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Co-Varying Eye Movements and Power Modulations of Alpha Oscillations during Working Memory: A Pilot Study

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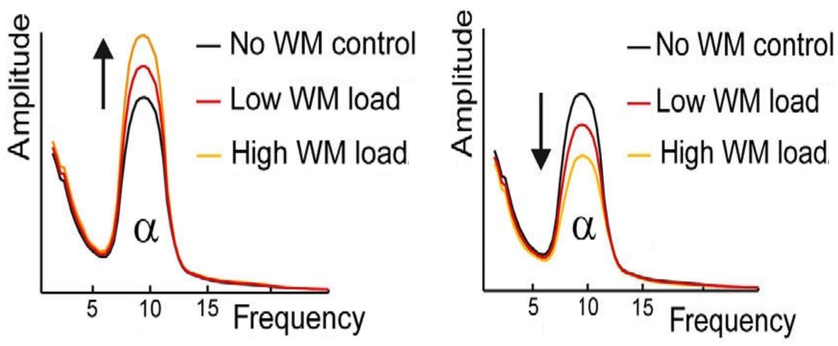
There is an inconsistency in the literature regarding the direction of the association between the extend of synchronized oscillatory activity in the alpha band (~ 8-13 Hz, i.e. alpha power) and working memory (WM) load (see Fig. 1).[1] Previous studies postulated that differences in alpha power varied with the variability in oculomotor activity.[2] Increased gaze variability is associated with a reduction in alpha power, and vice versa. Here, we propose that **different gaze patterns during commonly used WM tasks (i.e., Sternberg and N-back) can explain the task- and subject-specific discrepancies between alpha power and WM load**.

We hypothesize that although fluctuations in alpha power in relation to WM load appear to be associated with the cognitive demands of the task, these modulations likely evolved primarily to facilitate/support oculomotor control.



A | Alpha Power increase with increasing WM load

B | Alpha Power decrease with increasing WM load

Fig. 1: WM load dependent increase (**A**) or decrease (**B**) of posterior alpha power, showcasing the inconsistency in the literature regarding the direction of the association between alpha power and WM load in different WM tasks. Adapted from van Ede, 2018.

Methods

Sample
N = 10 pilot participants (M = 25.9, SD = 2.13, 50% f.)

N-back Task

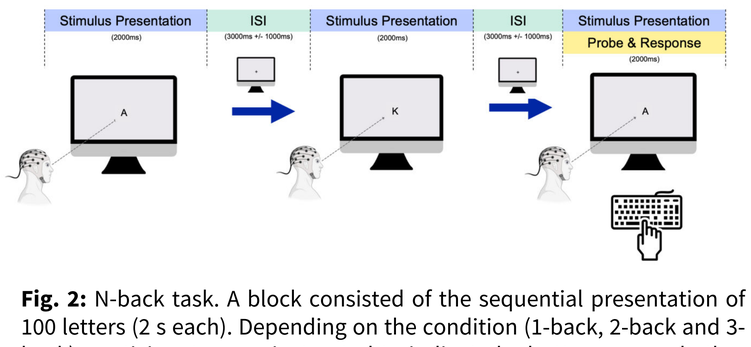


Fig. 2: N-back task. A block consisted of the sequential presentation of 100 letters (2 s each). Depending on the condition (1-back, 2-back and 3-back), participants were instructed to indicate by button press whether they thought the currently presented letter was a match to the letter N-back.

Sternberg Task

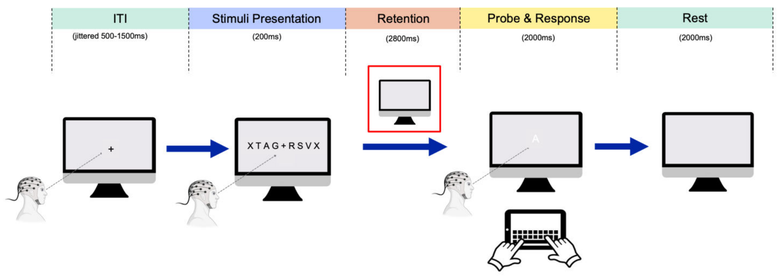


Fig. 3: Sternberg task. A trial consisted of a simultaneous presentation of 2, 4, 6 or 8 letters for 200 ms. The letters and the load were randomized. After a retention interval of 2.8 s, another letter was presented. Participants were instructed to indicate by button press whether they thought it was a match or not.

