Heart Rate Variability During Light Exposure and Subsequent Network Connectivity Patterns

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Background

- Heart Rate Variability (HRV) has been shown to increase at the onset of sleep. Interestingly, exposure to blue wavelength light prior to sleep can inhibit this increase, suggesting a possible biomarker of increased alertness. Ishibashi, K., Kitamura, S., Kozaki, T., & Yasukouchi, A. (2007)
- Previous work has shown that these effects are not specific to blue light and exposure to red light can also lead to sympathetically driven changes in HRV. Figueiro, M. G., Bierman, A., Plitnick, B., & Rea, M. S. (2009)
- In addition, acute exposure to blue light has been demonstrated to increase alertness, reduce sleepiness, increase performance on the Psychomotor Vigilance Test (PVT), and increase sympathetic cardiac influence. Lockley, S. W., Evans, E. E., Scheer, F., Brainard, G. C., Czeisler, C. A., & Aeschbach, D. (2006)
- A brain region associated with working memory and attention, the dorsolateral prefrontal cortex, has been shown to display aberrant positive, instead of typical negative, correlations to default mode areas following sleep deprivation. De Havas, J. A., Parimal, S., Soon, C. S., & Chee, M. W. (2012)
- We hypothesized that individuals who show smaller increases in HRV during light exposure (presumably reflecting greater alertness and associated sympathetic influence) would have better performance on the PVT and greater post-exposure frontoparietal connectivity.

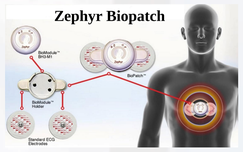
Methods and Materials

SUBJECTS

- Twenty healthy adults ranging in age from 18-30 years (11 females; Mean age: 20.95 years).

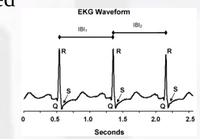
PROCEDURE

- Participants underwent a half hour baseline acclimation period in low amber light, beginning at 9:45 a.m. and at 10:15 am participants underwent a half hour exposure to bright blue light (469 nm; n=10) or bright amber light (578 nm; n=10).
- EKG was acquired using a Zephyr Biopatch sampling at 1000 hz.
- The PVT was administered before and after light exposure.
- A six-minute resting state functional connectivity neuroimaging scan at 3T was performed immediately following light exposure.



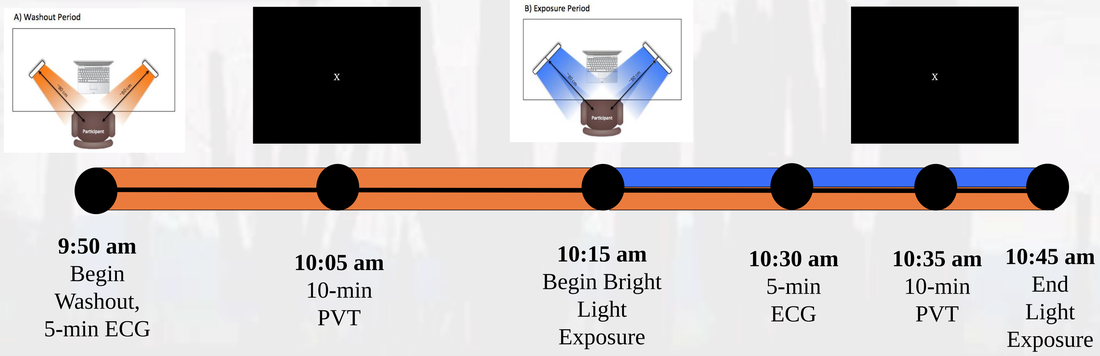
ANALYSES

- Offline analysis of EKG with QRSTool and CmetX Cardiac Metric Software was used to extract log-transformed heart rate variability (total HRV across all frequencies).
- Functional connectivity was examined cortical/subcortical regions ($p < .05$, FDR analysis level corrected) utilizing the CONN toolbox and SPM12.
- Behavioral data were processed in SPSS



Allen et al 2007

Study Design



9:50 am Begin Washout, 5-min ECG

10:05 am 10-min PVT

10:15 am Begin Bright Light Exposure

10:30 am 5-min ECG

10:35 am 10-min PVT

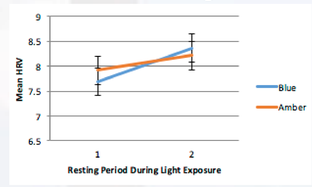
10:45 am End Light Exposure

PVT Results

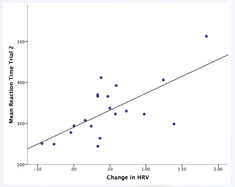
- As expected, there were no significant difference in baseline HRV, performance on the PVT, or sleepiness between subjects assigned to the two light conditions.
- Both groups showed an increase in HRV between baseline and the bright light exposure (p=.001).
- However, smaller increases in HRV were associated with fewer lapses in vigilance (p=.037) and faster reaction time (p=.005) on the PVT.

