On the Possible Representation of the Electromagnetic Equivalents of All Human Memory within the Earth's Magnetic Field: Implications for Theoretical Biology

Michael A. Persinger

Behavioural Neuroscience and Biomolecular Science Programs, Departments of Psychology and Biology, Laurentian University, Sudbury, Ontario, Canada P3E 2C6.

Summary: Digital information in biological systems is represented as spatial sequences of bases in DNA and as temporal patterns of action potentials within neurons. The hypothesis is developed that during the approximately 1 to 2 ksec of electrical lability, when the information contained in temporal patterns of action potentials is transformed into synaptic equivalents as memory within the human brain, the energy is also represented within the space occupied by the earth's magnetic field. Quantitative solutions indicate the energy that can be stored within this field exceeds the total energy associated with every action potential within the brain of every person who has ever lived. There are multiple intensity, durational, and frequency congruences between primary activities involved with memory consolidation within the human brain and relevant geomagnetic spaces. Access to this "extracerebral" information by the appropriate technology might allow a person's individual memories, which are lost following brain damage or due to neurodegenerative disorders, to be reconstituted. Because of its microstructure, electrophysiology, and functions, the entorhinal cortices-hippocampal formation would be a central interface with the extracerebrally represented information. Implications of this hypothesis for theoretical biology are discussed.

Keywords: geomagnetic field, action potentials, memory, information representation, energy

The fundamental assumption of modern neuroscience is that all behaviours are generated by brain activity. Experiences are one of the subjective forms of behaviours. Memory is the general term to describe the representation of experiences within brain space [1]. Autobiographical memories define the individual as an entity of unique experiences [2]. When the organization of brain matter is altered following death these memories no longer exist. However biological information can be maintained within a species over large spaces and extended times. Genetic information, preserved as sequences of nucleotides within DNA, has been maintained for billions of years. Although the unique characteristics of the individuals who contributed to this temporal and topological continuity may not be evident, the averaged residual information that will affect the structure and function of future inheritants remains. The inheritance of DNA sequences reflects, in large part, the entire genetic history of life forms [3].

The hypothesis proposed in this paper is that the neuroelectromagnetic information associated with the approximately 1 to 2 ksec (about 15 to 30 min) of electrical lability during the first stages of consolidation [4] of the digital patterns of action potentials for neurons is associated with two forms of representation. The first involves the more obvious growth of dendritic spines [5] within brain space whose patterns are the person's memories. Synaptic activation of the type that induces long term potentiation (LTP) results in the growth of dendritic filopodia within about 15 min [6]. When the person's brain deteriorates, these microspatial patterns (and hence personal memories), are lost forever. The second form involves the simultaneous representation of the energetic equivalent of this digital information external to brain space. The integrity of the information would exist as long as the medium in which it was represented was maintained.

This second representation would contain only patterns of information and would not be associated with the sense of self, individuality, or self-awareness. The latter phenomena are likely to be correlates of or epiphenomena generated by the microstructural complexities of the left hemispheric, the processes

Correspondence: Michael A. Persinger, Behavioural Neuroscience and Biomolecular Science Programs, Departments of Psychology and Biology, Laurentian University, Sudbury, Ontario, Canada P3E 2C6.
Email: mpersinger@laurentian.ca.

involved with language, and the verbal equivalence of the stimuli that evoke experiences [7]. Like a person's genome, that contains the information by which the matter composing the organism is maintained, the electromagnetic representation contains the cerebral information. Like genetic information, personal awareness and the sense of self are not required phenomenology.

This model is an extension of the intrinsic duality of matter and energy as manifestations of a third factor that can simultaneously display properties of particles and waves [8]. The verification of the simultaneous representation would have potential application for retrieving experiential information for patients who sustained traumatic brain injury or whose brains (senile dementia) are undergoing insidious loss of synaptic microstructure. The physical mechanism for this parallel extracerebral representation may appear untenable at this time. However if a motion picture film of a contemporary individual after his demise would have been shown to people living two hundred years ago, this "storage" of information would also have been considered impossible.

One test of the potential validity of the hypothesis involves the convergence of quantitative solutions rather than the a priori identification of the mechanism. For example two hundred years ago Galvani, in order to explain the hypothesis that "animal electricity exits in a state of 'disequilibrium', postulated there was a "particular machine capable of generating such disequilibrium" [9]. We now know this "machine", that was once "totally occult to the most acute sight", corresponds to the cell membrane with its complex organization of ion channels and pumps.

