Brain electromagnetic activity and lightning: potentially congruent scale-invariant quantitative properties

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The space-time characteristics of the axonal action potential are remarkably similar to the scaled equivalents of lightning. The energy and current densities from these transients within their respective volumes or cross-sectional areas are the same order of magnitude. Length–velocity ratios and temporal durations are nearly identical. There are similar chemical consequences such as the production of nitric oxide. Careful, quantitative examination of the characteristics of lightning may reveal analogous features of the action potential that could lead to a more accurate understanding of these powerful correlates of neurocognitive processes.

Keywords: lightning, action potentials, current density, resonance, natural patterns, nitric oxide

INTRODUCTION

That information is propagated as sequential series of digital signals along distinct paths whose lengths are much longer than their widths is a primary assumption of contemporary neuronal function. Dispersion rates are within the range of 1–100 m/s with space constants in the order of about 1 mm. The fastest of these transients exhibit saltatory movements between specialized conductive spaces along the axon barrels. The ratios and scaling of the spatial and temporal relationships of these mediators of the "language of the brain" share remarkable similarities to lightning. Because lightning's absolute spatial scale is so large compared to the observer's reference point, minute characteristics are discerned whose equivalence at the level of the axon are below contemporary resolution. Quantitative identities between these two classes of phenomena could encourage alternative interpretations of the electromagnetic (EM) components of action potentials and reveal recondite relationships concerning neuronal function.

The identity between exogenous and endogenous "electricity" is not really a new idea. The observation that atmospheric electricity, lightning, and the electrical fields within living systems, "nerve conduction," shared similar origins was considered as early as the 18th century by Galvani and Volta. Galvani showed contractions in frog muscles elicited from Leyden jars and electric machines was the same as those evoked during lightning when a long metallic wire was connected to the crural nerves and pointed to the sky (Piccolino, 1997). The similarity has been viewed historically as more of a congruence of quality than a potential blueprint for quantitative characteristics. In the present comparison these features are demonstrated. To facilitate understanding the calculations and reasoning for the similarities between action potentials and lightning will be articulated in greater detail than the usual narrative discussion in the neurosciences.

The concept of scale-invariance or recurrent ratios (Kolombet, 1996) within measurements of the physical world assumes an intrinsic repeated structure within the varying increments of space (Δs) and time (Δt) as well as their relationships (Persinger, 1999). For example the proportion of matter (protons and electrons) that occupies the space (volume) occupied by an atom is about 1 part per trillion. The ratios of the volume of the sun and planets within the space of the solar system and the stars within galactic space are the same order of magnitude.

One temporal example is the equivalent order of magnitude of the ratio of the electron orbital time of a hydrogen atom to its precession and the earth's rotation to its spin axis gyration. Comparable "scale-invariance" has been found within the human brain (Persinger and Lavallee, 2010, 2012) and for functional EM fields within the cerebrum and over very large spaces (Persinger, 2008, 2011; Persinger et al., 2008). The concept is similar to that described as gnomons (Gazalé, 1999) and fractals. A gnomon is "that form that, when added to some form, results in a new form similar to the original".

ENERGY DENSITIES IN THE HUMAN BRAIN AND THE ATMOSPHERE

Action potentials are the carriers of the discrete signals along the axon barrel. An average net potential difference for an action potential (-70 to $+50$ mV) is 1.2×10^{-1} V which would exert on each unit charge of 1.6×10^{-19} Coulomb (A·s) an energy of 1.9×10^{-20} J (Wei, 1969). If we assume $\sim 10^{10}$ neurons occupy human cerebral cortices (Blinkov and Glezer, 1968) with an average frequency of propagation of 1 Hz, the total energy per second involved with just the effects of all action potentials within brain space would be about 10^{-10} J/s. The volume (~ 1330 cc) of an average brain is 1.3×10^{-3} m^3. This results in an energy density of about 10^{-7} J/s·m^3 (Persinger, 2010).

