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On the possibility of phosphenes being generated by the energetic radiation from lightning flashes and thunderstorms

Vernon Cooray [a,*], Gerald Cooray [b], Joseph Dwyer [c]

[a] Division for Electricity, Department of Engineering Sciences, Uppsala University, Box 534, 751 21 Uppsala, Sweden
[b] Department of Clinical Neuroscience, Karolinska Institute, Stockholm, Sweden
[c] Florida Institute of Technology, Melbourne, FL, USA

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ABSTRACT

After the first report of this phenomenon by Apollo 11 astronauts, experiments conducted in space and on the ground confirmed the creation of phosphenes by the interaction of energetic radiation with the human visual system. The aim of this Letter is to show that the energetic radiation generated in the form of X-rays, gamma rays, electrons and neutrons by thunderstorms and lightning is strong enough for the creation of phosphenes in humans. It is also pointed out that some of the visual observations reported during thunderstorms might be attributable to phosphenes excited by this energetic radiation.

1. Introduction

A phosphene is a visual sensation that is characterized by perceiving luminous phenomena without light entering the eye. Normal visual perception is created by the conversion of light falling on the retina into electrical signals by photo-receptors and subsequent interpretation of this signal by the occipital brain. Phosphenes are created when such electrical signals are created by other means in the absence of light stimuli. Phosphenes can be induced by direct stimulation of the retina or the optical nerve, either by mechanical, magnetic or electrical means. Phosphenes are created by the interaction of low frequency magnetic fields with the retina or the visual cortex as the time-varying magnetic fields generate currents which disrupt their normal electrical activity. The occurrence of phosphenes was recorded in Transcranial Magnetic Stimulation (TMS) studies. In TMS investigations, time varying magnetic fields are applied repeatedly to the brain using circular coils located on the head [1].

Phosphenes that occur in the vicinity of thunderstorms and lightning flashes are of interest in lightning research because they provide a scientific explanation for some observations of ball lightning. Despite the fact that ball lightning has been seen and described since antiquity, and recorded in many places around the globe, it has not been produced in the laboratory yet. Furthermore, the authenticity of the photographs available is questionable: the properties of ball lightning have to be extracted from eyewitness accounts. The observed properties of ball lightning have been summarized in several books [2,3], in which ball lightning is described as being spherical in shape, although other shapes, such as teardrops or ovals, have also been reported. On rare occasions, 'ball' lightning shaped like rods has been observed. The diameter of ball lightning is usually 10–40 cm, although, occasionally, ball lightning with a diameter as large as one meter has been reported. Most ball lightning phenomena are said to move horizontally, however descriptions including motionlessness, a zig-zag movement or moving from a cloud towards the ground can also be found. The life-time of ball lightning is reported to be about 10 seconds, but occasionally a duration of as long as one minute has been observed. Ball lightning can be manifested in different colors, such as red, red-yellow, yellow, white, green and purple. Although ball lightning is usually observed during thunderstorms, a significant number of sightings have also been reported during fine weather without any connection to thunderstorms or lightning. They have also been reported under stressful natural conditions, such as tornadoes, storms and earthquakes. Most of the ball lightning has been sighted indoors, and in some cases it was observed inside aircrafts.

The idea that ball lightning observations could be attributable to abnormal neuron activity in the occipital brain is not new. For example, Cooray and Cooray [4] pointed out that the visual

* Corresponding author. Tel.: +46 18 4715809.
E-mail address: Vernon.Cooray@angstrom.uu.se (V. Cooray).

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perceptions experienced by a person having a partial seizure of the occipital lobe are very similar to those of the recorded ball lightning observations. According to them, since the person remains conscious during such partial seizures and since some people may experience only one seizure of this kind during their lifetime, some of the 'ball lightning' observations could very well be attributable to experiences like this.

In a recent study, Peer and Kendl [5] concluded that the magnetic fields generated by lightning within about 100 m of a lightning strike are large enough to generate phosphenes through interaction with the visual cortex. However, in a revised study Peer et al. [6] showed that electric fields large enough to induce phosphenes could be induced in the brain only by the time varying magnetic fields of lightning return strokes with rather high current derivatives ($dI/dt > 100$ kA μs^{-1}) striking within about 50 m of a person. Moreover, it is only the initial peak of the magnetic field derivative (which is proportional to the induced electric field in the brain), whose width is about 10 to 20 μs, that exceeds the threshold necessary for the induction of phosphenes. Since the widths of the initial peaks are of much shorter duration than the TMS pulses (i.e. 250–450 μs; [5]) which induced the phosphenes, the question of whether these short pulses are capable of generating phosphenes by the stimulation of the visual cortex was left open. However, it is the charge delivered that causes neural polarization and hence a shorter pulse of higher amplitude could still give rise to phosphenes. Based on their analysis Peer et al. [6] suggested that the retinal phosphenes induced by the magnetic fields of lightning flashes could provide a scientific explanation for ball lightning experiences.