Brain Activity and Representation of Experience

Each action potential generated by a neuron with a net change of approximately 10^{-1} V (100 mV) is associated with an energy of approximately 2×10^{-20} J when applied to a dipole with a charge of 1.9×10^{-19} A s [10]. This quantum of energy is also comparable to that produced across the length of an atomic bond of 0.2×10^{-9} m in order to break a bond maintained with a force in the order of 0.1×10^{-9} N and is equivalent to a photon with an ideal frequency of 3×10^{12} Hz or a wavelength of 10 micrometers, the average width of neuronal soma. For information coupled to vision, for example, the energy is transferred through successive brain spaces that progress from the chemical changes in rhodopsin to the action potential and then as miniature EPSPs (excitatory postsynaptic potentials) in the form of about 150 quanta, each about 0.5 mV [11], at the synaptic cleft.

Until these patterns of neuronal electromagnetic patterns are transformed into the microspatial patterns of dendritic spines and receptor expressions, which require about 1 to 2 ksec, the phenomena of "memory and experience" exist as vulnerable and ephemeral states [12]. These temporal-spatial patterns of action potentials can be altered or even eliminated by disruptions within the regions of the brain such as the hippocampal formation. It is involved with the first stages of consolidation [13]. The concomitant behaviour is amnesia.

The total informational storage within the cerebral cortices is finite and would in large part be determined by the numbers of dendritic spines that would function analogously to the magnetic domains within a computer disk. The area of contact at synapses between neurons has a diameter of 0.5 to 2.0 um [14]. Within 1 mm^3 of grey matter in the human cortices there are about 50,000 neurons and each gives rise to 6,000 synapses [14]. This means that in the human cortices alone, with a surface area of about 10^5 mm^2, there would be (and are [16]) about 10^{10} (10 billion) neurons and hence 60×10^{12} synapses and dendritic spines [17]. The storage capacity for this 0,1 (digital) brain matter within the cerebral cortices alone, even assuming diffuse distributed redundancies, would be in the range of Terabytes. When the brain deteriorates, these microstructural patterns disintegrate and the information is lost.

Life Time Energy from Action Potentials for All Human Beings

The resting adult body utilizes about 100 J/s or 100 Watts [18] of which the brain accounts for about 20% of this value. Most of this energy is involved with metabolism and the maintenance of cellular integrity and vascular constituents. If we assume that each neuron displays on average 10 action potentials per sec (10 Hz), there are 10^{11} neurons (including those outside the cerebral cortices) and each action potential is the equivalent of 10^{-20} J, then the average total "action potential energy" per sec would be 10^{-8} J. If each person lived for about 2×10^9 s (68 years old), then the lifetime energy associated with the electromagnetic patterns of

action potentials that define the totality of the person's experience would be about 10^1 J. In other words it would be similar to the energy displayed by the whole brain in a second.

This value of about 10^1 J would represent the energy equivalence for the information summed or integrated over the person's life time during the approximately 15 to 30 min of electrical lability before it becomes represented in proteinaceous patterns of dendritic spines and synapses that are only contained within the individual brain and are destroyed when the brain deteriorates. For 6 billion brains that exist at present the total lifetime "brain energy" would be 10^1 J $\times$ 6 $\times$ 10^9 brains or about 6×10^{10} J. If we assume the total numbers of human brains to have been about 55 billion within the last 3,500 years, the total energy would be in the order of 5.5×10^{11} J. If only a subset of neurons were involved, such as the approximately 4×10^7 neurons within the human hippocampal formation [19], this total energy value would be in the order of 10^9 J.

The Geomagnetic Field's Potential for Representation

The energy E within a magnetic field is defined as

$$E = [B^2/2u]\ v_o$$

where B is the strength of the static field, u is the constant for permeability and v_o is the volume. The earth's magnetic field extends for at least 10 earth' radii into the space [20] around it and interfaces with the interplanetary magnetic field generated by the expanding coronal of the sun [21]. Although the average strength of the field would certainly change with distance and after integration for volume would display different coefficients, the average field strength within the most proximal volume within which human beings are immersed will be assumed to be 50,000 nT (0.5 gauss) or 5×10^{-5} T.

