Role of frontal and parietal regions in retention of information in spatial working memory: A repetitive transcranial magnetic stimulation study

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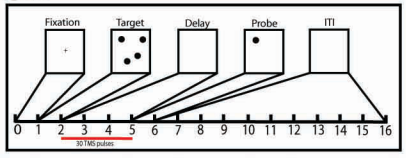
Introduction

- Working memory refers to the ability to maintain information in an active state when it is no longer present in the environment.
- The relative contributions of the dorsolateral prefrontal cortex (dlPFC) and posterior cortical areas to the retention of information in spatial working memory are the focus of considerable debate (e.g., Goldman-Rakic & Leung, 2002; Curtis & D'Esposito, 2003).
- We tested the neccesity of two frontal regions (dlPFC and frontal eye fields (FEF)) and two parietal areas (superior parietal lobule (SPL) and intraparietal sulcus (IPS)) for the retention of spatial information in working memory by targeting each region with high frequency repetitive transcranial magnetic stimulation (rTMS).

Subjects & Methods

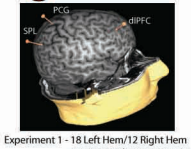
- 54 right-handed healthy subjects (28 male) participated.
- 1st session - Screening and Training
  - Subjects were trained to achieve an accuracy of at least 70%.
- 2nd session - MRI
  - High-resolution anatomical volumes acquired for all subjects.
- 3rd session - rTMS
  - Subjects completed 4 blocks of 48 trials of the task for each brain area targeted with rTMS.

Task

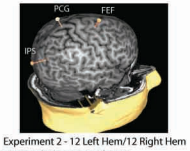


- Target: 4 circles (1 degree of visual angle in diameter) presented at random locations, one in each quadrant of the screen.
- Probe: required Y/N recognition decision; matched a target location with p=0.5; invalid probes were offset from the nearest target location by an average of 3.08 (S.D. = 0.4) deg. along one of the 8 cardinal or ordinal axes.

Targets of rTMS



Experiment 1 - 18 Left Hem/12 Right Hem

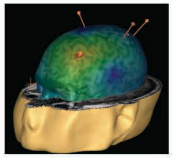


Experiment 2 - 12 Left Hem/12 Right Hem

Postcentral gyrus (PCG) served as a stimulation control area.

rTMS

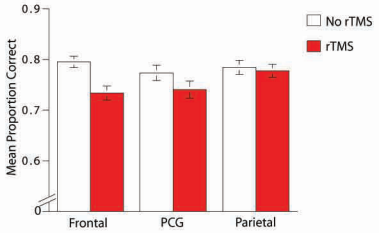
- Each subject's head was coregistered with his/her MRI using eXimia Navigated Brain Stimulation (NBS) frameless stereotaxy navigation system (Nexstim, Helsinki).
- rTMS (10 Hz, 110% MT, 3 sec. - Magstim Standard Rapid, Whitland, UK) coincided with the delay period on half the trials (randomly determined order).
- Stimulation intensity was corrected for scalp-to-cortex distance using eXimia NBS's calculation of induced electric field potential.



Results

Aggregated Across All Subjects (N=54)

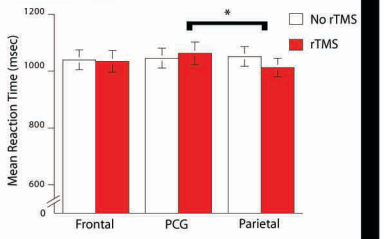
Accuracy



Signal detection measures:

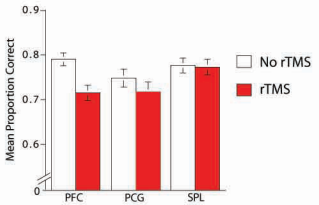
- d' *decreased* with rTMS:
  - Main effect of rTMS [$F(1,53)=18.2$; $p<0.0001$].
  - Brain Area x rTMS interaction [$F(2,106)=3.21$; $p<0.05$].
  - However, neither area differed from the PCG.
- Criterion *decreased* with rTMS:
  - Main effect of rTMS [$F(1,53)=4.22$; $p<0.05$].
  - No significant interactions.

