Behavioral and EEG Effects of Working Memory Training

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Introduction

Voltage (i.e., ERP) measures of the delay-period during a short-term memory task show considerable individual differences that correlate with memory capacity (Vogel et al., 2004) and reflect selection efficiency (Vogel et al., 2005)

Training on delayed-recall tasks causes change in BOLD and FA measures which localize to fronto-parietal brain regions, i.e. areas thought to support short-term memory maintenance (Olesen et al., 2004; Takeuchi et al., 2010)

Prolonged, adaptive training on working memory 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 cause systematic task-related changes in delay-period EEG activity?

Methods

2 Groups : Dual N-back training (n=13; Brain Workshop http://brainworkshop.sourceforge.net/) and **control training** (n=13 ; 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 with 2 variants: 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. Variant 1 had distractors presented during encoding. Variant 2 had distractors presented during the delay period. Distractors were blue squares.

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.

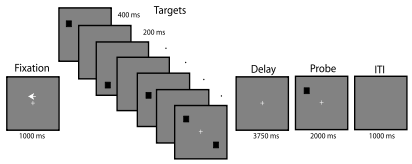
Psychometric Measures:

1. Short term memory capacity (K value) derived from change detection task.
2. Raven's Advanced Progressive Matrices (RAPM; Raven, 1990)
3. Operation Span (OPAN; Turner & Engle, 1989)
4. Stroop Task(Stroop, 1935)
5. Visual Search Task (Wolfe, 1994)

EEG:

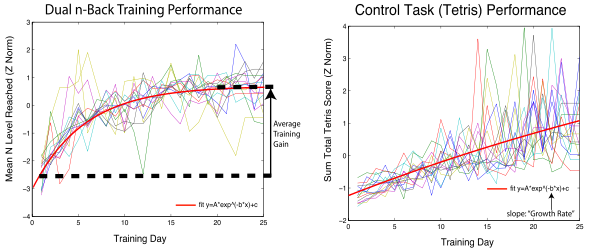
Recorded with a 256-channel hd-EEG amplifier (Electrical Geodesics, Inc). Data were acquired at 500Hz. All data processing was done with a combination of MATLAB (Mathworks, Inc), EEGLAB and ERPtoolbox (USCD) and, Fieldtrip (Donders Institute, Nijmegen).

Pre-Post Spatial Delayed Recognition Task



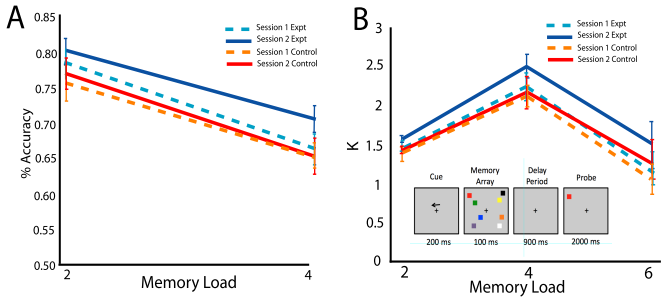
Results

Training



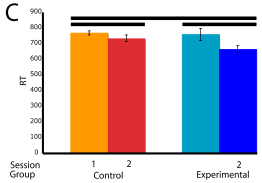
Learning on n-back task well fit by power law. Data were smoothed with moving average window over 5 day span. High b parameter value implies high growth rate and thus effective learning on the task. Mean **b (nback)** = 0.178, adj R^2=0.98; mean **b (tetris)** = 0.014, adj R^2=0.99. Red line indicates fit to mean over subjects Training gain (difference in mean n-back score from week 5 versus week 1) in experimental group correlates with pre-training K (r=0.41, $p < 0.05$)

Pre-Post Psychometric Measures



Significant improvement in Experimental group for both delay recognition (p = 0.013, 3-way interaction) and change detection (p = 0.03, simple effect Load 4) tasks.

C. Training resulted in improved filtering efficiency during encoding (significantly faster RT during variant of delayed-recognition task with distractors presented during encoding; p=0.05) but not for condition with distraction presented during delay.



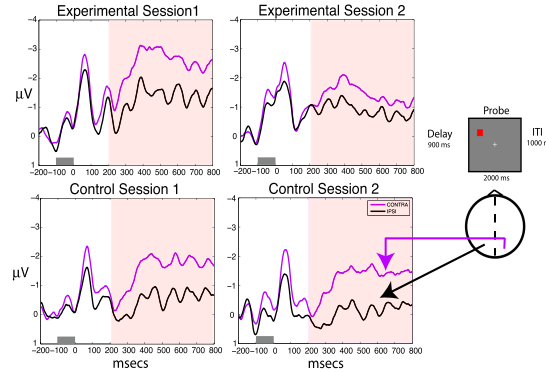
Significant individual differences: K correlates with gF (r = 0.36, $p<0.05$), but delayed-recognition task performance does not correlate with gF (r= -0.005, ns).

No significant interaction effect of training on: complex span capacity (OSPAN), fluid intelligence (RAPM), interference control (Stroop task), filtering efficiency when distractors presented during delay of a delayed-recognition task, and search efficiency (derived from search task).

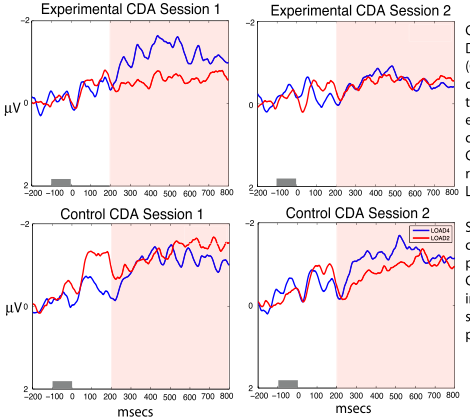
Conclusions

1. Training gains correlate with pre-training K.
2. Training does not appear to transfer to gf or complex span.
3. ERP correlate of K, the CDA, shows changes with training. Suggests that memory representation becomes more efficient. This is consistent with a distributed resources model of working memory.

Pre-Post "Change Detection" ERP Measures

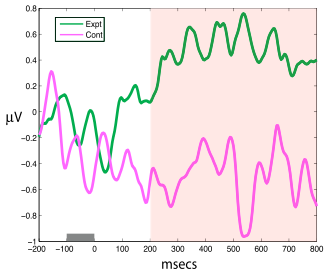


Grandaverage ERP waveforms derived from lateralized target conditions over P3/P4, P5/P6, P7/P8, and PO3/PO4 channels of Load 4 condition. Stimulus onset at -100 ms (grey bar). Delay period onset at 0 ms. Delay continues to 900 ms. Contralateral ERP amplitide is reduced post-training in experimental group.



Contralateral Delay Activity (Contra-Ipsi) is depressed post training in experimental, not control groups. CDA amplitude reduction for Load 4 condition.

Statistical comparison period in pink. Grey box indicates stimulus presentation.



Significant interaction (Group x Session) effect on change in CDA amplitude (Load 4 - Load 2). Mean signal change over 200-800 msecs of the delay, p=0.005

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