The radius of the earth is 6.76×10^6 m and its volume would be 1.29×10^{21} m^3. If we assumed the major component of the geomagnetic field was within an additional radius from the earth's surface or 13.52×10^6 m then the volume occupied by the geomagnetic field within that shell of one radius above the earth's surface would be 1.03×10^{22} m^3. With these values the energy that might be contained within the earth's magnetic field could be $[(5 \times 10^{-5}T)^2/(2 \times 4\ pi \times 10^{-7})] \times 1.03 \times 10^{22}$ m^3 or 10^{19} J. This value is within an order of magnitude of that calculated with more accurate and sophisticated formulae to accommodate the complex geometry of the geomagnetic field [22]. It is also similar to the value for energy obtained by the product of the dipole moment of geomagnetic field and its intensity which is (8×10^{22} A m^2 [20] multiplied by 5×10^{-5} T) or 4×10^{18} J.

Consequently the energy "storage" capacity within the earth's magnetic field would be 10^{19} J while the total energy associated with every action potential within the brain during the life time of every person who has existed in our species within the last 3,500 years has between 10^{11} J to 10^{12} J (or for the hippocampal formation about 10^9 J). This means that even accommodating for irregularities or errors of assumptions during the derivation of this solution, there would be more than sufficient potential (by a factor of about 10^7 to 10^{10}, if only a subset of neurons were involved) to represent brain information within the space occupied by the static magnetic field of the earth. This surplus of magnetic potential would also suggest that there would be sufficient capacity for the information contained within the action potentials of all species to be represented.

The Brain Locus of Interface with the Earth's Magnetic Field

Action potentials are the principal means of communication between neurons. They convey information through their timing and frequency. The first candidate for the physical interface with the geomagnetic field would be the entorhinal cortices and the hipppocampal formation which is contained within the parahippocampal gyrus of the human brain. According to Gloor [19], the hippocampus acts as a temporary storage mechanism for memories while final consolidation occurs elsewhere, within the isocortices. This region is a singular interface where temporal codes from various sensory modalities are transformed to the same frequency-modulated "format" so that information can be processed independently of modality of origin [23]. The parahippocampal region has multiple inputs into the entire cerebrum where representation of "personal" information is maintained with the cortical manifold [24].

In fact repetitive stimulation of the hippocampus can induce long-term potentiation (LTP), the primary correlate of synaptic plasticity and information storage, within the frontal cortices.

Experiments have shown that many synapses in the hippocampus and neocortex are bidirectionally modifiable [25]. LTP is generally associated with the growth of dendritic spines that emerge within about 1 ksec after a fast-frequency electromagnetic burst of only 1 sec [5,6]. The most common slender stem spines are widely distributed throughout the human brain and are remarkably similar in all animals that diverged in Precambrian times. This again supports the possibility that there has been the potential for "storage" of information displayed as action potentials in animals.

The entorhinal cortices is the primary input to the dentate gyrus whose axons stimulate specific regions of the hippocampus, particularly the CA(Cornu Ammonis) region 3 from which Schaffer collaterals emerge to activate large areas of pyramidal neurons within the CA2 and CA1 region. The CA1 region (Sommer's Sector) of the human brain has evolved furthest from the prototypical mammalian brain. The estimated numbers of total cells within the dentate gyrus, hilus, CA2-CA3 and CA1 of the human brain are in the order of 10^7 [19].

It has been suggested that the "infantile amnesia", defined as the extreme paucity of autobiographical memories available to adults before the age of about 4 years, is due to the "immaturity" of the connections between the dentate gyrus and hippocampus proper before that time [26]. In young infants the CA2 neurons are the most form-differentiated while CA1 neurons, the bulk generator access to the neocortices, are immature until early childhood [27]. This is presumably associated with the shift in microstructure such as increased numbers of thorny excrescences on proximal dendrites of mossy cells [28].

The interface between the dentate gyrus and CA3 displays a marked capacity for multiple representations of neuroplasticity, such as reactive synaptogenesis and postnatal neurogenesis. Although other brain regions may show this propensity they are not directly related to memory consolidation. This property could change the synaptic patterns of representations that could change the hippocampus' sensitivity to different patterns of information from extracerebral sources. Substantial reorganization of mossy fibers from granule cells occurs in a high percentage of humans with complex partial seizures (temporal lobe epilepsy), particularly in the inner molecular layer of the dentate gyrus [29].