On the other hand the typical lightning stroke involves a flow of ~ 10 Coulomb (C) of electrons across a potential difference of 10^8 V resulting in 10^9 J (Ogawa, 1982). There are about

70–100 lightning flashes/s world wide (Israel, 1973; Rennie, 1999) resulting in (assuming 100 flashes) the generation of 10^{11} J/s or 100 Gigawatts of power. For reference there is 4.3×10^{12} J per kiloton (kT) of standard explosives such that the energy generated every approximately 14 min by global electrical discharges is equivalent to about a 20 kT (Hiroshima-like) nuclear explosion.

Most of this energy from lightning discharges is within a narrow shell of about 2 km within the biosphere. The volume of this shell, assuming a radius of 6,378 km for the earth, would be about 1×10^{18} m^3. This means the energy density would be 10^{11} J/s·10^{18} m^3 or 10^{-7} J/s·m^3 (10^{-7} W/m^3). This energy density is remarkably similar to that generated by action potentials within the brain. When applied across the 3–5 mm thickness of the cerebral cortices, the value is equivalent to 10^{-10} W/m^2 which is within the range of power of photon emissions near the skull when subjects engage in specific imagination (Dotta et al., 2011; Dotta and Persinger, 2011) and which is strongly correlated with the power of electroencephalographic (EEG) activity (Dotta et al., 2012).

COMPARABLE SCALED CURRENT DENSITIES
About 5 C is distributed within a lightning channel with an average current of 100 A. Although the width of a leader channel is about 1 m the current flows through a channel with a radius of about 1 cm (Chang and Grossman, 1996). With this cross-sectional area the density is 10×10^1 A divided by 3.14×10^{-4} m^2 or 3.2×10^5 A/m^2.

A reasonable radius for an axon is 1 μm. However the actual locations of the major movements of ions that affect the transmission of EM field-mediated information along the axon are within the membrane which is about 10 nm in width. The cross-sectional area of this small annulus around the axon would be 2×10^{-14} m^2. Given the average current of 10^{-9} A (from the approximately 10^3 ion channels each with 1 pA capacities around the ring or circumference of the axon), this would mean that the cross-sectional current "density" would be $\sim 10^5$ A/m^2.

Consequently even though the current is much larger in a lightning stroke because of its absolute size by a factor of 10^{10}, the "minuscule" axon potential current is comparable per cross-sectional area. The range in the widths of normal axons would affect the coefficients rather than the order of magnitude. It may also be relevant that the actual charge and current per lightning stroke also displays a comparable range in the coefficient of variation. Such a large relative magnitude of potential across neuronal membranes is not a new concept. For example, the 90 mV potential difference across a 10 nm membrane is equivalent to 9×10^7 V/m.

SHARED "SALTATORY" CONDUCTION AND PULSE PATTERNS
Most lightning (90%) is between clouds. The leader moves in discrete jumps of 50 m at about 1.2×10^5 m/s to 1.5×10^5 m/s. This conspicuous "saltatory" conduction of lightening has a ratio of $[1.2 \times 10^5$ m/s]/50 m or 2.4×10^3 Hz (about 2 kHz or 0.5 ms) which is remarkably similar to the absolute refractory period of the action potential. In comparison the action potential moves along the myelinated axon in discrete steps of 1 mm compared to the approximately 2 μm width of the nodes of Ranvier.

The wave shape characteristics of action potentials and lightning flashes are similar. Villanueva et al. (1994) found all lightning pulses were the same polarity; most were single peak but about one-third were multiple-peaked. Although the mean width of the initial peak was 25 μs (SD 13 μs), the ratio of the overshoot duration to the initial peak was 5.7 (SD 2.1). This ratio is within the range of the typical relative refractory to absolute refractory period in the average axon. More recent measurements of artificially triggered lightening (Zhang et al., 2009) revealed comparable peak widths. Interestingly, the initial-stage discharge time was about 20 ms and the time between strokes ranged from 18 to 210 ms (mean 87 ms). This interval is within the range of the global rostral–caudal propagating, coherent waves over the cerebral cortices and the microstates that determine a percept and consciousness (Llinas and Ribary, 1993; Koenig et al., 2002).

