Home and Laboratory Sleep EEG Reveal Anxiety-Related Slow Wave Reductions in Preadolescent Girls

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Background

- Childhood Anxiety Disorders (ADs) affect up to 30% of children [1]
- Early life anxiety is known to be a risk factor for developing stress-related psychopathology later in life
- Up to 90% of children with anxiety disorders report sleep related problems [2]
- Few studies utilizing objective measures like EEG to understand neural underpinnings of sleep problems in youth with ADs
- Slow wave sleep (SWS) may be relevant to anxiety due to associations with emotion regulation, fear learning, and memory [3]
- We compared at-home single channel EEG and laboratory high density EEG (hdEEG) methods in sample of preadolescent girls with a range of anxiety focusing on anxiety-related alterations in sleep slow wave activity (SWA).

Sample Demographics

32 preadolescent females (ages 8-12) with range of anxiety symptoms

- Three groups based on clinical interview: 1) healthy control, 2) subthreshold-AD (sub-AD), or 3) AD (generalized, separation, or social)
- Treatment free and no other current or past psychiatric disorders

Screen for Child Anxiety Related Disorders (SCARED)

- Child's anxiety severity over the last 3 months as rated by the parent and child
- Collected prior to the start of home sleep period and at each lab sleep visit.

Group	**Age** (years, Mean ± SD)	**Parent SCARED** (Mean ± SD)	**Child SCARED** (Mean ± SD)
Control (N=18)	10.6 (1.1)	9.1 (8.2)	9.0 (6.1)
Sub-AD (N=9)	9.8 (1.0)	16.6 (13.0)	23.3 (14.1)
AD (N=5)	10.9 (0.9)	36.0 (7.0)	40.6 (14.5)
	Main Effect of Group ns, p=.88	Main Effect of Group p <.05, AD> Sub-AD, Con	Main Effect of Group p <.05, AD>Sub-AD>Con

Detailed EEG Acquisition Methods

Home Sleep Data Collection

- SmartSleep wearable sleep EEG headband [4,5] worn on weeknights for 2 weeks (up to 10 nights) at home. Single frontal (Fpz) recording electrode referenced to the right mastoid (M2).
- Signal acquired at 1000 Hz, notch-filtered at 60 Hz, band-pass filtered at 0.3-40 Hz, then downsampled to 100 Hz. Power spectral density calculated using a fast Fourier transform on 4-s, Hanning-windowed EEG segments, yielding a frequency resolution of 0.25 Hz.
- Only complete nights of home sleep data were included in the analysis. Average of 6.3 complete nights per participant (range: 1-10 nights).

Laboratory Sleep Data Collection

- In-lab 128-channel high density EEG for two nights (~1-3 weeks apart for acclimation).
- Signals acquired at 500 Hz, band-pass filtered from 0.5-40 Hz, then downsampled to 200 Hz. Arousals and epochs scored as wake were removed. Zapline used to remove 30, 20, and 10 Hz artifacts across whole night of sleep. Sleep subdivided into NREM (N2/N3) and REM. Applied semiautomatic artifact rejection to NREM sleep by removing 6-s segments with channel-specific excess power in either 1-4 Hz or 20-30 Hz ranges. Visual inspection and manual removal of noisy channels and periods of interrupted signal. Data was re-referenced to the mean voltage across the remaining channels. Removed channels were interpolated before calculating spectral power in canonical frequency bands. Spectral analysis performed in 6-s segments using Welch's method with a Hamming window.
- Only the second night of laboratory sleep was analyzed to avoid potential first night effects [6].

