Non-visual Impacts of Light on Effective Connectivity associated to executive brain responses

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Introduction:

Beyond vision, light has many non-visual biological effects including the stimulation of alertness and cognition. These effects are considered to be mediated mainly through the recently discovered blue-light-sensitive intrinsically photosensitive retinal ganglion cells i.e., ipRGCs (Warthen, D. M., & Provencio, 2012).
Direct projections of ipRGCs mainly reach subcortical structures, including the hypothalamus and thalamus. However, non-visual impacts of light have also been reported on the activity of cortical regions, presumably through an initial subcortical impact.
Here, we assessed the impact of blue-enriched light on the connectivity of a brain network sustaining the brain activity associated with an ongoing auditory executive task in healthy young adults. We anticipated that blue-enriched light would mainly affect subcortical to cortical connectivity.

Method:

25 healthy participants (60% Female, 23.2±4.1 years) who met our inclusion criteria assessing both physical and mental health in addition to having regular sleep habits, were included in the study. Participants started the study protocol with a structural 7T MRI scan in which high resolution T1-weighted structural images of their brain were collected. Following a loose sleep-wake schedule (±1h; verified with actigraphy) for 7 days, participants came to the lab, ~2 hours before/after their habitual sleep/wake time to do a functional 7T MRI scan (GRE-EPI sequence, TR = 2340 ms, TE = 24 ms, voxel size = $1.4 \times 1.4 \times 1.4$ mm^3). Participants completed an auditory working memory task (N-back: 0-back(N0) and 2-back(N2)) under different light conditions including an active blue-enriched polychromatic light, to stimulate ipRGCs (6500K; 190, 92 and 37 melanopic Equivalent Daylight Illumination (EDI) lux) and a control monochromatic orange light (590 nm; 0.2 mel EDI luc), to which ipRGCs are almost non-responsive. Based on a standard whole-brain GLM analysis using SPM12, 3 regions significantly involved in the N-back task ($p_{FWE\ whole\text{-}brain} < 0.05$) were isolated: a dorsoposterior part of the thalamus corresponding to the pulvinar, the Intraparietal sulcus (IPS) and Anterior insula (AI) (Figure.1)

Effective connectivity among the 3-region network and the modulatory effect of different light conditions on the inter-region connections were estimated using the Dynamic Causal Modeling as part of SPM12 (Figure.2A). Effects were considered robust for posterior probably (Pp) > 0.95.

Results:

The DCM analysis indicated that only the driving inputs of the 2-back task was effective for the IPS and AI ($Pp \geq 0.95$). The baseline effective connectivity showed that among the connections defined in the initial model, 3 connections were robust ($Pp \geq 0.95$). The pulvinar to IPS and pulvinar to AI connectivity were excitatory while the AI to IPS connectivity was inhibitory (Figure.2B).
Evaluation of the modulatory effect of light conditions (blue-enriched and orange) revealed a robust modulation of the connections going from the pulvinar to both the IPS and AI with only blue-enriched light significantly strengthening the two aforementioned connectivities ($Pp \geq .95$) (Figure.2C).

Conclusion:

These results are in line with the initial non-visual impact of light on the information flow going from subcortical to cortical areas (Vandewalle et al., 2009). In the context of an executive task, blue-enriched, but not orange light, seems to affect thalamo-cortical loops. Future analyses will consider the different levels of blue-enriched light.

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References:

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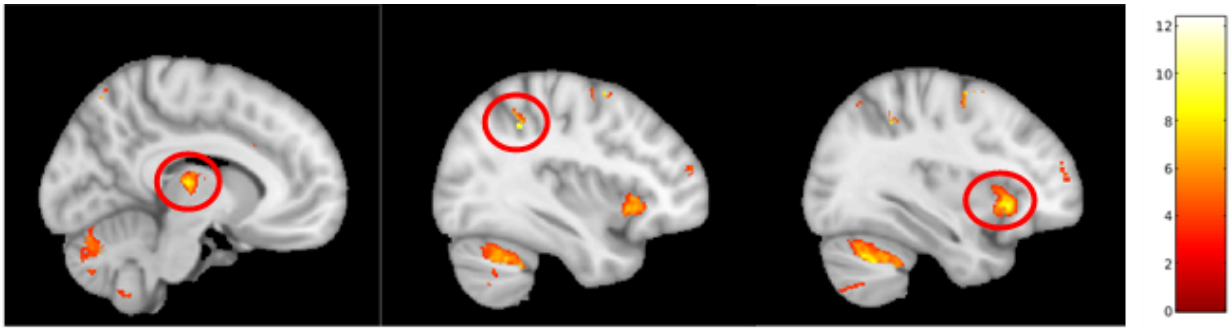

