Epilepsy & Behavior 51 (2015) 127–132

Contents lists available at ScienceDirect

Epilepsy & Behavior

journal homepage: www.elsevier.com/locate/yebeh

LORETA indicates frequency-specific suppressions of current sources within the cerebrums of blindfolded subjects from patterns of blue light flashes applied over the skull

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ARTICLE INFO

Article history:
Received 11 March 2015
Revised 27 May 2015
Accepted 20 June 2015
Available online 10 August 2015

Keywords:
LORETA
Temporal lobes
Parahippocampal region
Light-emitting diodes
Gamma activity
Sensed presence
Blue light
Bokkon photon field

ABSTRACT

An array of eight cloistered (completely covered) 470-nm LEDs was attached to the right caudal scalp of subjects while each sat blindfolded within a darkened chamber. The LEDs were activated by a computer-generated complex (frequency-modulated) temporal pattern that, when applied as weak magnetic fields, has elicited sensed presences and changes in LORETA (low-resolution electromagnetic tomography) configurations. Serial 5-min on to 5-min off presentations of the blue light (10,000 lx) resulted in suppression of gamma activity within the right cuneus (including the extrastriate area), beta activity within the left angular and right superior temporal regions, and alpha power within the right parahippocampal region. The effect required about 5 min to emerge followed by a transient asymptote for about 15 to 20 min when diminished current source density was evident even during no light conditions. Subjective experiences, as measured by our standard exit questionnaire, reflected sensations similar to those reported when the pattern was presented as a weak magnetic field. Given previous evidence that photon flux density of this magnitude can penetrate the skull, these results suggest that properly configured LEDs that generate physiologically patterned light sequences might be employed as noninvasive methods to explore the dynamic characteristics of cerebral activity in epileptic and nonepileptic brains.

1. Introduction

The sensitivity of the human brain as inferred by quantitative electroencephalography (QEEG) and sLORETA (low-resolution electromagnetic tomography) to external sources of *physiologically patterned* electromagnetic fields and energies has been demonstrated by several experiments [1]. "Physiologically patterned" refers to those complex temporal sequences that are similar to those generated by cerebral tissue rather than symmetrical, sinusoidal, or square-wave signatures generated by traditional electronic devices. Similarly patterned magnetic fields have been shown to affect the nociceptive thresholds for rodents [2] and planarians [3] and to influence signaling pathways within malignant cells [4]. Irregularly patterned magnetic fields can be "sensed" by cells. The importance of precise timing within the domain occupied by EEG activity has been reported [5].

Neuronal cells and hippocampal slices emit photons with radiant flux densities in the order of 10^{-12} W·m^{-2} whose amplitude fluctuations are coupled in real time with electrophysiological patterns [6]. Cells also respond to photons within the visible wavelengths [7]. There have been multiple recent experiments demonstrating the effectiveness of specific wavelength photon densities delivered through LEDs (light-emitting diodes) upon the cell plasma membrane [8] and the molecular pathways associated with its stimulation. The new areas of "optogenetics" [9] by which cell function is controlled by light and "photoimmunotherapy" whereby near-infrared wavelengths are employed to target specific molecules indicate that photon stimulation may have potential application to electrophysiological phenomena such as those involved with epilepsy. Intercellular photon emissions may be a central method of interaction and exchange of information between cells. Biophotons can also be detected approximately 15 cm from the side of the right (but not the left) hemisphere when people sit in hyper-dark settings and engage in imagination of white light. The fluctuations in the photon flux density were correlated 0.9 with the power of beta EEG activity over the left prefrontal region [10].

Elicitation by visually discernible light pulses of paroxysmal EEG activity from the brains of patients who have been diagnosed with epilepsy has been a classic method of clinical verification of the vulnerability of some cerebral tissue to recruitment and summation in response to repetitive stimuli [11]. However, the effects of photons applied to the human skull *without* being processed directly by the retinal visual

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http://dx.doi.org/10.1016/j.yebeh.2015.06.039
1525-5050/

system have not been systematically explored. Persinger et al. [12] demonstrated that application of 10 klx different fixed-frequency light flashes applied against the skull resulted in small, reliable increases (~$2.5 \cdot 10^{-11}$ W·m^{-2}) in photon emissions from the opposite side of the head as measured by photomultiplier tubes (PMTs) or digital units. The effect was most reliable with either constant light or light flashed between 3 Hz and 7 Hz. When the light stimulation occurred, there was enhanced QEEG (quantitative electroencephalographic) power within the theta and the low beta range. The power within the right parahippocampal region was particularly enhanced.

In that study, subjects were blindfolded while sitting in a darkened chamber. Any extraneous light from the light source was blocked with several layers of black towels. That the response latency was about 1 s and that the difference between applications of the light along the X-axis (left versus right) compared with the Z-axis (rostral–caudal) reflected the actual distance ratio of the cerebrum indicated that the effect was not artifact. If there had been "inadvertent light", the PMT response would have been conspicuous, immediate, and protracted. The study had been inspired by the results of Starck et al. [13] who showed that light applied with a flux density of 8000 lx to the ear canals from LEDs with a primary peak spectrum at 465 nm or blue color (and a secondary peak at 550 nm) elicited clear and specific changes in fMRI (functional magnetic resonance imaging) profiles. The greater functional connectivity during the external light stimulation was significantly greater (equivalent to about 5.2 cm^3) across the extrastriate visual cortices. A smaller locus of enhancement occurred in the region of the locus ceruleus and anterior cerebellum. The functional connectivity during the light stimulation gradually increased during the first 5 min and displayed an asymptote after about 6 min.