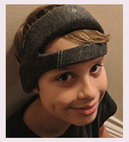
Acknowledgments

This work was funded by the following NIH grants: **R01-MH132671**

References

1. Merikangas KR, He JP, Burstein M, Swanson SA, Avenevoli S, Cui L, Benjet C, Georgiades K, Swendsen J. Lifetime prevalence of mental disorders in U.S. adolescents: results from the National Comorbidity Survey Replication--Adolescent Supplement (NCS-A). J Am Acad Child Adolesc Psychiatry. 2010 Oct;49(10):980-9. doi: 10.1016/j.jaac.2010.05.017. Epub 2010 Jul 31. PMID: 20855043; PMCID: PMC2946114.
2. Alfano, C. A. (2018). (Re)Conceptualizing Sleep Among Children with Anxiety Disorders: Where to Next? *Clinical Child and Family Psychology Review*, *21*(4), 482–499. https://doi.org/10.1007/s10567-018-0267-4
3. Tononi, G., & Cirelli, C. (2006). Sleep function and synaptic homeostasis. *Sleep Medicine Reviews*, *10*(1), 49–62. https://doi.org/10.1016/j.smrv.2005.05.002
4. Garcia-Molina, G., Tsoneva, T., Jasko, J., Steele, B., Aquino, A., Baher, K., Pastoor, S., Pfundtner, S., Ostrowski, L., Miller, B., Papas, N., Riedner, B., Tononi, G., & White, D. P. (2018). Closed-loop system to enhance slow-wave activity. *Journal of Neural Engineering*, *15*(6), 066018. https://doi.org/10.1088/1741-2552/aae18f
5. Molina, G. G., Matthews, C., Myers, A., Peterson, B., Strainis, E., Riedner, B., Vascan, A. M., Tononi, G., & Jones, S. (2024). Auditory stimulation during deep sleep enhances total slow-wave activity in a young cohort: A feasibility trial. *Journal of Sleep Research*. https://doi.org/10.1111/jsr.14404
6. Mayeli, A., Janssen, S. A., Sharma, K., & Ferrarelli, F. (2022). Examining First Night Effect on Sleep Parameters with hd-EEG in Healthy Individuals. *Brain Sciences*, *12*(2), 233. https://doi.org/10.3390/BRAINSCI12020233/S1

Methods & Results



Home Sleep
10 nights of single channel (Fpz) sleep EEG at home

Power spectral analysis performed on each night of NREM sleep data (absolute and relative power in canonical frequency bands)

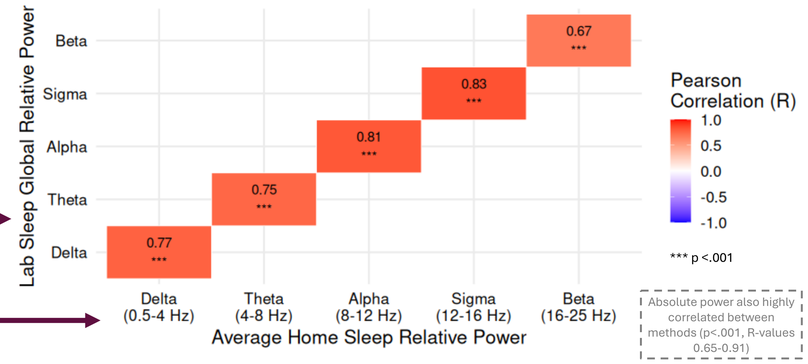
Subject average power calculated across complete nights of data

Laboratory Sleep
Two nights of 128-channel high density sleep EEG in the lab.

Power spectral analysis performed at each electrode for second night of NREM sleep data (absolute and relative power in canonical frequency bands)

Global power (average of all scalp electrodes) calculated for each subject

High Correlations between Home and Laboratory NREM Spectral Power across all Frequency Bands



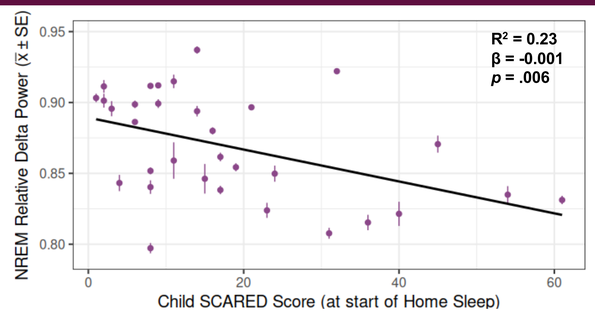
Anxiety is Associated with Decreased Slow Wave Activity at Home and Laboratory Sleep

