Decoding Pre-trial Pupil Diameter from EEG Dynamics in an Auditory Oddball Task

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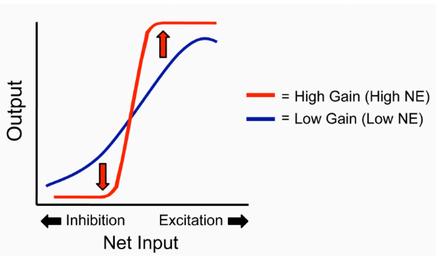
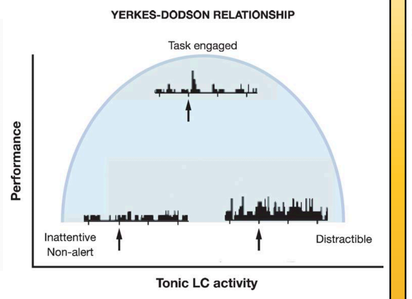
LC and Pupil Diameter

Adaptive Gain Theory

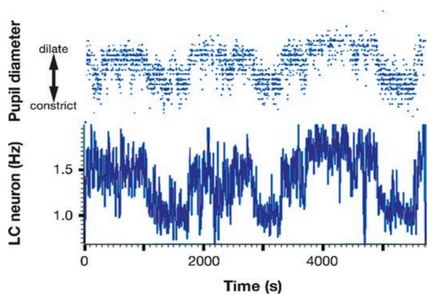
- Locus Coeruleus (LC) releases norepinephrine (NE) throughout the brain
- NE increases neural gain
- Adaptive gain theory posits an inverse-U relationship between LC activity (arousal) and performance[1]

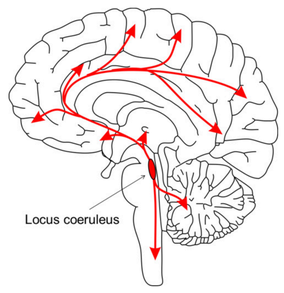




LC and Pupil Size

- LC is thought to be causally related to pupil size
- Pupil size highly correlated with LC firing[2]
- LC firing precedes pupil dilation by about 355ms[3]
- Electrical stimulation of LC neurons evokes pupil dilation[3]

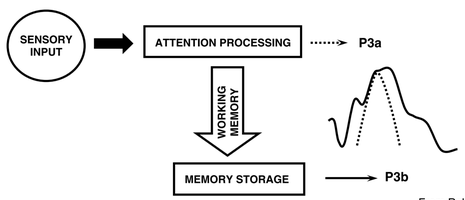


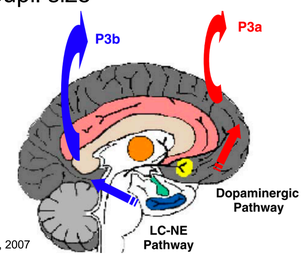


EEG and Attention

P300 Event-related Potential (ERP)

- Generally thought to index attention
- Murphy et al., (2011) found that P300 amplitude shows an inverse-U relationship when binned according to pre-trial pupil size[4]

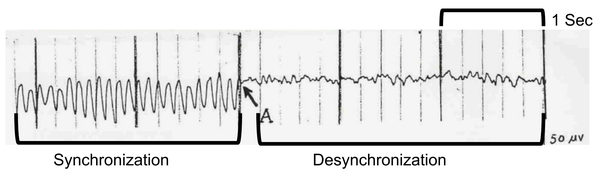




From Polich et al., 2007

Alpha Oscillations

- Increased alpha synchronization thought to represent "cortical idling"
- Alpha desynchronization thought to index attention [6]



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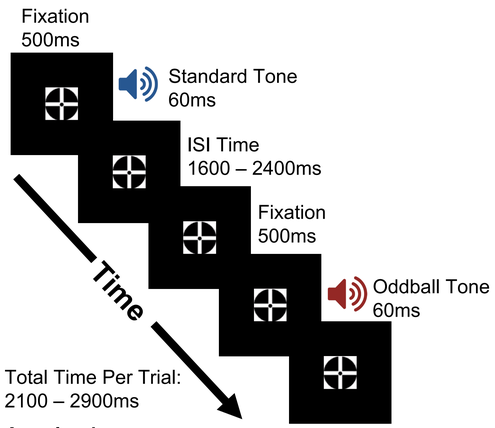
Research Questions and Methods

Research Questions

- Can we replicate inverse-U relationship between pre-trial pupil diameter and the P300 ERP?
- What information does the EEG signal carry about pre-trial pupil size?
- Can we decode pre-trial pupil size from ERP and oscillatory dynamics during the pre-trial period and after stimulus onset?



Auditory Oddball Task

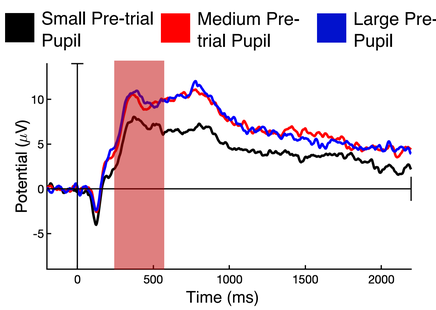
- Direct, registered replication of Murphy et al., 2011
- 900 trials in 1 continuous block
- 80% standard trials, 20% oddball trials
- Minimum of 3 standard trials between every oddball trial
- Right-handed spacebar press on oddball trials
- EEG and pupillometry recorded

