NEURAL ACTIVITY IS MODULATED BY SPONTANEOUS AND VOLITIONALLY CONTROLLED BREATHING

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INTRODUCTION

Breathing is a cyclic bodily rhythm consisting of active inspiration and passive expiration. Although mainly in autonomic control, breathing can also be volitionally controlled to adapt to internal and external environmental changes [1]. Recent animal and human studies have provided evidence regarding respiration-brain coupling [2] [3], but less is known on how breathing modulates the state of the body and brain.

- **Whether and how respiratory, cardiac and neural measures differ between spontaneous and volitionally controlled breathing?**
- **Is neural activity modulated by the phases of breathing?**

METHODS

Participants

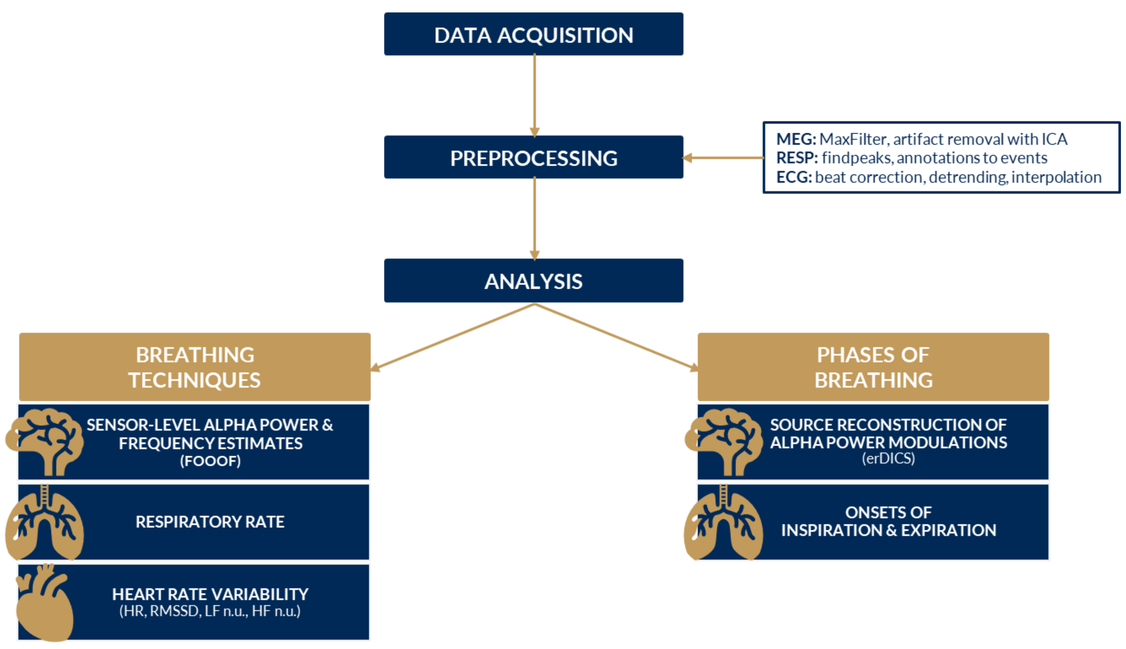
- n = 33; 24 female, 9 male
- 25.39 ± 6.87 years, 19-57 years

Equipment

- Magnetoencephalography (MEG)
- Respiratory belt
- Electrocardiography (ECG)

Breathing-related tasks

- Spontaneous breathing with eyes closed (4 min)
- Spontaneous breathing with eyes open (8 min)
- Deep breathing with eyes open (8 min)
- Square breathing with eyes open (8 min)