Behavioral Data
- Reaction time (ms)
- Accuracy (%)

Eye Tracking
- Load dependent changes in gaze density & gaze standard deviation during retention interval
- Eye tracker EyeLink 1000 Plus; sampling rate 500 Hz

EEG
- Load dependent posterior alpha power modulations during retention interval
- 128-channel ANT Neuro EEG system, sampling rate 500 Hz
- Preprocessing with Automagic[3]: removal of noisy/outlier channels, high pass filter 0.1 Hz, ZapLine 50 Hz, artifact removal with ICLabel, ocular correction with OPTICAT

Results

Behavioral

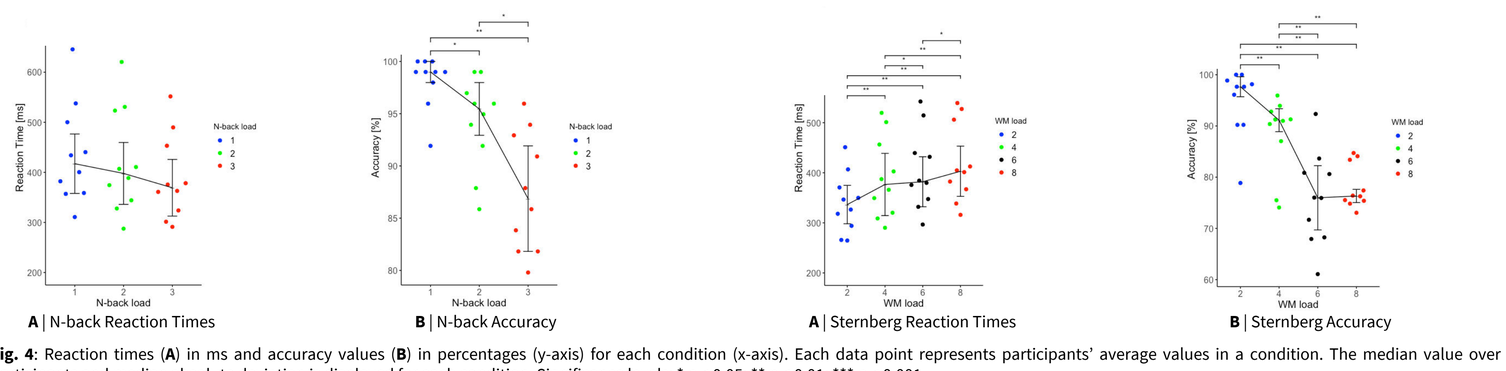
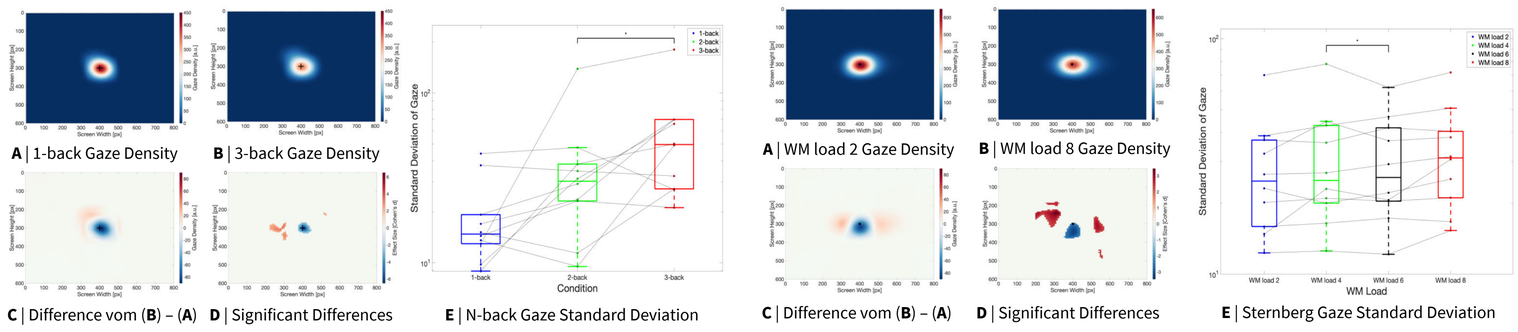