SIMILAR MASS-CHARGE VELOCITY RATIOS
Although the velocity of a leader exceeds the 10 m/s values exhibited by non-myelinated axons by a factor of $1.2–1.5 \times 10^4$, the scaled values for the mass mediating the movements of charges are similar. For example, the mass of Na+, the major mediator of the action potential, is 30 Daltons or 48×10^{-27} kg while the mass of an electron is 9.8×10^{-31} kg. The difference is in the order of 10^4. The coefficients converge more closely when the range of hydration states (accompanying H$_2$O molecules) associated with the ions are included.

INTERFACE TIMES: STROKE-GROUND vs AXON-DENDRITE
As the leader approaches to about 10 m above the ground it creates an electric field sufficient to initiate discharges rising from the ground (streams). When contact is made between the upward and downward fields a heavy surge of current occurs within 1–5 ms. This surge produces the luminosity that progresses up the path produced by the step leader at $\sim 10^8$ m/s. About 40–50 ms after the return stroke, another region of luminosity, about 50 m long, moves from the cloud to the ground (dart leader). It does not fork or branch. There is an average of three to four strokes with a maximum around 20 (Israel, 1973; Ogawa, 1982).

The approximately 10 m interface or boundary where the exchange of energy between the atmosphere and ground occurs is about 3×10^{-3} the length of the pathway. For cortical axons with lengths between 1 and 5 mm, this would be equivalent to a length of between 3 and 15 μm which is within the range of the length of the terminal endings or boutons within which the digital information of the action potential is transformed to chemical equivalents.

The surge of current lasting for 1–5 ms is within the range of the time involved with release of the contents of the synaptic vesicles (Clements, 1996). The energy transfer mediated by the mass of molecules released from the vesicles into the synaptic space would be analogous to this relatively large increment of current. The occurrences of subsequent surges from the cloud to the ground after an interval of 40–50 ms or about 20 times after the first surge is comparable to the first and second surges of vesicular releases (Clements, 1996).

EMERGENCE OF AGGREGATE PROPERTIES

The billions of action potentials and their correlates per second within the cerebral cortices generate emergent phenomena inferred by EEG measurements that include microstates (Koenig et al., 2002) and transient coherence of activity (Lehmann et al., 1998; Burkitt et al., 2000) over areas (tens of mm^2 to tens of cm^2) of the human brain's cortical surface. Between the earth's surface and the lower ionosphere there is a shell of optimum conduction within which the results of focal energies in one area are generated throughout the volume. Cloud-to-ground lightning discharges from global thunderstorm activity are the main excitation sources within the earth-ionospheric cavity. These omnipresent pulses propagate for megameters (Persinger et al., 1973) without appreciable attenuation and behave as a "cortical manifold" for distributing tissue-level energies (Schienle et al., 1997, 1998; Durand-Manterola et al., 2001) throughout the biosphere. The observation by Houwelling and Brecht (2008) that the activity of only one axon affected the direction of a rat's gross responding predicted that such singular neuronal "discharges" could affect the state of the entire cerebral cortical manifold (Li et al., 2009).

The fundamental frequency (1/s = Hz) is the velocity divided by the circumference. Assuming the speed of light of 3×10^8 m/s and the circumference of the earth as 40,000 km (4×10^7 m) the natural frequency is 7.8 Hz. Harmonics for this values, often described as the Schumann resonances (Cherry, 2002), can be obtained by taking the square root of $[(n(n + 1))/2]$ multiplied by the base frequency (7.8 Hz), where n is the progressive series of integers 1, 2, 3, . . . , etc. Those that have been measured have peaks around 8, 14, 20, and 26 Hz (Campbell, 1967).

As described by Nunez (1995) in his classic chapter on "Towards a physics of the neocortex," comparable solutions exist for the human brain. The probability density function for myelinated cortico-cortical propagation peaks at about 6–9 m/s with the half-width of the distribution is estimated to be between 3 and 4.5 m/s. Published estimates of the neocortical surface areas range from 1,600 to 4,000 cm^2. The effective cortical radius after flat-mapping is between 11 and 18 cm. As a result the non-dispersive brain waves from mode $n = 1$ would be between 7 and 18 Hz. Subtle shifts in peak power in this frequency vary with head size, defined by the cube root of the product of three linear measures (Nunez, 1995). As the size increased over a normal range of volunteers the peak frequency decreased from 10.6 to 9.8 Hz.