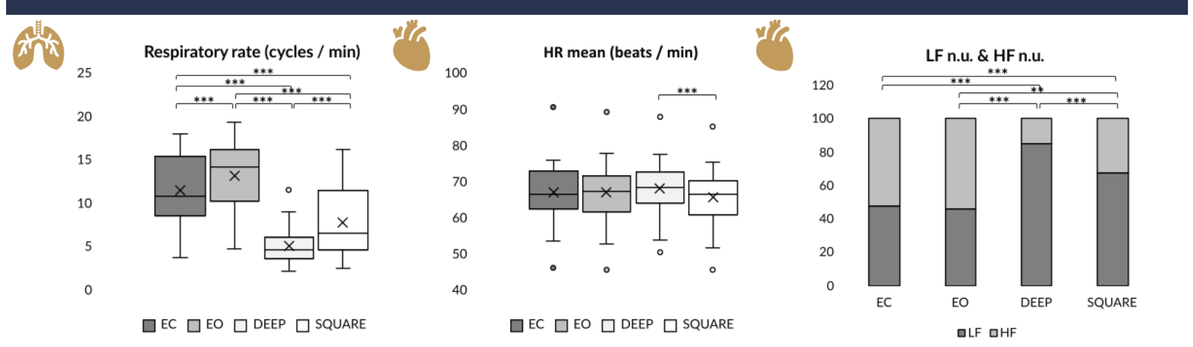


	Spontaneous breathing (EC)	Spontaneous breathing (EO)	Deep breathing	Square breathing
Respiratory rate (cycles / min)	11.75 ± 3.86	13.34 ± 3.84	5.30 ± 2.19	8.03 ± 3.87
HR mean (beats / min)	67.68 ± 8.12	67.57 ± 8.22	68.64 ± 7.30	66.30 ± 7.58
RMSSD	64.94 ± 42.91	63.58 ± 46.14	62.66 ± 33.43	67.53 ± 40.33
LF n.u.	47.86 ± 26.49	45.83 ± 24.47	85.30 ± 16.04	67.29 ± 29.18
HF n.u.	52.11 ± 26.48	54.11 ± 24.42	14.69 ± 16.04	32.70 ± 29.17

FOOOF, fitting oscillations and one over f; erDICS, event-related dynamic imaging of coherent sources; HR, heart rate; RMSSD, root mean square of successive differences between heartbeats; LF n.u., power of low frequency band (0.04-0.15 Hz) in normalized units; HF n.u., power of high frequency band (0.15-0.4 Hz) in normalized units

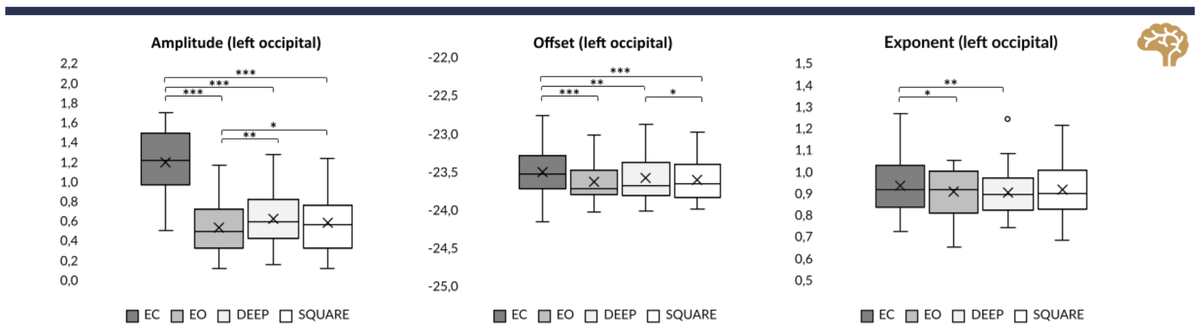
[1] Homma & Masaoka (2008) https://doi.org/10.1113/expphysiol.2008.042424
[2] Karalis & Sirota (2022) https://doi.org/10.1038/s41467-022-28090-5
[3] Kluger & Gross (2021) https://doi.org/10.1371/journal.pbio.3001457