These aberrant axonal collaterals within the supragranular layer in conjunction with fusiform-shaped swellings, change the firing patterns and resonance characteristics of the hippocampal formation. Such plasticity creates the potential for recovery of information through chaotic synchronization between the functional equivalents of the transmitter and the receiver [30] and for coupling the resonance with the resonator [31]. This indicates that information might be accessed within brain space from the external representations. As long as the brain is immersed within this space, access could occur even if the person moved within its boundaries.

The spatial organizations of cells within the hippocampus are unique within brain space. Structurally the human hippocampus is two, interlocking C-shape structures that are geometrically congruous with a smaller spherical condenser wrapped and partially interdigitated by a larger spherical condenser [19]. Geometrically, the C-shaped structure is similar to a toroid with a gap which allows a discrete leakage of magnetic flux. It is strongly affected by the polarization (or phase) vector [32] that can be matched within an order of magnitude to the geomagnetic scalar potential [33].

In addition to being one of the most electrical labile regions of the brain, the intercellular distances within hippocampal space are within the range that might access representations within a real Hilbert space [34]. The densely packed layers of granule cells and pyramidal cells, whose configurations are not seen in any other region of the brain, exist within functional widths of approximately 75 micrometers. This value is where the intersection between slopes for the expansion of space and the associated electromagnetic wavelength converge [35]. The human hippocampus is punctated by magnetic material that could differentially affect these parameters [36], particularly during the periods of reversed polarity [37] induced by infrequent or unexpected events.

The hippocampal formation is also known as a source of theta activity (4 Hz to 7 Hz) and its harmonics, including the 40 to 45 Hz band correlated with human consciousness [38]. Short-term memories are stored as high frequency ("40 Hz") subcycles of low frequency (5 to 12 Hz) oscillations [39]. The 40 Hz oscillation is correlated with cognitive processing during the waking and dream (REM) state and is associated with a 12.5 ms

rostrocaudal phase shift [40,41]. Activity within the theta band plays an important role in waking during infancy and childhood and in waking and sleep during adulthood [42]. It facilitates the induction of LTP in hippocampal circuits [43] and can enhance long term memory for auditory narratives when applied as weak magnetic fields across the temporal lobes [44]. Theta oscillations predominate within the temporal cortices during spatial cognition [45], a primarily right hemispheric process.

The Brain-geophysical Interaction

From the perspective of the hypothesis this concurrence with the fundamental Schumann resonance of around 7 to 8 Hz and its harmonics (including 40 to 45 Hz) that are generated within the spherical condenser (spherical capacitor) produced between the earth's surface and the ionosphere is not spurious [46]. Intermittent overlap between the structural frequencies of the hippocampal region and the intrinsic oscillation of the earth-ionosphere cavity would allow resonance mechanisms to access the space in which the associated information could be presented. It may be relevant that even gravity waves if they share the same frequency as the earth-ionosphere system would be amplified and represented substantially [47].

The marked similarity of frequency and temporal aggregates of frequencies (the essential features that define information) between the electroencephalographic patterns of the human brain and the signals generated within the earth-ionospheric cavity [48] and by weak geomagnetic oscillations [49] is an example of the necessary congruence between intra- and extra-cerebral space required to support the hypothesis. Nunez [50] has also described the remarkable similarity of the resonance frequency solutions for the human brain and the earth-ionospheric cavity, with $f_r = [\text{sqrt}(n(n+1))]$ multiplied by v/(2*pi*r) where v is the velocity of the electromagnetic field, 2*pi*r is the circumference and the "n" within the square root term refers to normal mode frequencies of the electromagnetic fields within a resonant cavity.

The values for the earth and human brain converge for fundamental resonance (n = 1) because the velocities (approximately the speed of light vs. the bulk velocities of axons) of the electromagnetic fields match their respective circumferences. The range between 7 and 18 Hz for human beings (and dolphins, [50]) overlaps with recently quantified and distinct microstates whose stable durations exist for between 80 and 120 ms or 8.3 Hz to 12.5 Hz [51]. They are generated across the person's life time and are equivalent to the minimal duration of a percept [52]. These microstates may correspond to the basic blocks of human information processing [51].

