Neural oscillatory dynamics in directed and divided attention

Marie C. McCusker[1], Alex I. Wiesman[1], Mikki D. Schantell[1], Jacob A. Eastman[1], Tony W. Wilson[1]

[1]University of Nebraska Medical Center, Omaha, NE, USA

Introduction

- The anatomical representations of visual attention are well documented, but it remains uncertain which *oscillatory* neural responses are preferentially affected by the direction and division of attentional resources in the visual space
- Directed attention: the ability to focus on stimuli or domains in isolation
- Divided attention: the ability to focus on multiple stimuli or domains in parallel
- Hypotheses:
  1. Attention effects would be most robust in oscillatory rhythms commonly associated with the allocation of neural resources to the visual space (i.e., the theta and alpha bands)
  2. Neural responses would involve major attention networks
  3. Neural responses in visual cortices would be significantly reduced when attention was directed away from the visual stimulus or divided between sensory modalities compared to when attention was sustained towards the visual domain

Methods

- *Participants*: Healthy young adults
  - Experiment 1 (Directed Attention): N = 26 (M = 24 years)
  - Experiment 2 (Divided Attention): N = 34 (M = 26 years)
- *Paradigm*: Visual-somatosensory oddball task during magnetoencephalography (MEG) recording
  - MEG: noninvasive functional neuroimaging technique that measures magnetic fields emanating from neuronal activity
  - Visual-somatosensory oddball task: two pseudo-randomized 88-trial blocks per experiment (8 temporal oddballs/modality)

	Experiment 1	Experiment 2
Conditions	Attend Visual (respond to visual oddballs)	Attend Visual
	Attend Somato (respond to somatosensory oddballs)	Attend Both (respond to both oddballs)

Table 1. Experimental Task Conditions

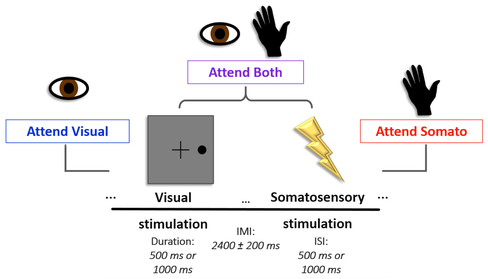

Figure 1. Visual-Somatosensory Oddball Task

- *Sensor-level and source-level analyses*:
  - Transformed artifact-free epochs into time-frequency domain
  - MRI co-registration
  - Imaged significant responses using a frequency-resolved beamformer
  - Whole-brain cluster-based permutation testing (cluster threshold: p < 0.005)

Results

MEG sensor-level spectrograms:

- Occipital gamma (γ): 74 – 84 Hz; 300 – 550 ms
- Parietal beta (β): 16 – 22 Hz; 225 – 525 ms
- Occipital alpha (α): 8 – 14 Hz; 300 – 800 ms
- Occipital theta (θ): 4 – 8 Hz; 0 – 250 ms