***Figure 1**: Whole-brain executive brain responses (Contrast: N2-N0; P-value<0.05: whole-brain FWE corrected). Pulvinar (left), Intraparietal sulcus (middle) and anterior insula (right) are among the activated regions. The colored legend on the right corresponds to t-values of the statistical tests displayed on the average structural image of the sample.*

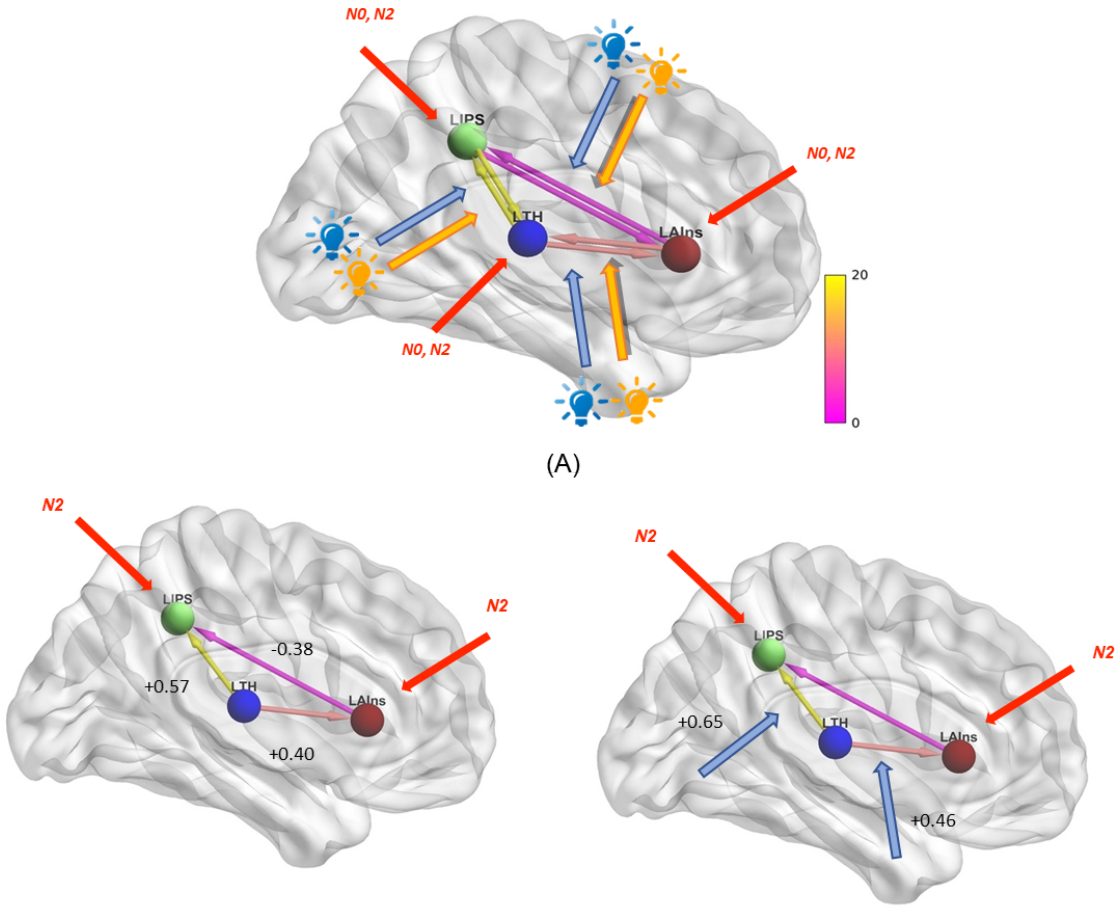

Figure 2. *Initial DCM model along with the winning model. (A): In the initial model, 6 connections between the 3 regions were considered. Both 0-back and 2-back were considered as driving inputs for all the 3 regions. Light (both blueish and orange) were assumed to be able to affect any of the 6 connections. (B) effective driving inputs and significant baseline connectivity (Pp > 0.95). (C) Only blue-enriched light has a robust modulatory effect, and the effect is only on the connections going from the subcortical region to the cortical regions (Pp > 0.95).*