The hypothesis would also require the right parahippocampal region to be more directly involved with this representation of neuroelectromagnetic digital information than the left for several reasons. First, the right hippocampal region is more generally involved with minimal linguistic information regarding space-time [53]. Consequently the essential patterns of the more universal properties of the information could be extracted and represented without interference from the "analytical overlay" of the linguistic processes that generate the sense of self and awareness.

Secondly, there are accumulating data that the right hemisphere is more sensitive to geomagnetic activity than the left in human beings [54]. We have recently shown that during development, at least in rats, the density of nuclei within the right side of specific brain structures was more responsive to 5 to 10 nT, 0.5 Hz magnetic fields than the left [55]; the cellular organization of the (right) hippocampal formation is particularly sensitive to perinatal exposures to physiologically-patterned magnetic fields [56]. That shifts in functional asymmetry of the human brain is correlated with geomagnetic field variations coupled to 10 to 11 year cycles within large populations has been shown by Volcheck [57].

Third, the interhemispheric interaction between the left and right hippocampal formation is mediated through the dorsal hippocampal commissure [58]. Consequently the information within the hippocampus can circumvent the cortical-cortical connections through the corpus callosum. The coherence peaks between the two hippocampal formations and the amygdalas which contribute to them are within the theta range. This property would facilitate the passive transformation of any information accessed from an external space to the individual's unique linguistic, left hemispheric coding without "awareness". The autobiographical "memories", which should

require bihemispheric engagement within the temporal lobes and associated prefrontal regions, could then be reconstructed.

Representation and Time Latencies

If the electromagnetic component (or its fundamental entity) of information is represented within the space occupied by the geomagnetic field or the concomitant field potential generated between the earth and the ionosphere, then the time constants for both the electrical transience of the hippocampal formation and geomagnetic parameters should be similar. Several different solutions for time constants support this supposition. For example the current decay within the electric field between the earth's surface and ionosphere can be obtained by dividing the permittivity of space $e_o = 8.85 \times 10^{-12}$ F/m by the average conductivity of about 2×10^{-14} S/m. This value is in the order of 7 minutes [59] which is within the period of the electrical lability for consolidation of information. If the electronic assumption of "three times" the fundamental time constant before "saturation" is employed, this value would be within 20 min range.

This value is also convergent with a temporal solution that involves the frequency of the field. The total flux of the earth's surface area (5.1×10^{14} m^2) for an average 5×10^{-5} T strength is 2.55×10^{10} Webers. The total amperage for this field would be the dipole moment (8×10^{22} Am^2) divided by the surface area, or, 1.6×10^8 A. Therefore the inductance, which is Webers/amps would be 1.6×10^2 Henrys. With this value for inductance, a capacitance of 2 Farads [59,60] and a frequency of 7 Hz (both theta and Schumann resonance), the solution is about 2 ksec or about 30 min.

Magnetic Energy within Neurons

The physical form by which the information is represented within the earth's magnetic field would primarily involve the magnetic component (or its third-variable source) of neuronal activity. Within the earth's magnetic field of 5×10^{-5} T the amount of energy stored within the volume of a neuronal soma with the average diameter of 10 micrometer is 5.2×10^{-19} J, which is equivalent to about 32 action potentials per sec. For larger neurons of 20 to 30 microns in diameter the energy would be equivalent to about 400 to 500 action potentials per sec. These diameters are more typical of cells within the hippocampus and neocortices that are capable of fast ripple frequencies, particularly in the epileptics, between 200 to 500 Hz [61].

Known Interactions Between Brain Frequencies and Natural and Simulated Geophysical Fluctuations

Reviews by Cherry [46] and Breus et al. [62] only partially summarize the copious numbers of temporal associations between geomagnetic-ionospheric activity and multiple indices of brain function. They can be subtle. For example, the east-west vs. north-south orientation of the person can affect the onset of REM time [63]. Weak, 5 nT or 50 nT magnetic fields varying between .01 and .1 Hz to simulate geomagnetic pulsations disrupted alpha rhythms when the heads of prone adults were oriented towards the north [64]. However there was an accentuation of alpha and beta rhythms during either 5 nT or 50 nT applications if the subjects were lying with their heads oriented eastward.

