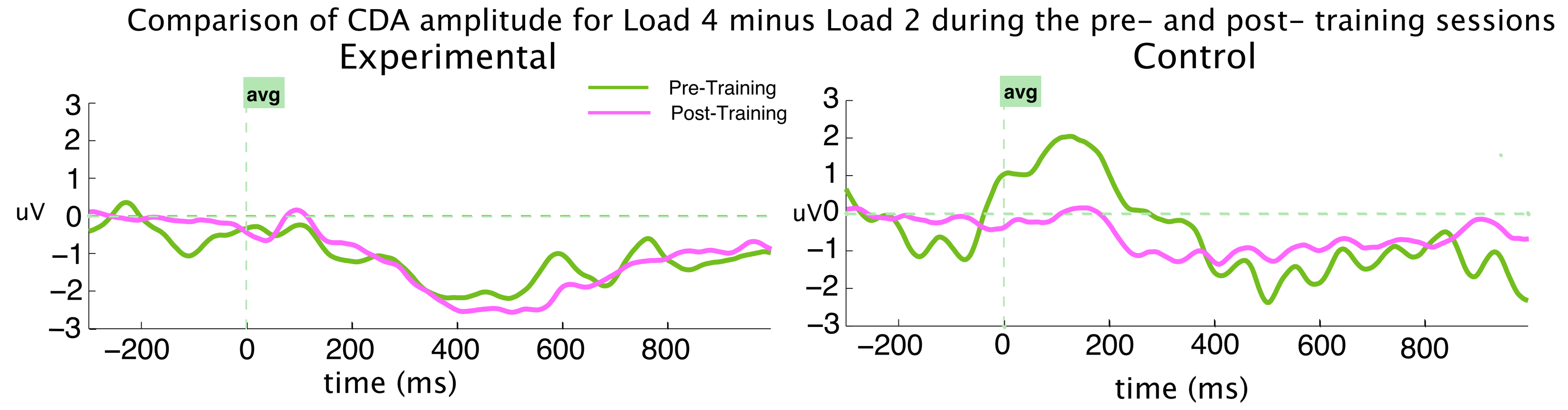
Pre-Post Psychometric Measures

Measure	Session					
Group		**Experimental**			**Control**		
Subject		**1**	**2**	**6**	**3**	**4**	**5**
K	1	1.46	2.24	2.36	1.96	2.36	1.96
	2	2.04	2.36	2.84	1.42	2.60	1.84
	Mean Change	0.40			-0.14		
RAPM	1	26	31	30	30	31	24
	2	32	29	32	30	35	26
	Mean Change	2			2		
OSPAN	1	50	39	43	38	56	61
	2	52	45	44	62	50	75
	Mean Change	3			10		

Pre-Post "Change Detection" ERP Measures

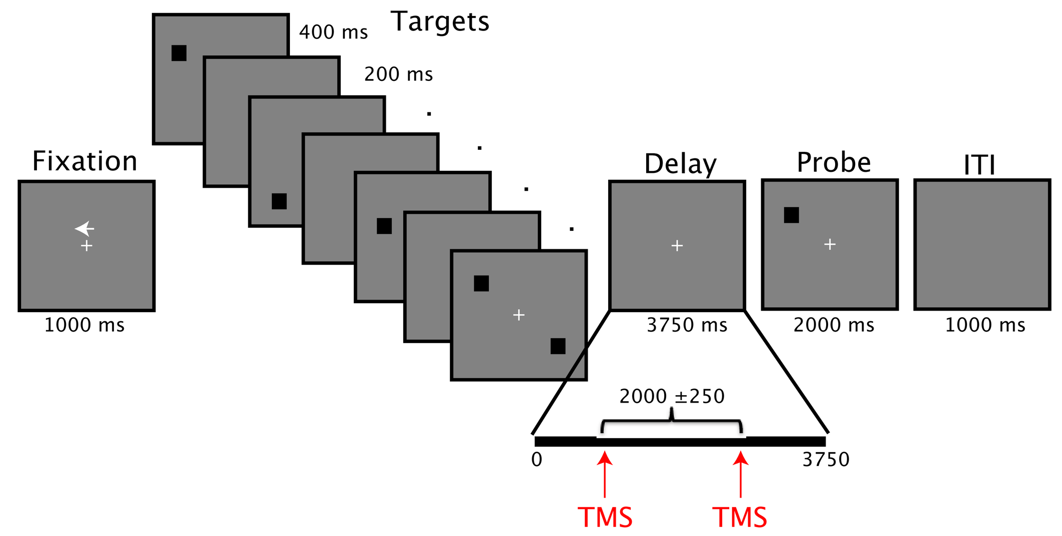


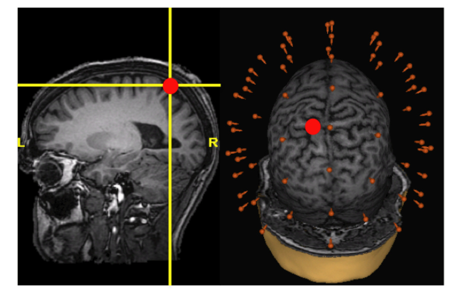
Comparison of CDA amplitude for Load 4 minus Load 2 during the pre- and post- training sessions