RESISTANCE-CAPACITANCE AND TIME CONSTANTS

The EM signals associated with lightning are propagated through a medium. The simplest calculation of a time constant is the product of the resistance (in Ohms) and capacitance in Farads (F). For free space resistance is 3.70×10^2 Ohms $[(kg \cdot m^2)/(A^2 \cdot s^3)]$ and capacitance is 8.8×10^{-12} F/m $[(A^2 \cdot s^4)/(kg \cdot m^2)]/m$ or 32.56×10^{-10} S/m. When multiplied by the circumference of the earth, the time constant is 130 ms or about 7.7 Hz; this is within the natural variation of the fundamental Schumann resonance.

Cerebral tissue is also a medium. The permeability (inductance/m) of cortical gray matter at 1 kHz is about 10^{-2} Henrys, while the permittivity of gray matter is 2×10^{-1} F/m (Tsang et al., 2004). Application of the formula $f = 1/(2\pi(LC)^{-1/2})$, the

equation for resonance frequency of a closed circuit, results in a value of about 7 Hz. The convergence of a fundamental cerebral resonance with the Schumann solutions indicates that higher order harmonics may exist within EM fields within cerebral space and be associated with specific functions. There are often strong correlations between fluctuations in power values measured by quantitative EEG across traditional frequency bands. That resonance could occur *between* fields within cerebral volumes and the Schumann phenomena may have significant implications for the biosciences (Cherry, 2002; Persinger, 2008).

SIMILARITY OF "AVERAGED" WAVE PATTERNS OVER SPACE

The classical although arbitrary division of EEG activity into delta, theta, alpha, and beta activity with a myriad of complexes and transients have been considered both emergent and reflective of "distant" fields of neuronal activity. As shown by Koenig et al. (1981) all of the fundamental frequencies and patterns of EEG activity are measured within the Schumann (earth–ionospheric) cavity or as local electric field configurations during thunderstorms. In addition, biofrequency (1–100 Hz) pulses of about 0.5 ms whose carrier frequencies diminish from 100 kHz to about 10 kHz at distances more than 1000 km (Schienle et al., 1998) from the source display magnitudes in the nanoTesla (nT) to picoTesla (pT) range (Durand-Manterola et al., 2001).

SAME ORDER OF MAGNITUDES OF OPERATING INTENSITIES

Within the range of 7 –40 Hz the electric field components associated with the EM fields generated through the ionospheric–earth cavity are about a mV/m, while the magnetic field components are between 1 and 10 pT (Koenig et al., 1981). For comparison the magnetic field intensities within galaxies are in the order of 10^{-10} T with upper limits of 10^{-13} T for extragalactic fields (Persinger, 2011). In a manner similar to the changing, averaged power outputs of neuronal activity within the cerebral volume that can vary in response to fluctuations in subtle external energy, the Schumann values also display discrete alterations.

The long-term averages for the Schumann frequency, damping, and amplitude change as a function of solar proton events (SPE). They increase the Schumann resonance frequency from a reference value of ∼7.8 Hz by between 0.04 and 0.14 Hz depending upon the intensity of the proton flux. The amplitude of the resonance increased by several 10% from a mean value of about 1.0 pT (Schlegel and Fullekrug, 1999). Electric fields within the mV/m range and magnetic fields within the pT range also define the operating intensities overly spatially distributed cerebral functions (Persinger et al., 2008; Persinger and Lavallee, 2010, 2012). The strong correlations between variable power densities within the ionosphere–earth cavity and power changes within quantitative EEG measures (Mulligan et al., 2010) as well as the quantum-like properties of interhemispheric interactions (Persinger et al., 2008) indicate that physical connectivity may be pervasive.