Although increased geomagnetic activity has been correlated with epileptic seizures in humans for decades [65] and verified by experimental simulation of these conditions in epileptic rats [66], the indirect role of geomagnetic activity-induced suppression of melatonin [67] and consequently electrical disinhibition could not be excluded. However Babayev et al. [68], employing quantitative EEG to measure microstates [51], showed strong amplification of theta-rhythm components in real time within the right cerebral hemisphere during days of severe geomagnetic storms.

We [69] have also found a conspicuous coherence in electroencephalographic activity within the theta range in real time within the right hemisphere during periods of increased atmospheric power, a recent index based upon an aggregate of measurements within the geomagnetic and ionospheric regions. The sensitivity of theta activity and its underlying neurophysiological processes within the hippocampal formation to applied magnetic fields has been reported by Adey [70], Jenrow et al. [71] and Ahmed and Wierz [72] although the applied fields were stronger than those generated within the geomagnetic-ionospheric environment. More natural intensities (30 to 50 nT) when applied to the whole body (to rats) as 7 Hz square waves with amplitude

modulations to simulate geophysical conditions markedly altered immunological responses [73].

Probable Mechanisms of the Actual Localization

The convergence of quantitative solutions suggests validity for the hypothesis that electromagnetic information or its energetic equivalent could be stored within an as yet unspecified space occupied by the geomagnetic field. The most likely candidate would be a physical correlate of Hilbert space. Hilbert space involves a set of elements within a dense span in space in which a type of resonance congruence between elements as well as the substitution of elements can occur [34].

These conditions allow the principle of superposition of states to be applied. Essentially, a new state of a system (a composition of elements) composed of two or more states exists such that the new state shares some of the properties of each of the combined states [74]. Entanglement is the application of this principle to a composite system consisting of two or more subsystems. Although at present considered an abstraction, realistic solutions have been derived [75]. That other frameworks of relativistic space-time, such as Minkowski space, may exist as realities has also been considered [76].

The transposition by Prosen [75] of factors within quantum mechanics which propagate from and to Hilbert space suggests that there is a characteristic of space within which the geomagnetic field and ionospheric potentials are embedded that would facilitate representation and storage of information within the brain as quantum elements. There are multiple spatial dimensions [34] that occupy the range between the threshold where matter exists as correlations between protons, electrons and neutrons (at about 10^{-15} m) and the smallest estimated length of 10^{-35} m from Planck's solution.

In quantum mechanics electric and magnetic fields are expressed as potentials and electromagnetic fields are due to a more fundamental physical entity [77] where phase angle, much like the phase modulation of cerebral cortical waves [40], defines the representation. The existence of entanglement between two particle-waves, one within the brain and one represented externally, would create the conditions for stability over long durations of time. As a result a change in one element in intracerebral space would produce a complimentary change in the other element in extracerebral space or visa versa. Such a quantum phenomenon has been defined in optically coherent states as the disembodied transport of an unknown quantum state from one place to another [78]. When the physical substrate for this process is isolated then the transformation from the electromagnetic features of information processing [79] to the quantum equivalents [80,81] will allow a direct testing of the present hypothesis.

Implications

If this model is valid, there are several major implications that would require a reinterpretation of contemporary explanations. First, if the information is represented in an electromagnetic form (or the third factor from which the electric and magnetic fields are derived) within the space contained within the earth's magnetic field then this information might be accessed. This would require either: 1) the reconfiguration of the hippocampal formation to the condition that was present when the information was first consolidated, or, 2) the simulation of this condition by functional (electrophysiological) alterations in this structure or the cerebral cortices that accesses it.

However if the hippocampus has been damaged or has undergone neurodegeneration, this retrieval would be difficult. One method of circumvention would be to expose the brain to a virtual, physiologically-patterned magnetic field that simulates the absent properties of the hippocampal formation or its activity. We have demonstrated this in principle [82] by exposing rats that displayed significant learning and memory deficits, subsequent to seizure-induced damage within the hippocampus (particularly CA1 and CA3), to weak magnetic fields with the same patterns that induced LTP in hippocampal slices. Within this "virtual LTP field" the rats behaved more normally and learned the inhibitory schedule. When the field was not present their behaviours deteriorated.