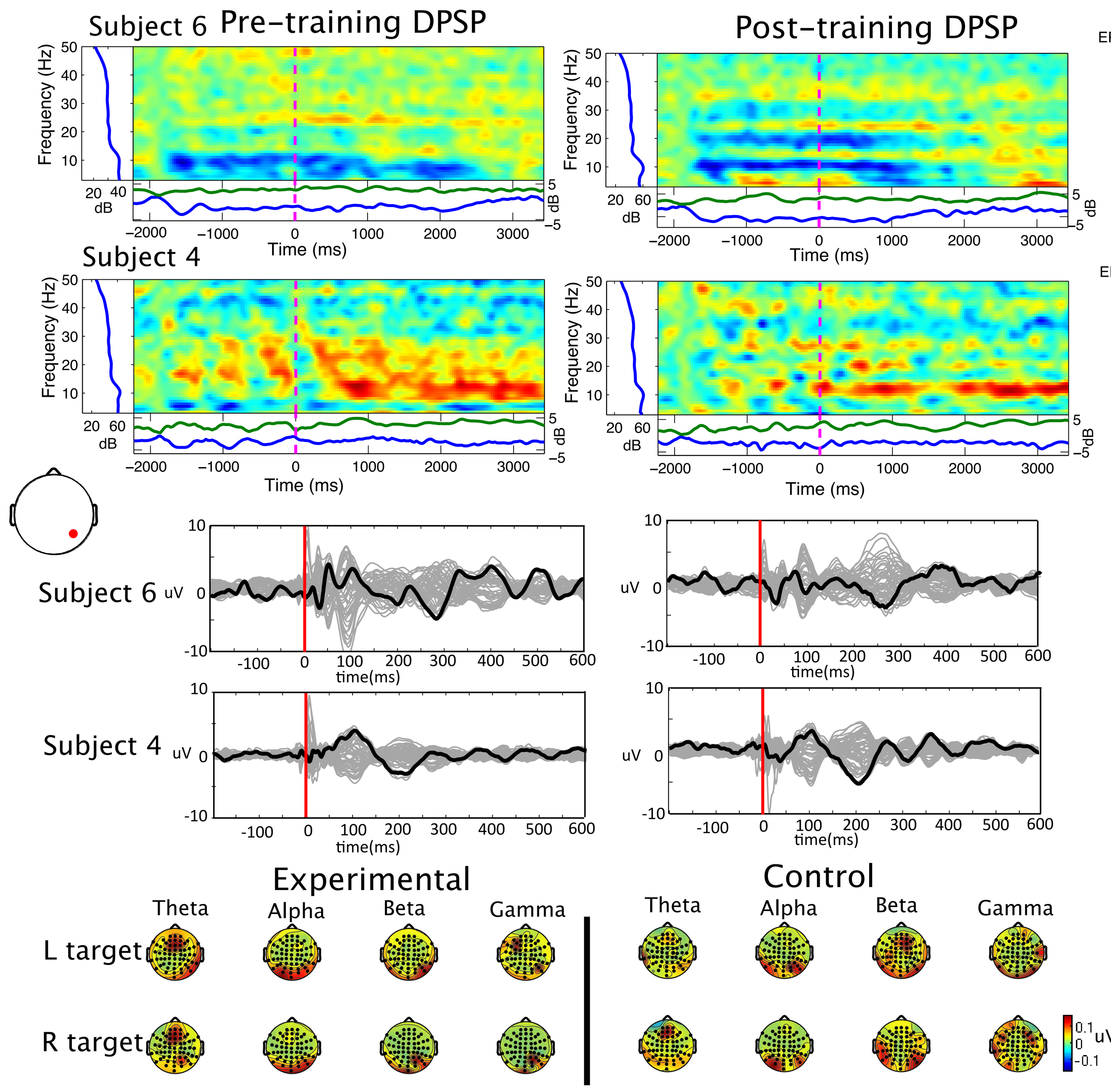


There is change in neural contralateral delay activity (CDA) between pre- and post-training sessions. Increased separation of load-related CDA (loads 6, 4, and 2) post-training vs pre-training for experimental compared to control subjects.