Analysis

- n = 27, pre-trial baseline pupil size calculated by averaging 1 second of pupil diameter data before stimulus onset
- Pupil data was then ranked into terciles (small, medium, and large), EEG data was binned according to these terciles
- Machine learning (SVM) employed to predict pre-trial pupil size from EEG

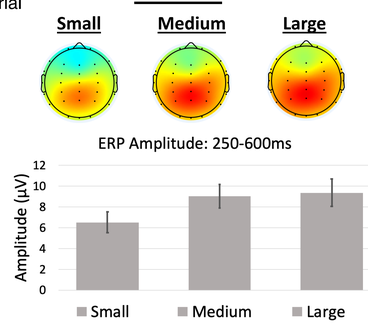
ERP Results

Correct Oddball ERP

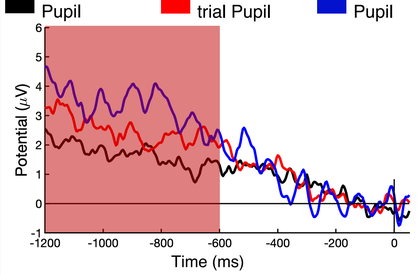


Linear: F(1,26) = 9.16, p = 0.006, η2 = 0.261
Quadratic: F(1,26) = 3.70, p = 0.066, η2 = 0.124

Scalp Topography: 250 – 600ms

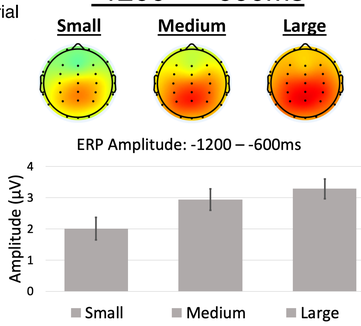


Correct Oddball Pre-trial ERP



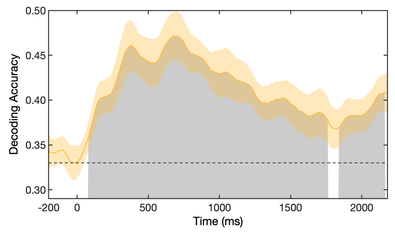
Linear: F(1,26) = 7.77, p = 0.01, η2 = 0.23
Quadratic: F(1,26) = 1.62, p = 0.22, η2 = 0.06

Scalp Topography: -1200 – -600ms

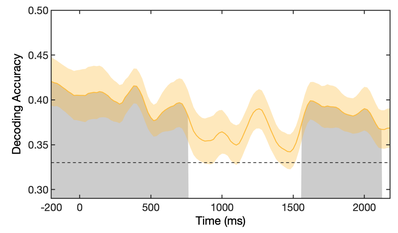


SVM Analysis

ERP Decoding



Alpha Decoding



Confusion Matrix: 250-600ms

Actual Pre-trial Pupil / Predicted Pre-trial Pupil

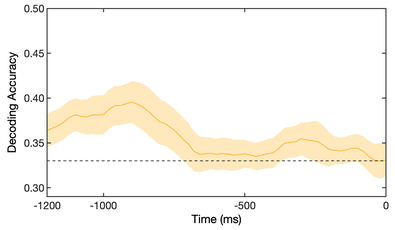
	Small	Medium	Large
Small	47.89%	32.02%	20.08%
Medium	27.66%	40.21%	32.12%
Large	18.42%	32.02%	49.56%

Confusion Matrix: 250-600ms

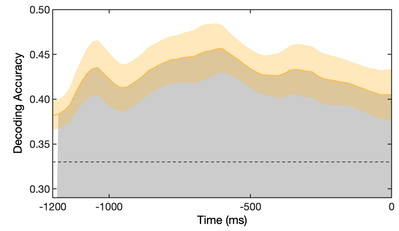
Actual Pre-trial Pupil / Predicted Pre-trial Pupil

	Small	Medium	Large
Small	46.25%	26.69%	24.06%
Medium	32.56%	34.25%	33.19%
Large	24.64%	34.25%	41.11%

Pre-trial ERP Decoding



Pre-trial Alpha Decoding



Confusion Matrix: -1200 – -600ms

Actual Pre-trial Pupil / Predicted Pre-trial Pupil

	Small	Medium	Large
Small	36.60%	35.50%	27.89%
Medium	30.72%	34.48%	34.80%
Large	24.79%	34.94%	40.27%

Confusion Matrix: -1200 – -600ms

Actual Pre-trial Pupil / Predicted Pre-trial Pupil

	Small	Medium	Large
Small	48.76%	31.52%	19.72%
Medium	33.66%	35.74%	30.60%
Large	20.59%	32.99%	46.43%

Conclusion

- Although approaching significance, P300 ERP analysis failed to find a quadratic trend. This could be due to inadequate power, binning trials in terciles as opposed to quintiles, or participants not entering "over-aroused" states during our oddball paradigm.
- Pre-trial ERP analysis revealed a significant linear trend, although a quadratic trend was not observed
- SVM decoding revealed that the EEG activity is accurately able to classify pre-trial pupil size, with ERP decoding providing greater prediction during the trial, and alpha decoding providing greater prediction during the pre-trial period

References

1. Aston-Jones & Cohen. *Ann Rev Neuro.* 2005
2. Rajkowski et al. *Soc Neuro.* 1993.
3. Joshi et al., *Neuron. 2016.*
4. Murphy, et al. *Psychophys.* 2011.
5. Polich. *Clin Neuorphys.* 2007.
6. Klimesch. *Neurosci Lett.* 1998.