CONGRUENT PHASE MODULATIONS

Phase modulation has been considered the most optimal means to propagate the most information over distance. Phase shift can be obtained by time divided by the square root of v^2/c^2. Because the EM fields associated with lightening generated within the

earth–ionospheric cavity are within the 10–100 kHz ("atmospherics" or "sferics") range, the $\Delta c/c$ (c, velocity of light) is 0.05 for this range (Tu et al., 2005). This means that the phase shift for every 1 s is 1/0.9897 s or 16 ms. This magnitude of phase shift is remarkably similar to phase comparisons associated with the presence of the continuous "40 Hz-oscillations" over the entire cerebral cortical mantle. An approximately 12 ms phase shift between the rostral and caudal pole of the brain has been reported (Llinas and Pare, 1991; Llinas and Ribary, 1993).

POSSIBLE NEUROSCIENCE-RELEVANT PHENOMENA
RETURN STROKE AND BACKPROPAGATION
A search for the "missing" equivalents between lightning and action potentials could be revealing in a manner similar to the search for Mendeleyev's missing elements in the Periodic Table. There is no traditional equivalent of the "return stroke" at the synapse, although backpropagation might be considered a conceptual candidate (Golding et al., 1999). However, backpropagation influences the dendrites of the neuron from which the action potential has been propagated. Its variable effect depends upon the extent by which the neuron's action potential penetrates into its own distal dendrites.

When a stepped leader approaches within a few tens of meters above the ground, it is met by a positively charged return stroke towards the cloud. Within a synaptic scenario, this would be equivalent to a "return field" transiently generated from the post-synaptic region towards the presynaptic membrane just before the arrival of the action potential. If the quantitative scale-invariant relationships between lightning and action potentials can be generalized in this context, then impulse magnetic flux densities (Rai and Bhattacharya, 1971) from the post-synaptic membrane must emerge and cross the synapse into the presynaptic membrane during the few milliseconds *before* the helical EM field (the action potential) reaches the synapse. In other words, a comparison with lightning would predict that sub-threshold, electrotonic-like shifts in voltage (approximately the Landauer principle limit: ln 2 kT, or about 10^{-21} J) should be apparent at the synapse in advance of the arrival of the major action potential.

It is more likely we have not measured this equivalent rather than a frank deviation from Newton's third law: for every force there is an equal and opposite force. It is well known the repolarization of the (heart) atria after its depolarization (P) during electrocardiographic measurements is masked by the QRS component of the massive depolarization of the ventricles. The "occlusion" of the independent $K+$ and $Na+$ current profiles during the measurement of the spike would be another conspicuous example.

NITRIC OXIDE PRODUCTION
One class of candidates for the equivalent of the "return stroke" might be mediated by the post-synaptic release of nitric oxide (NO) or the quantal energies associated with its presence. The ionization energies of N and O differ by 0.92 eV (electron volt) and would require an addition for "equivalence" (such as for hydrogen and oxygen) of about 2×10^{-20} J which would be available with the voltage changes associated with an action potential (Persinger, 2010). Such charge carriers moving toward the origin (presynaptic

space) could modulate presynaptic changes initiated by the source or subsequent action potential. Even the presence and functions of Hyden intersynaptic filaments, which deviate significantly from Cajal's law of neuronal independence, might be viewed from a different perspective as contributing to the "return stroke" or backpropagation.

Nitric oxide, which was once known as "endothelium-derived relaxing factor," is an important gas which diffuses freely across membranes concomitant with neurotransmission (Zweier et al., 1999) and has been considered a means by which space and time are linked within the brain (Edelman and Gally, 1992). With a half-life in the order of 1–5 s (Gally et al., 1990) and a diffusion constant (2.6×10^{-5} cm^2/s) that is equivalent to passing through a 1 μm^2 area of membrane in the duration of an action potential (0.5 ms), it serves as a transient paracrine and autocrine signaling molecule. NO is produced in neurons in response to action potential-dependent release of glutamate whose post-synaptic sequestering facilitates the influx of Ca++ ions through NMDA (N-methyl-D-aspartate) receptors. NO is considered a major candidate as the retrograde messenger (post- to presynaptic direction) for long-term potentiation (LTP) associated with memory.