Considering the specific changes within cerebral space as measured by sLORETA when a weak, frequency-modulated, spatially rotating magnetic field was applied with slightly greater intensity over the right temporal lobe, we designed an experiment whereby light from blue (470 nm) LEDs with base intensities of about 10,000 lx would be applied instead on the skull over the caudal right temporal lobe region. Brief (15 to 30 min) applications of physiologically patterned magnetic fields have been associated with the experience of altered states and sensed presences similar to those reported by patients who have been diagnosed with complex partial epileptic seizures and when such patients received direct electrical stimulation within the temporal lobes [14]. Here, we report that this complex temporal pattern when applied over the caudal right temporal lobe as temporal configurations of blue light (similar to that employed by Starck et al. [13]) within a relatively narrow wavelength elicited clear changes in specific brain activities within the cerebrum as measured by sLORETA. The change was sufficient to be potentially useful for revealing recondite conditions that are consistent with complex partial epilepsy or for related forms of electrical lability.

2. Methods

A total of 7 (4 males and 3 females) participants volunteered for the experiment after the protocol had been approved by the University's Research Ethics Board. Each participant sat within a comfortable arm chair that was housed within an acoustic chamber (13 m^3). A sensor cap (Electro-Cap International) with 19 AgCl sensors, sited according to the 10–20 International Standard of Electrodes placements, was placed onto the scalp for monopolar (reference to the ear) recordings. Impedance of all sensors was maintained less than 10 kΩ. Data collection to the laptop computers external to the closed chamber was by a Mitsar 201 system amplifier, using a sampling rate of 250 Hz with an input range of +/−500 μV and a 16-bit analog-to-digital conversion [15]. The subject was then blindfolded with triple layer material to ensure that no light was experienced during the experiment.

A custom-constructed LED application device was then placed and maintained by Velcro just behind the right ear at the level of the temporal lobe. The entire device was further secured with an additional Velcro band. The device was composed of 8 (4 pairs) 470-nm LEDs (Fig. 1). The onset of light emissions for each of the pairs of LEDs was controlled by the frequency-modulated ("Thomas") pattern by a laptop computer. Its temporal configuration has been published several times [3,16]. It is composed of 839 points with values between 0 and 256 which are transformed to voltages between −5 and +5. The point duration, or the time the current activated each pair of LEDs, was 3 ms in order to simulate the optimal point duration that has shown to be effective when this pattern is presented as approximately 1 to 5 μT magnetic fields [17]. However, the magnetic field intensity produced by the LED device was only 50 to 90 nT (0.5 to 0.9 mG) or comparable with the background 60-Hz power levels.

Thirty-second segments extracted from the end of each ~5-minute trial (light off/light on), for each of 3 participants (with the most artifact free records), were segmented into 5-second segments. Each of these segments (total = 108) was then imported into sLORETA software for computation of current source densities. Simple paired t-tests were performed using the statistics function in the sLORETA package to compare light-off and light-on segments. For further statistical analyses, current source densities (μA·mm^{-2}) for ROIs of the major effects were computed using the *sLORETA to ROI* function. These data were then imported into SPSS. Although the analyses of the other 4 subjects' records were similar for different blocks (on–off pairs), at least one block was ambiguous because of electronic artifacts from the LED array that began immediately upon activation and stopped with termination.

After the exposure, each subject was given the experience rating questionnaire whose items were listed by Persinger and Saroka [14]. One set of items (n = 20) involves ratings of various experiences (0 = never, 1 = at least once, 2 = frequently) that included sensations (for example) of dizziness, sensed presence, visual images, various measures of emotion (including terror), odd tastes, childhood memories, and images from dreams. This form was administered in order to compare, semiqualitatively, the profile of experiences associated with the LED stimulation with that reported following exposures to physiologically patterned magnetic fields. The means of the scores for each of the items were converted to z-scores and compared with the profile of within item z-scores reported in Table 1 [14] for surgical stimulation from published clinical cases and from university and film crew populations exposed to the weak externally applied magnetic fields. Correlations of these scores for the 20 items between the three groups and the group from the present study were completed. Residuals following regression analyses between the university group exposed to weak magnetic fields across the temporal lobes and the present LED-exposed group were completed to discern any potential differences in the subjective profiles with respect to the clinical literature. The point of this analysis was to discern the differences in the pattern of the experiences rather than the significant differences in the magnitudes of a particularly reported experience.

3. Results

The most conspicuous effect revealed by the sLORETA paired t-tests indicated a significant suppression ($t = -6.13$, $p < .05$) of gamma (>30 Hz) activation within the cuneus of the left and right occipital regions (Fig. 2A). When the saved ROI seeds were graphed as a function of condition (light off/light on), there was a conspicuous decrease in current source density of the right cuneal region for the first two trials, with an increase during the third trial (Fig. 2B). The graph revealed that, except for one trial in the first participant, there was always a suppression of gamma activity upon light stimulation relative to the eye-closed baseline (no light) collected before the beginning of the experiment.

The initial sLORETA statistical analysis also revealed a significant ($t = -4.08$, $p < .05$) suppression of power within beta-3 (25–30 Hz) range over the left angular and right middle temporal gyri (Fig. 2A).