BLUE LIGHT RAPIDLY MODULATES COGNITIVE BRAIN ACTIVITY IN SOME BLIND INDIVIDUALS

INTRODUCTION

Light regulates multiple ‘non-image-forming’ or ‘non-visual’ circadian, neuromodulatory and neurobehavioral functions in humans including direct enhancement of alertness and cognition. The relative contributions of inputs from visual (rod/cone) and intrinsically photosensitive retinal ganglion cell (ipRGC) photoreception to the stimulant effect of light and the brain mechanisms involved remain unclear, however. A small percentage of blind individuals with complete loss of sight retain circadian responses to light and offer a unique opportunity to investigate the impact of light on cognitive brain functions, in the absence of a functional outer retina and presumably via melanopsin-expressing ipRGCs.

OBJECTIVES

- We used fMRI to test whether exposure to high intensity blue light for 55s modulates cognitive brain responses to an auditory task in blind participants who retain non-image-forming responses to light.
- We used EEG to investigate whether 0.5s or 2s exposure to high intensity blue light modifies auditory evoked potentials in these individuals.
- We wanted to test the presence of light ‘awareness’ using a two alternative forced choice paradigm

METHODS

- PARTICIPANTS: Three participants with complete loss of sight for at least 10 years and confirmed light induced melanin suppression took part to the study, (9 such individuals have been identified so far, worldwide). Participants followed a regular sleep/wake schedule 7 days prior to and during their stay in Montreal. Absence of visually evoked potential was verified using EEG flashes of high intensity blue light (100 cd/m^2).

- fMRI: One hour after habitual sleep time, participants performed twenty 55s blocks of an auditory 2-back task alternatively in complete darkness or while exposed to high intensity blue light for 55s (480nm; 1.95 x 10^11 photons/cm^2). This task requires updating, maintenance and comparing of information in working memory, in addition to attention and auditory processing.

- EEG: In the afternoon, participants performed an auditory psychovigilance task while exposed to 0.5s or 2s pulses of high intensity blue light (465nm; 9.7 x 10^11 photons/cm^2). The task probes the ability to maintain sustained attention. Light exposures and sounds were administered either alone or simultaneously (300 trials per condition), in which case auditory stimuli were produced during the last 150ms of the light exposure so that lights offs and the termination of the sound coincided. EEG data were collected using a 37-channel BrainAmp. Data were analyzed using Fieldtrip. A fixed effect analysis was performed to compare two different light exposure conditions (blue light exposure alone vs. blue light exposure across the 3 subjects). Significance level was fixed at p<0.05 after correction for multiple comparisons over the entire brain volumes.

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- LIGHT AWARENESS: In the afternoon, participants had to report on the presence of high intensity blue light (465nm; 9.7 x 10^11 photons/cm^2) in a two-alternative forced-choice task. In 3 separate sessions, they were given forty 4s, 10s and 25s trials (one trial duration per session) randomized for whether the first and second half of the test included blue light exposure, the other half consisting of darkness. The 4s and 10s sessions were conducted on the same day; the 25s session was conducted the previous or following day. Cumulative probability of discrimination was carried out to determine whether responses were significantly different from random choices (p > 0.05).

SUMMARY/CONCLUSIONS

In the absence of a functional outer retina, but when non-image-forming photoreception is retained, i. exposure to light for less than a minute modulates cognitive brain activity in prefrontal areas involved in higher cognitive functions, in the occipital cortex, and in the pulvinar, which is implicated in arousal regulation; ii. light rapidly decreases activation in medial prefrontal areas of the default mode network; iii. as little as 2 seconds of light modulates EEG brain activity, but only when the brain is actively processing the acoustic stimulations; iv. awareness of light can occur.

Our results indicate that melanopsin ipRGC signaling can rapidly affect brain activity and fundamental cerebral organization, so that it could potentially participate in the regulation of numerous aspects of human brain function, in addition to the recruitment of supplemental brain areas to perform an ongoing cognitive process.

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Figure 1. Light increases brain activity during an auditory cognitive task in fMRI

Blue areas show significant activation increases during 55s exposure to blue light, while performing a 2-back task, as compared to darkness. Statistical comparisons were made using t-values for each subject, as well as the within-subjects t-values for each subject. *p<0.05. Average activity estimates of the 3 participants (left) are consistent with the individual activity estimates (right) to show the intra-individual variability.

PTC: Periorbital cortex

Significant differences were observed in the ventrolateral and medial prefrontal cortices, in the anterior cingulate, precuneus and thalamus, as well as in the occipital cortex (corticinal sulcus, superior and inferior occipital gyri).

Figure 2. Light prevents decreased activation in medial prefrontal areas of the default mode network

Red areas showing significant decrease in activation in response to the task when performed in darkness. The areas correspond to the default mode network.

Blue Areas: Area of figure 1

White: Overlaps in the medial prefrontal cortex and anterior cingulate, i.e., significant decreases in activation to the task in darkness.

Figure 3. Two seconds of light modulates EEG activity as administered simultaneously to auditory stimulation, but not if administered alone

EEG activity was evaluated at the Cz location by an auditory stimuli alone (green), by blue light exposure alone (blue), or light and sound stimuli simultaneously (red). The EEG was compared to the mathematical sum of both auditory and light alone trials (black line). Horizontal bars correspond to periods of the presentation of the stimuli (i.e., 1800ms and 1850ms). Trials in the left hemisphere condition were preceded by 350ms of light, while in the right hemisphere condition, each auditory stimulus was preceded by 350ms of light. In the 2s condition, all 3 participants show significant differences, while in the 55s condition only participant 2 presented marginal but significant differences.

Figure 4. Light awareness is present in at least two participants

Participants chose whether the light was on or off during the first or second half of a 4, 15 or 20s epoch.

Participant 1 had high accuracy (92%) irrespective of trial duration. Participant 2 exhibited a duration dependent behavior with a linear increase in accuracy from 52.5% (2s), 68% (5s) and 80% (15s). Participant 3 exhibited a duration dependent trend in accuracy with 62.5% (5s) and 36% (15s) selection accuracy. The latter value indicates that participant 3 stated the incorrect option on 75% of occasions, which is a non-random behavior.