The goal of the present communication is to point out the possibility of phosphene induction in humans by the high energetic radiation environment in the vicinity of thunderstorms and lightning.

2. Visual effects produced by energetic radiation

The fact that energetic radiation produced by radium can give rise to phosphenes was first noted by Giesel in 1899 [7]. It was subsequently estimated that 80% of the phosphenes are created by the β radiation and the rest by the γ radiation of the radioactive radium [8]. A resurge of studies related to the creation of phosphenes by energetic radiation took place after the reports of light flashes observed in space by Apollo astronauts and first reported by Buzz Aldrin after the Apollo 11 flight to the Moon in 1969 [9]. Actually, the possibility that visual effects would be caused by energetic radiation in space was first predicted by Tobias in 1952 [10]. Detailed information on the observations made by astronauts was published recently by Fuglesang [11]. Based on a questionnaire comprised of 29 questions distributed to 98 astronauts, 47 out of 58 responded saying that they had experienced phosphenes in at least some space flights, but not necessarily in all of them. Importantly, in any given flight, not all of the astronauts had experienced phosphenes. Phosphenes were mostly noted just before going to sleep when the eye is adapting to the darkness. However, some have experienced them during the 'day-time' when wide awake. The shapes of the phosphenes were either rods, comet shaped, or comprised of a single dot, several dots or blobs. The colors were mostly white, but some had been colored yellow, orange, blue, green or red. Schematic drawings of the phosphenes observed by astronauts on the Apollo flights are shown in Fig. 1 [12]. The majority of the astronauts had perceived some kind of motion in association with the phosphenes. Most of the time, they were moving horizontally (from the periphery of the vision to the center) and sometimes diagonally, but never vertically [11]. Experiments conducted in subsequent space missions and in the Mir space station have confirmed that the phosphenes are created by the passage of energetic particles through the eyes [11]. The apparent motion of the phosphenes that was observed had to be physiological because the flight time of the energetic particles through the optical system was of the order of nanoseconds.

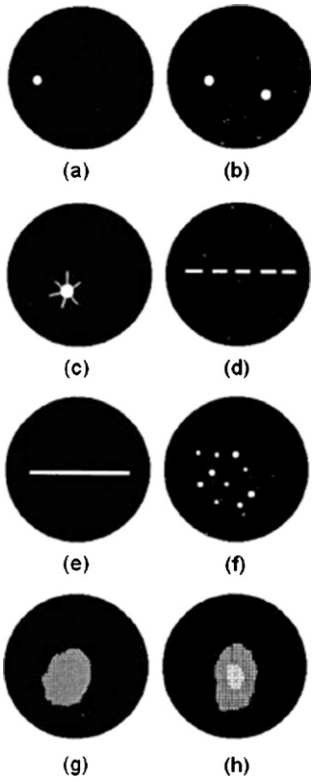

Fig. 1. Schematic diagrams of the phosphenes observed by astronauts in Apollo missions (from [12]).

The observations of the Apollo astronauts motivated some scientists to expose themselves to low energy particle beams to study the occurrence of phosphenes. Other experiments were conducted using cosmic rays (see [11], for a summary of these experiments). These experiments managed to reproduce what the astronauts experienced. Phosphenes were observed by human volunteers participating in experiments using neutron generators at energies of 3, 8, 14 and 300 MeV, as well as from Cf-252 at around 1 MeV (as summarized in [13]). Phosphenes have been also observed after exposure to low doses of X-rays [14]. In another study, ten cancer patients whose eyes were therapeutically irradiated with 6–18 MeV electrons reported phosphenes [15].

The exact mechanism behind the production of phosphenes has not been established yet, however, several mechanisms have been proposed for the creation of phosphenes by energetic particles [11, 13,14,16]. These include: (i) direct excitation of the photo receptors or other retinal elements, (ii) excitation of the optic nerve by the charged particles, (iii) Cherenkov radiation produced by the charged particles through the eye, (iv) excitation of photo receptors by emission from excited atoms and molecules along the particle track, and (v) scintillation in the eye lens. Narici et al. [16] proposed that the radicals produced by the ionizing radiation near photoreceptors are the cause of phosphenes. Margalit et al. [17] suggested that the electric stimulation of the retina or visual cortex evokes phosphenes by opening voltage sensitive ion channels.

The experimental data reviewed above confirm the occurrence of phosphenes by energetic radiation. One interesting question is whether the appropriate conditions are created at ground level under natural circumstances for the creation of phosphenes. The information available at present concerning the high energetic ra-