Even in the most elementary reactions NO (and CO, carbon monoxide) should be involved centrally with synaptic chemistry. With the copious presence of transient COOH (carboxyl) and NH$_3$ (amine) groups from amino acid dynamics, NH$_3$ + O$_2$ could yield a portion of NO + H$_2$O + H+ (a proton) and in more anaerobic environment COOH might yield a proportion of CO and OH— (a hydroxyl group) that when proximal to H+ could maintain a buffering zone (H$_2$O). NO reacting with O$_3$ (ozone) results in light emission and the formation of nitrous dioxide (NO$_2$) and oxygen. The occurrence of biophotons or visible wavelengths (Popp, 1988) during action potentials (Bokkon, 2005; Dotta et al., 2011, 2012) is an emerging field of study with paradigm-shifting potential.

About 25% of NO within the biosphere is formed by lightning discharges with absolute amounts of about 10 Tg/yr (range 2–100 Tg). The estimated numbers of NO$_x$ molecules (NO plus other oxides) created by lightning energy is within the range of $1–26 \times 10^{16}$ molecules/J (Chang and Grossman, 1996). The production and distribution of NO significantly affects the level of ozone within the biosphere. More recent space-based measurements from optical transient detectors (Martin et al., 2007) indicated 44 ± 5 flashes per s globally with an estimated (medial value) of 5×10^{25} N atoms/flash. Assuming 10^9 J/stroke the numbers of atoms per J is between 10^{16} and 10^{17}. Simulated lightning (Wang et al., 1998) produced 2×10^{21} NO molecules/m per 5 kJ/m of energy or about 10^{17} NO per J. These measurements indicate the formation in the order of 10^{-2} to 10^{-3} NO molecule per s per action potential equivalent of energy (10^{-20} J, Persinger, 2010).

Within the brain NO is assumed to be produced from L-arginine by isoforms of NO synthase as well as from non-enzymatic reactions associated with nitrite concentrations. The latter can increase 100-fold with pH shifts (increased proton concentration) between 7.4 and 5.5 (Zweier et al., 1999). The synthesis of NO from addition of 100 μM of L-arginine and NADPH (1 mM) to incubations containing synaptosomal cytosol induced synthesis of an average 40 pM/min per cc, as determined by the product NO$_2^-$ (Knowles et al., 1989). This is equivalent to 6×10^{-13} M/s·cc or ~3.6×10^{11}

molecules/s·cc. To simulate the volume of the dendritic spine of between 0.1 and 0.01 μm^3 (10^{-12} cc/μm^3) there would be $\sim 10^{-2}$ to 10^{-3} NO molecules/s.

Employing Zweier et al.'s (1999) curves for non-enzymatic NO synthesis, 10 μM of nitrite within a microenvironment of pH 3 yields 10^{-10} M/s of NO. The numbers of molecules of nitrite within a 0.1 μm^3 would be equivalent to 10^{-21} M or $\sim 6 \times 10^2$ molecules/s. The proportion of NO formed from this concentration of nitrate would be between 10^{-2} and 10^{-3}/s. Consequently both lightning and the processes associated with membrane function generate comparable proportions of molecules of NO. This would suggest that the temporal–spatial integration (analogous to spatial and temporal summation for EPSPs and IPSPs) of action potential energies (2×10^{-20} J) from between 100 and 400 Hz, the same range associated with optimal LTP, would be required to release a molecule of NO.

NO AS INTRINSIC INFORMATION

From the perspective of quantum theory, NO is a stable and unique radical. Even with its unpaired electron, the molecule displays no apparent paramagnetism. The magnetic susceptibility does not conform to the "spin-only" formula (Van Vleck, 1960; Kasai and Bishop, 1972) in one of its ground states due to the exact cancellation between the orbital magnetic moment and spin magnetic moment of the electron. This means NO is an example of a molecule that deviates from Curie's Law (the magnetic susceptibility of a paramagnetic material is proportional to the inverse of the absolute temperature) because the multiplets interval (the splitting of orbital energies) is comparable with the energy derived from the product of the Boltzmann constant and concurrent absolute temperature (the "kT" boundary). Hence the "information" contained within thermal noise within the synapse and the perisynaptic volume, when incorporated into the Boltzmann distribution, could be represented by NO within a magnetic field.