Reaction Time



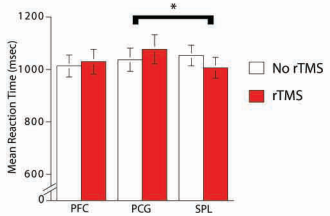
- Reaction Time:
  - Brain Area x rTMS interaction [$F(2,106)=6.31$; $p<0.005$].
  - rTMS *decreased* reaction time in parietal regions vs. PCG ($p<0.001$).

Experiment 1: Accuracy (N=30)



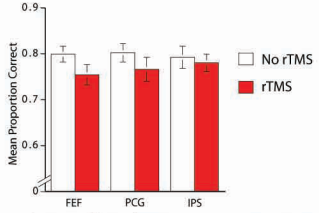
- d' *decreased* with rTMS:
  - Main effect of rTMS [$F(1,29)=10.08$; $p<0.005$].
  - Brain Area x rTMS interaction [$F(2,58)=4.00$; $p<0.05$].
  - However, neither area differed significantly from the PCG.

Reaction Time (N=30)



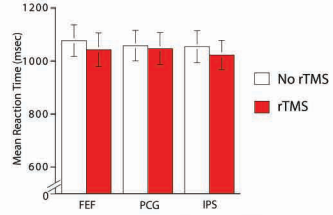
- Brain Area x rTMS interaction [$F(2,58)=9.06$; $p<0.001$].
- rTMS of SPL decreased reaction time compared to PCG ($p<0.001$).

Experiment 2: Accuracy (N=24)



- d': Main effect of rTMS [$F(1,23)=7.69$; $p<0.05$], but no significant interaction.
- Criterion: Main effect of rTMS [$F(1,23)=4.28$; $p=0.05$], but no significant interaction.
  - Criterion *decreased* with rTMS.

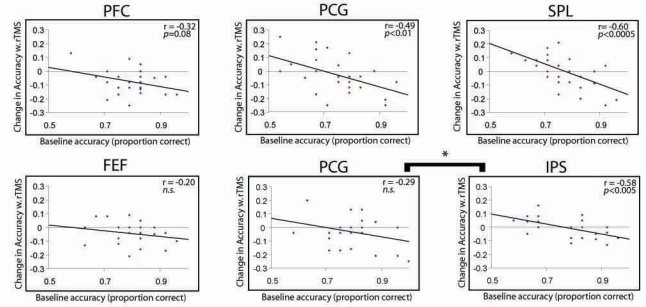
Reaction Time (N=24)



- Trend towards a main effect of rTMS decreasing reaction time [$F(1,23)=3.13$, $p=0.09$].

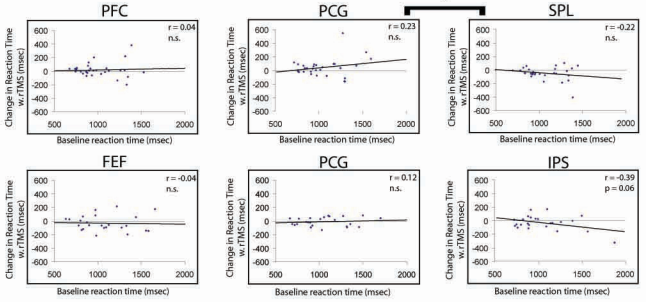
Region-specific Individual Differences

Baseline Accuracy vs. rTMS effect on Accuracy



- Subjects with higher baseline accuracy have larger rTMS-related decrement in performance, significantly so (vs. PCG) for IPS [$t(18) = 1.85$; $p<0.05$].

Baseline Reaction Time vs. rTMS effect on Reaction Time



- Subjects with slower baseline reaction time have larger rTMS-related decreases in reaction time (vs. PCG) in SPL [$t(25)=2.21$, $p<0.05$] and IPS [$t(17) = 1.58$, $p=0.07$].

Conclusions

- Spatial working memory is supported by a broadly distributed cortical network:
  - rTMS has a global effect of decreasing accuracy and making subjects more likely to give a *Yes* response.
- Failed to find evidence for a critical role of dlPFC in spatial working memory storage.
- Privileged role for parietal cortex in spatial working memory storage.
  - Paradoxical effect of parietal rTMS on reaction time?
    - rTMS to SPL and IPS has effect of *speeding* responses.
- Effect of rTMS in the parietal cortex depends on baseline performance on the task.
  - Are subjects with higher baseline accuracy more reliant on IPS?
  - Are subjects with slower baseline reaction time more reliant on SPL?

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