		Reaction Time PVT 1	Reaction Time PVT 2	Lapses PVT 1	Lapses PVT 2
Baseline HRV	Correlation Coefficient	-.391	-.397	-.174	-.302
	Sig. (2-tailed)	.088	.083	.462	.195
	N	20	20	20	20
Post Light Exposure HRV	Correlation Coefficient	-.030	-.002	.163	-.025
	Sig. (2-tailed)	.900	.995	.493	.917
	N	20	20	20	20
Change in HRV (post – pre)	Correlation Coefficient	**.486***	**.602****	**.473***	**.469***
	Sig. (2-tailed)	**.030**	**.005**	**.035**	**.037**
	N	**20**	**20**	**20**	**20**

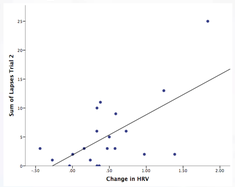
HRV Change



Reaction Time

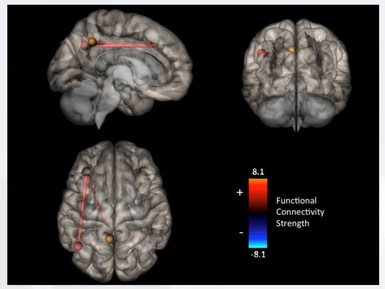


Lapses in Attention

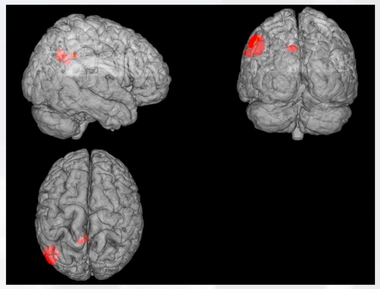


fMRI Results

Region of Interest Connectivity

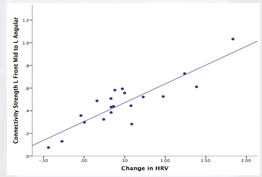


Seed to Voxel Connectivity

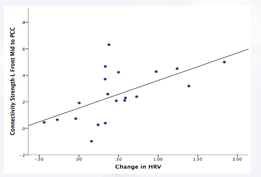


- Smaller increases in HRV from baseline to after bright light exposure correlated positively with increased functional connectivity between areas of the dorsal attention network and parietal segments of the default mode network.
- These include, specifically, the Left Middle Frontal Gyrus with the Left Angular Gyrus and Left Posterior Cingulate Cortex.
- To extend our findings a network connectivity atlas was used for ROI parcellation. Significant positive correlations for smaller changes in HRV and increased connectivity between the Default Mode B Network and Dorsal Attention A Network (p = .035) were found.

Connectivity Correlations with Change in HRV

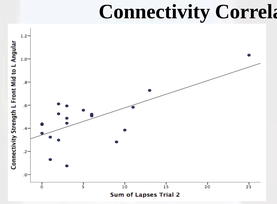


r_s = .768



r_s = .668

Connectivity Correlations with PVT Performance



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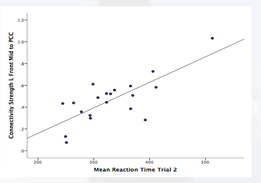

r_s = .565

Network ROI Connectivity

Default Mode B Areas:

Dorsal Prefrontal

Temporal

Anterior Inferior Parietal

Dorsal Attention A Areas:

Posterior Temporal Occipital

Superior Parietal

Inferior Parietal Occipital

Yeo et al 2011 17-Network Parcellation

Conclusions

- Contrary to expectations HRV increased following both wavelengths of bright light, however, consistent with our hypotheses, individuals with smaller HRV increases during light exposure, regardless of wavelength, had better performance on the PVT. Because we did not include a no-light control, it is possible that increases in HRV would have been larger in the absence of light exposure.
- Findings suggest that smaller increases in HRV during bright light exposure, regardless of wavelength, may be associated with better sustained attention and brain function that is directly associated with faster response times in the PVT. Whether this effect is mediated by sympathetic or parasympathetic mechanisms, or both, is unclear given that total HRV was examined.
- Imaging findings suggest that a key element of attention and autonomic modulation involves the decoupling of regions involved with exteroceptive awareness (Dorsal Attention A) and self-reflective processing and/or simulation (Default Mode B).
- Future work may focus on the role of individual differences in HRV during exposure to light on performance in environments where sleepiness may be an issue (e.g., military personnel, medical staff, shift workers).

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