THE ROLE OF THE PROTON

The role of the proton (H+), in addition to its contribution to pH and the hydronium (H_3O^+) molecule, may be more extensive than suspected. Protons are unique ions with respect to the mechanism by which they traverse channels (DeCoursey, 2003). The proton is also unique among ions because it is interchangeable with the protons that form water. Both K+ and Na+ display several hydration states during the dynamics of channel movements. In physiological solutions, "free protons," although concentrated at about 40 nM, have a fivefold higher conductivity in water than other cations like K+. Voltage-gated proton channels display both the largest and smallest single-channel currents.

Drift velocity is the square root of J/kg (energy/mass). If we assume the 0.2 μV change associated with a single-ion channel (Kandel et al., 2000), the energy exerted on a charge is 0.2×10^{-6} V $\times$ 1.6×10^{-19} A·s or 0.5×10^{-25} J. When the square root of this value divided by the mass of a proton (1.6×10^{-27} kg) is obtained the velocity is about 4.5 m/s which is remarkably congruent with the "bulk velocity" of the EM field that traverses the caudal–rostral plane of the cerebrum every $\sim$20 ms. The 4.5 m/s value divided by a typical human skull circumference of 6×10^{-1} m (60 cm) gives the value 7.5 Hz.

With this value (4.5 m/s) the time required for a proton to move through a membrane of 10 nm is 2.2×10^{-9} s. During the 1 ms associated with an action potential the number of protons moving through the membrane would be about 2.2 million. This number is remarkably similar in order of magnitude to the estimated number of cations that move through these <1 nm width intramembrane conductive cylinders and to the numbers of ions that actually generate the resting plasma membrane potential (Persinger, 2010). When multiplied by the unit charge the net current could be within the pA (10^{-12} A) range, the typical order of magnitude for ion channels.

This congruence might suggest that the role of Na+ in the action potential may be epiphenomenal because even the classical experiments that demonstrated "concentration-dependence" would have had concomitant changes in proton movements associated with hydration states. This concept has been elaborated by Del Giudice et al. (2010) and supported empirically by Gang et al. (2012). Interfacial water, contiguous to biological surfaces, remains static and generates exclusion zones that are about 10-fold more viscous than normal water, contain a concentrations of protons, and exhibit negative potentials with respect to neighboring water of up to 150 mV.

SHIFT IN PERSPECTIVE

As a possible historical example, the conspicuous retrograde movements in Mars across the star canopy over successive nights was explained just as well by the epicycles superimposed upon the concentric orbits around the earth (the "geocentric" universe) described in the *Almagest* by Ptolemy Claudius of ancient Alexandria as by the heretical heliocentric models proposed by Copernicus and Kepler. Only detailed examination and finer temporal and spatial resolutions revealed the relevancy of the more precise mechanism.

As indicated, the scale-invariant similarities between lightening and action potentials evoke the possibility of mutual interaction. In addition to comparable values for magnetic and electric fields, the power density for Schumann resonances within the 8–21 Hz range is in the order of 10^{-10} W/m²/Hz (Polk, 1982). This is the same order of magnitude as the power density of photon emissions from the human brain during imagination (Dotta et al., 2011) and the correlated changes in power measures from quantitative EEG (Dotta et al., 2012). Laboratory experiments by Schienle et al. (1997), who exposed volunteers for about 1 ks to simulated lightening-related sferics by generating 10 kHz signatures (amplitude 50 nT, pulse repetition: 7–20 Hz; pulse duration 0.5 ms), demonstrated that protracted changes within the alpha band and experiences similar to those attributed to natural phenomena were reliably elicited.

The similarities in quantitative characteristics between action potentials and lightening presented in this paper might be expected if the intrinsic organizations of matter and energy are reflected within different spatial and temporal levels of observation (Persinger and Koren, 2007). Perhaps by careful quantification and observation of the larger phenomena, such as lightning, processes can be discerned that will point the direction of focus for what we have not yet measured.

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