Pre-Post Spatial Delayed Recognition EEG and TMS-EEG





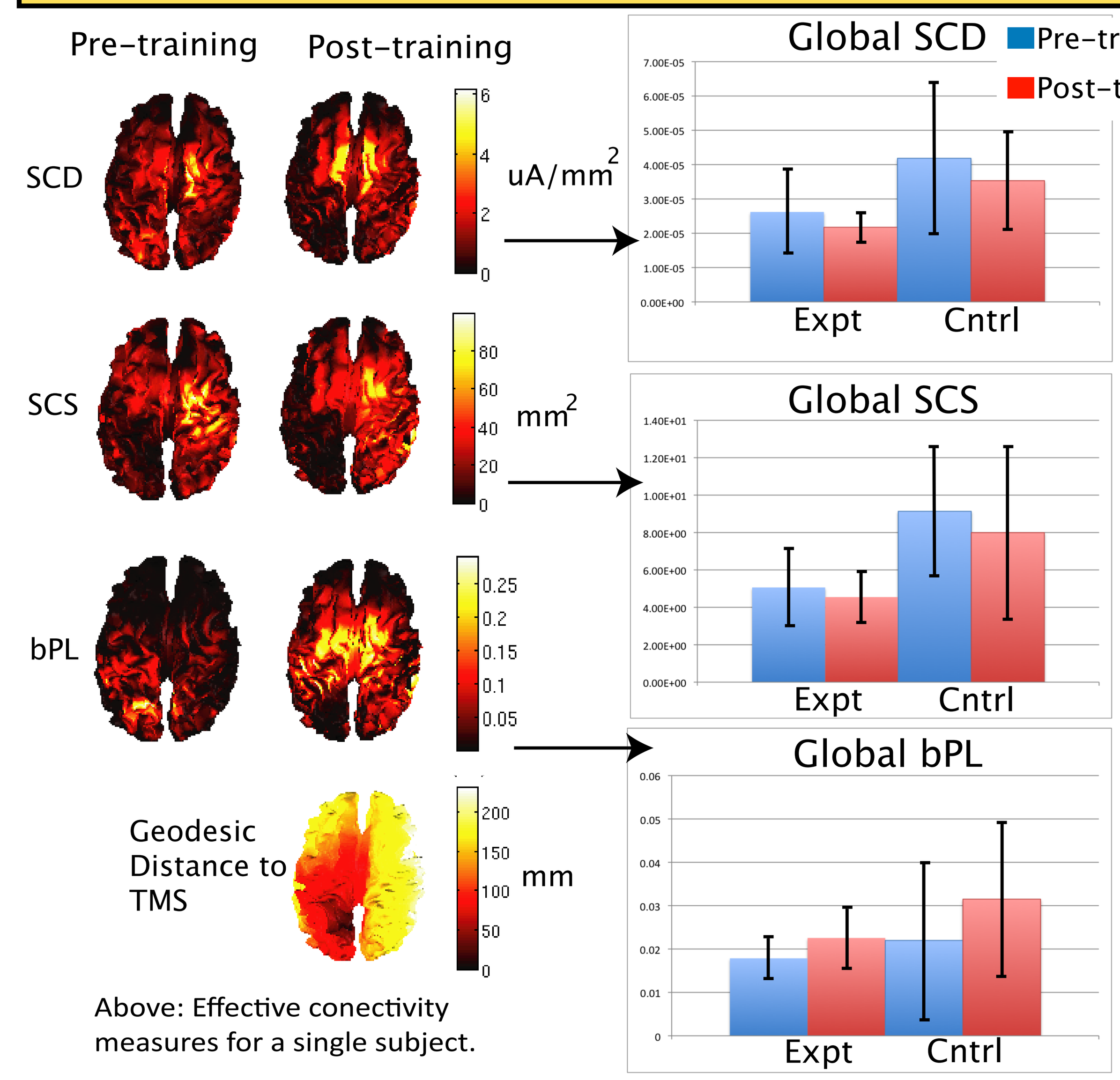


Delay period event related spectral perturbation (DPSP) plots for *Load 4 Left target condition*, channel P6, for 2 subjects. Subject 6 (top) is experimental. Subejct 4 is control. Subject-specific spectral patterns remain stable even with training perturbation.

Left: TMS evoked response for same 2 subejcts is also stable and trait-like.

Below: Absolute change in power between pre- and post-training delay period EEG divided into theta (4-7Hz), alpha (8-14Hz), beta (15-25Hz) and gamma (26-50Hz) bands. The fronto-parieto-occipital topographic distribution of absolute power change is reminiscent of results of past studies. Spefically, there are changes in frontal midline theta and posterior alpha power.

Does training on a working memory task show changes in cortical effective connectivity?



Above: Effective conectivity measures for a single subject.

Global measures of effective connectivity (Significant Current Density (SCD); Significant Current Scatter (SCS); and broadband Phase Locking (bPL) (Casali et al.) Experimental subjects show smaller fluctuations across measures and less variation within pre- and post-training sessions.

Conclusions

Training on a demanding working memory task :

1. Gains predicted by pre-training EEG (low-freq power).
2. Generalizes to other measures, including K and gF.
3. ERP correlate of K, the CDA, sharpens with training.
4. EEG suggests fronto- (theta) parietooccipital (alpha) strengthening.
5. TMS suggests systematic changes in the cortical effective connectivity.