RESULTS



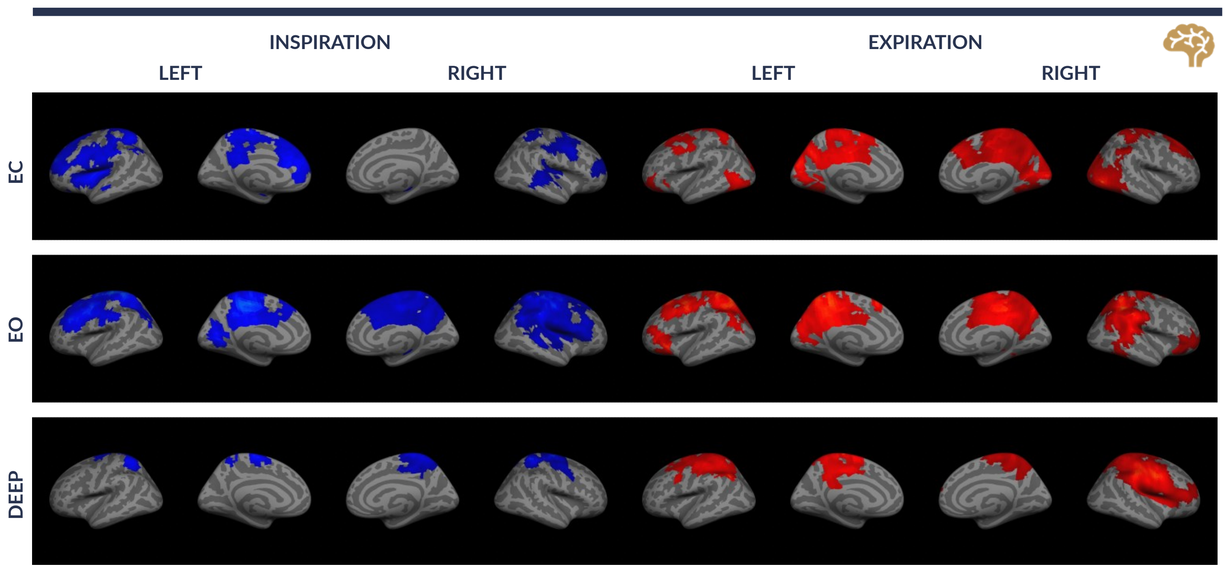
*Friedman test & Wilcoxon Signed-Rank test with Bonferroni correction (post hoc analyses) * p≤0.05 ** p≤0.01 *** p≤0.001*

- Respiratory rate differed between all breathing techniques ($\chi^2(3)=74.579$, $p<0.001$). Respiratory rate was higher during spontaneous breathing in comparison with deep and square breathing.
- Mean HR was decreased during square breathing in comparison with deep breathing. No other differences in mean HR were observed.
- RMSSD, a time-domain measure of HRV, did not differ between breathing techniques.
- LF n.u. and HF n.u., frequency-domain measures of HRV, differed between breathing techniques ($\chi^2(3)=45.545$, $p<0.001$). LF n.u. was higher and HF n.u. was lower during deep and square breathing in comparison with spontaneous breathing.



*Repeated measures ANOVA & pairwise comparisons with Bonferroni correction * p≤0.05 ** p≤0.01 *** p≤0.001*

- Main effects of breathing technique on alpha amplitude ($F(1.989, 53.690)=125.420$, $p<0.001$, $\eta_p^2=0.823$), frequency ($F(2.484, 67.078)=3.065$, $p=0.043$, $\eta_p^2=0.102$) and bandwidth ($F(1.673, 45.168)=5.365$, $p=0.012$, $\eta_p^2=0.166$) were observed. Pairwise comparisons showed significant differences in amplitude between ec vs. all other techniques as well as eo vs. deep and square.
- Main effects of breathing technique on offset ($F(2.428, 77.706)=17.282$, $p<0.001$, $\eta_p^2=0.351$) and exponent ($F(2.553, 81.683)=5.352$, $p=0.003$, $\eta_p^2=0.143$) were observed. Pairwise comparisons showed significant differences in offset between ec vs. all other techniques and deep vs. square as well as in exponent between ec vs. eo and deep.



Source-level cluster-based permutation test results indicated that alpha power (8—13 Hz) decreased during inspiration and increased during expiration in the time windows from 0 to 2000 ms with respect to the onset of inspiration and expiration in comparison with the baseline time window of -500 to 0 ms. This effect was observed especially in the sensorimotor and parietal areas during spontaneous and deep breathing ($p<0.05$). Figure above illustrates statistically significant decreases (blue) and increases (red) of alpha power in the time window from 1000 to 1500 ms.

CONCLUSIONS

- **Respiratory rate, heart rate and heart rate variability differ between spontaneous and volitionally controlled breathing.**
- **Both breathing technique and phases of breathing modulate the power of alpha-band oscillatory activity.**
- **Further research is needed to establish the possible behavioural and clinical implications of respiration-brain coupling.**

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