Fig. 4: Reaction times (**A**) in ms and accuracy values (**B**) in percentages (y-axis) for each condition (x-axis). Each data point represents participants' average values in a condition. The median value over participants and median absolute deviation is displayed for each condition. Significance levels: * p < 0.05; ** p < 0.01; *** p < 0.001.

Gaze

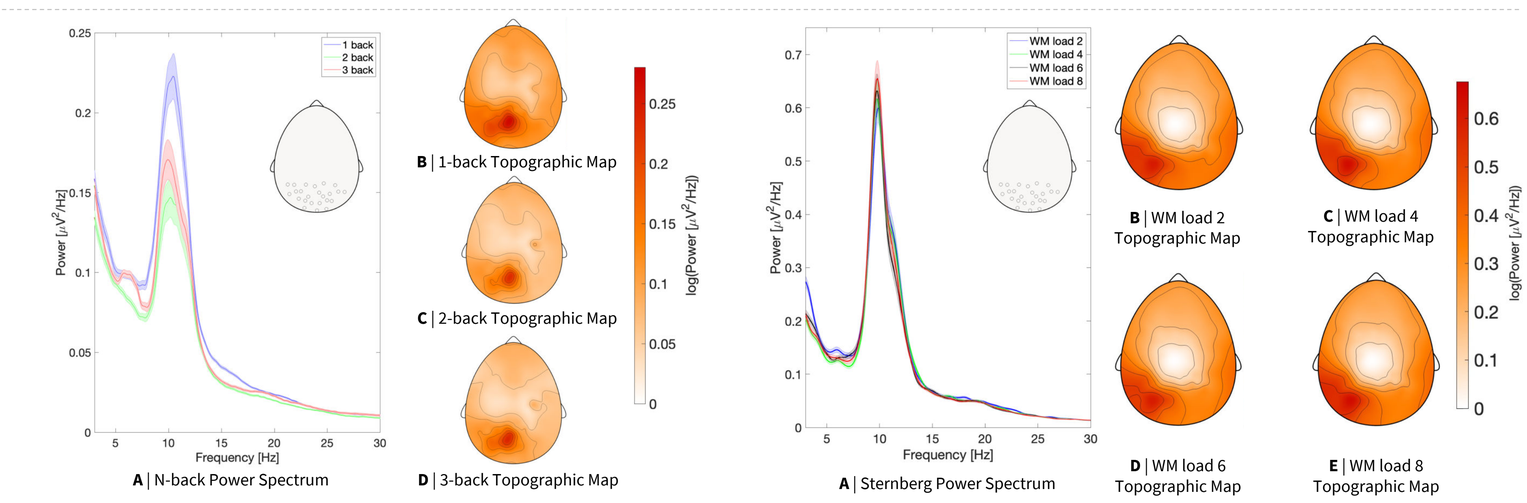


A | 1-back Gaze Density **B** | 3-back Gaze Density **C** | Difference vom (**B**) – (**A**) **D** | Significant Differences **E** | N-back Gaze Standard Deviation

A | WM load 2 Gaze Density **B** | WM load 8 Gaze Density **C** | Difference vom (**B**) – (**A**) **D** | Significant Differences **E** | Sternberg Gaze Standard Deviation

Fig. 5: Gaze density heatmaps for the (**A**) lowest and (**B**) highest WM load conditions. The axes represent the height and he width of the screen. (**C**) Difference in gaze density between the two conditions in (**A**) and (**B**). The values from (**B**) were subtracted from (**A**), showing higher gaze density in the higher WM load task condition as red pixels. (**D**) Bins from (**C**) with statistically significant differences (t-values). (**E**) shows boxplots illustrating the standard deviation of gaze (y-axis) during all conditions of the respective tasks. Significance levels: * p < 0.05; ** p < 0.01; *** p < 0.001.