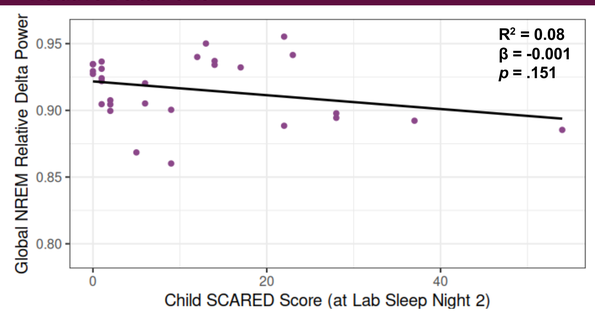
For each EEG method, **anxiety severity (SCARED) scores** were examined in relation to absolute and relative NREM **delta power** (0.5-4 Hz) and **alpha power** (8-12 Hz):

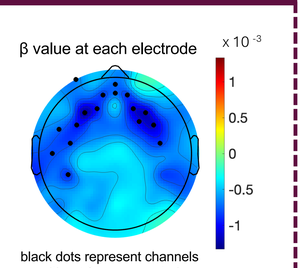
Home Sleep Relative Power
Linear mixed effects model including complete nights, controlling for age

Lab Sleep Relative Power
Linear regressions, controlling for age, for global and channel-wise power from second night of hdEEG

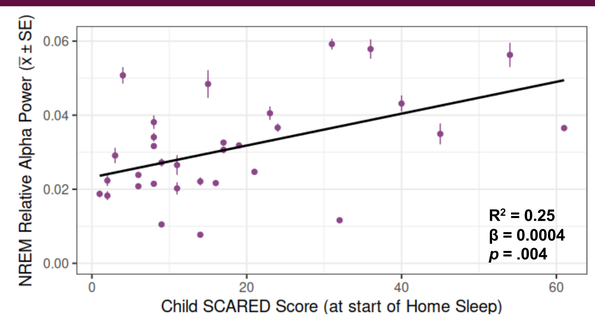
Relative Delta Power

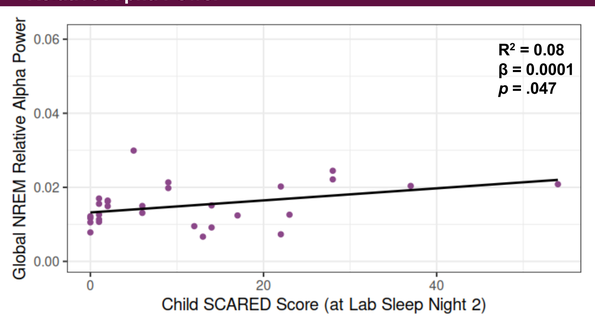


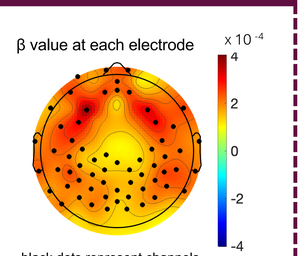




Relative Alpha Power







absolute power models not significant (all p>.05)

Discussion

- High correlations between at-home single-channel EEG and in-lab hdEEG sleep physiology suggest stability of sleep signatures across acquisition methods and time.
- Additionally, both sleep EEG methods consistently capture anxiety-related reductions in slow wave activity highlighting slow wave sleep as a potential treatment target for childhood anxiety disorders.
- Single-channel EEG data collection allows families to collect high-quality sleep data from home in children's natural sleeping environment. Additionally, the SmartSleep headband was designed with an integrated closed-loop platform for active intervention during sleep using auditory tones that could be employed to enhance SWS in youth with pathological anxiety [4, 5].
- High density EEG allows precise assessment of sleep microstructure and further exploration of regional differences in slow wave activity during sleep.