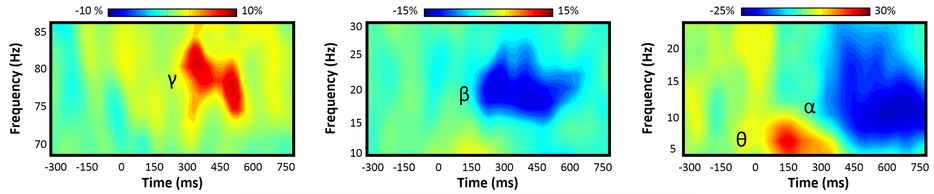

Figure 2. Experiment 1 (Directed Attention) Sensor-Level Spectrograms

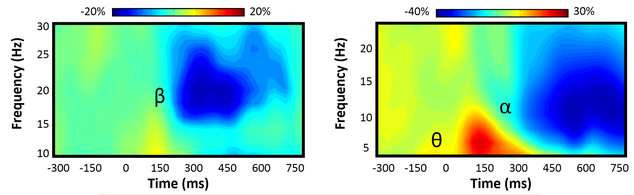

Figure 3. Experiment 2 (Divided Attention) Sensor-Level Spectrograms

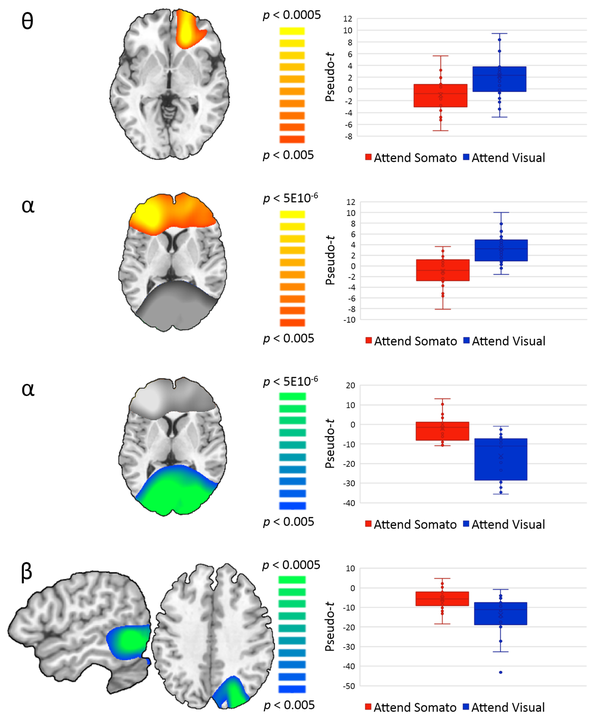

Figure 4. Effects of Directed Attention on Neural Oscillatory Dynamics

MEG source-level neural responses in the brain:

- Directed Attention (left)
  - θ: right anterior middle frontal gyrus
  - α: bilateral prefrontal and lateral occipital cortices
  - β: right lateral occipital cortex
- Divided Attention (below)
  - α & β: right temporoparietal junction (TPJ)

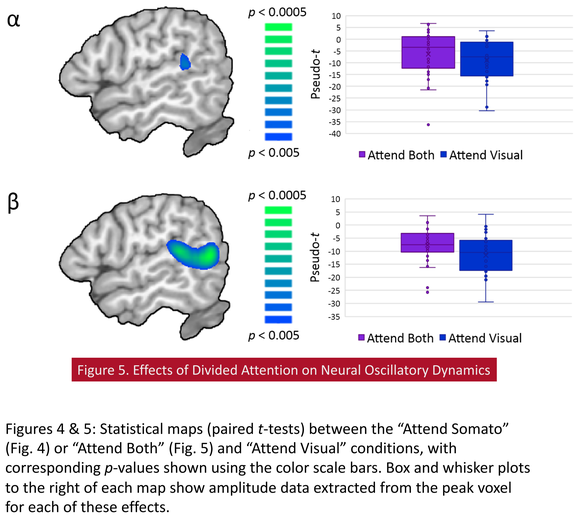

Figure 5. Effects of Divided Attention on Neural Oscillatory Dynamics

Figures 4 & 5: Statistical maps (paired t-tests) between the "Attend Somato" (Fig. 4) or "Attend Both" (Fig. 5) and "Attend Visual" conditions, with corresponding p-values shown using the color scale bars. Box and whisker plots to the right of each map show amplitude data extracted from the peak voxel for each of these effects.

Discussion

1. Directed Attention
   - Responses stronger when attention was sustained in the visual domain relative to when it was directed away
   - Middle frontal θ: early stimulus recognition and top-down modulatory feedback
   - Prefrontal α: attentional control
   - Occipital α: visual stimulus (inhibitory) processing
   - Posterior β: distinct from alpha and not due to movement
2. Divided Attention
   - Responses stronger when attention was sustained in the visual domain relative to when it was divided between modalities
   - Right TPJ: goal-directed attentional reorienting and visual attention

- Reflection on hypotheses:
  1. Neural responses were most robust in oscillations commonly associated with attention in the visual space: theta, alpha, and gamma
     - Beta was unexpected
  2. Neural responses presented in attention-related areas: prefrontal, frontal, temporoparietal, and occipital regions
  3. Directing attention away from the visual domain reduced oscillations compared with directing attention towards the visual domain
     - Synchronized prefrontal alpha was unexpected

  Dividing attention between visual and somatosensory domains reduced oscillations relative to when attention was sustained in the visual domain

Conclusions

- Using MEG and a visual-somatosensory oddball paradigm provided insights into the neural oscillatory dynamics in directed and divided visual attention in healthy adults
- Both experiments revealed multi-spectral effects of attention on neural oscillatory activity
- Sustaining attention to the visual domain enhanced neural responses to visual stimuli
- Future directions:
  - Examine effects of varying attentional loads
  - Explore how attentional neural activity relates to behavioral performance
- Investigating how attentional gain is implemented in the human brain is essential for better understanding how this process is degraded in disease and may provide useful targets for future therapies

Acknowledgements

This research was supported by grants R01-MH103220 (TWW), R01-MH116782 (TWW), R01-MH118013 (TWW), R01-DA047828 (TWW), and F31-AG055332 (AIW) from the National Institutes of Health and grant #1539067 from the National Science Foundation (TWW). Thanks to the participants for volunteering to participate in the study, as well as our staff and local collaborators for their contributions to the work.

Contact: Email: marie.mccusker@unmc.edu