EEG



A | N-back Power Spectrum **B** | 1-back Topographic Map **C** | 2-back Topographic Map **D** | 3-back Topographic Map

A | Sternberg Power Spectrum **B** | WM load 2 Topographic Map **C** | WM load 4 Topographic Map **D** | WM load 6 Topographic Map **E** | WM load 8 Topographic Map

Fig. 6: Power spectral density of grand averages for all task conditions (**A**). Frequency in Hz is displayed on the x-axis with power in $\mu V^2/Hz$ on the y-axis. Shaded areas around each line depict the standard error of the mean. The corresponding topographical distributions of EEG power (**B-D**, resp. **B-E**) within the alpha band (8 to 13 Hz) are shown in $\mu V^2/Hz$ for each WM load condition. Red values indicate more activation in the higher WM load conditions, blue values indicate less activation.

Association

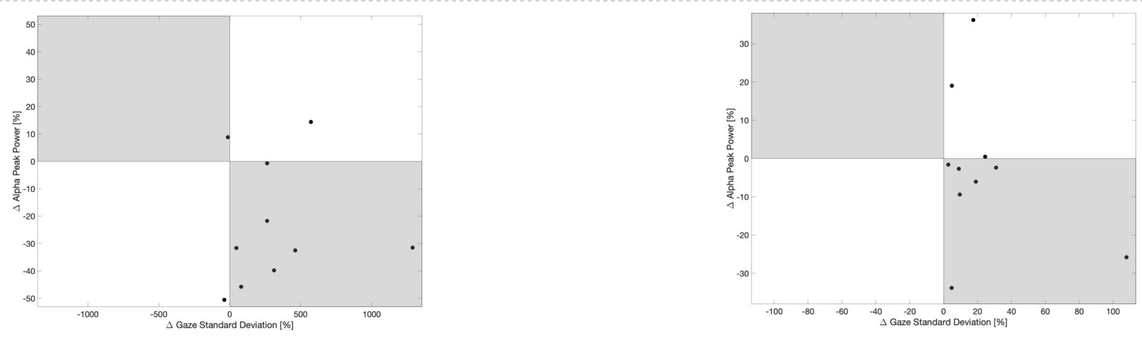


Fig. 7: Association for each subject between relative alpha power changes (y-axes) and gaze variability as percentage change in standard gaze deviation (x-axes) from the lowest to the highest WM load condition. The transparent boxes highlight single subjects with data which are in line with the hypothesized relation between alpha power and eye movements. Thus, these participants exhibited an increase in gaze standard deviation with increasing WM load and a corresponding decrease in posterior alpha power or a decrease in gaze and an increase in alpha power with increasing WM load.

References

1 van Ede, F. (2018). Mnemonic and attentional roles for states of attenuated alpha oscillations in perceptual working memory: A review. European Journal of Neuroscience, 48(7), 2509–2515.

2 Popov, T., Miller, G. A., Rockstroh, B., Jensen, O., & Langer, N. (2021). Alpha oscillations link action to cognition: An oculomotor account of the brain's dominant rhythm. Neuroscience.

3 Pedroni, A., Bahreini, A., and Langer, N. (2019). Automagic: Standardized preprocessing of big EEG data. NeuroImage, 200:460–473.

Conclusion

This pilot study examined posterior alpha power modulations and gaze patterns across different WM tasks. In both tasks, **high WM load was linked to increased gaze variability**. However, **only N-back task conditions with high WM load exhibited stronger alpha power reduction**. This could not be shown for the Sternberg task. Due to insufficient statistical power, no definitive conclusions can be drawn regarding the relationship between alpha power and gaze variability. This study sets the stage for a future registered report with an adequately powered sample size.