The second implication is that there would be "incidental retrieval" of information from the "geomagnetic reservoir" because the hippocampus has the capacity for adult neurogenesis which means new synaptic patterns can be formed that are compatible with the resonant extracerebral information. This hypothesis predicts the probability would be higher for children between two and five years of age because this period is associated with the alteration of basal dendrites in neurons

within the dentate-gyrus and hippocampal interface as well as with the switch in the transient dominance of right hemispheric function [83].

Third, if all information from action potentials is represented for periods of time exceeding the demise of the person's brain, then this information could be accessible [84]. The information would not exist as "memories", per se, but as the essential sequences of electromagnetic pulses from which "memories" were created within the synaptic structure of brain space. Like the DNA-sequence that contains the record of biological structure on this planet, these neuroelectromagnetic representations may be an alternative source of historical information originating from brain activity.

Disclosure

The authors report no conflicts of interest.

References

[1] Squire, L.R. 1986. Mechanisms of memory. *Science*, 232:1612–9.

[2] Bruckner, R.L. and Petersen, S. 1996. What does neuroimaging tell us about the role of prefrontal cortex in memory retrieval? *Seminars Neurosci.*, 8:57–5.

[3] Alberts, A., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P. Molecular biology of the cell, Garland Science, New York, 2002 (4th edition).

[4] McGaugh, J.L. 2000. Memory-a century of consolidation. *Science*, 287:248–50.

[5] Greenough, W.T. 1984. Structural correlates of information storage in the mammalian brain: a review and hypothesis. *Trends Neurosci.*, 7:229–33.

[6] Nikonenko, I., Jourdain, P., Alberi, S., Toni, N. and Muller, D. 2002. Activity-induced changes in spine morphology. *Hippocampus*, 12:585–91.

[7] Hoffman, R.E. 1986. Verbal hallucinations and language production processes in schizophrenia. *Behav. Brain Sci.*, 9:503–48.

[8] de Broglie, L. New perspectives in physics, Basic Books, New York, 1962.

[9] Piccolino, M. 1997. Luigi Galvani and animal electricity: two centuries after the foundation of electrophysiology. *Trends in Neurosci.*, 20:443–8.

[10] Wei, L.Y. 1969. Molecular mechanisms of nerve excitation and conduction. *Bul. Math. Biophys.*, 31:39–59.

[11] Kandel, E.R., Schwartz, J.H. and Jessell, T.M. 2000. Principles of neural science, McGraw-Hill, New York, (4th ed), 258–62.

[12] Bower, G.H., A brief history of memory research. In: Tulving E and Craik FIM (eds) The oxford handbook of memory, Oxford University Press, New York, 2000, 3–32.

[13] Izquierdo, I. and Medina, J.H. 1997. Memory formation: the sequence of biochemical events in the hippocampus and its connection to activity in other brain structures. *Neurobiol. Learn Mem.*, 68:285–316.

[14] Nimshinsky, E.A., Sabatini, B.L. and Svoboda, K. 2002. Structure and function of dendritic spines. *Annu. Rev. Physiol.*, 64:313–53.

[15] Shepherd, G.M. The synaptic organization of the brain, Oxford University Press, Oxford, 2004 (5th edition).

[16] Blinkov, S.M. and Glezer, I.I. 1968. The human brain in figures and tables: a quantitative handbook, Basic Books (Plenum), New York, 396.

[17] Tsay, D. and Yuste, R. 2004. On the electrical function of dendritic spines. *Trends in Neurosci.*, 27:77–82.

[18] Cameron, J.R., Skofronick, J.G. and Grant, R.M. 1992. Physics of the body. Medical Physics Publishing: Madison (Wisconsin).

[19] Gloor, P. 1997. The temporal lobe and limbic system, Oxford University Press, New York.

[20] Campbell, W.H. 1997. Introduction to geomagnetic fields, Cambridge University Press, Cambridge (U.K).

[21] Lyon, J.G. 2000. The solar wind-magnetosphere-ionosphere system. *Science*, 288:1987–91.

[22] Humphreys, D.R. 2002. The earth's magnetic field is still losing energy. *CRS Quart.*, 39:1–11.

[23] Van Hoesen, G.W. 1982. The parahippocampal gyrus. *Trends Neurosci.*, Oct:345–9.

[24] Insausti, R., Tunon, T., Sobreviela, T., Insausti, A.M. and Gonzalo, L.M. 1995. The human entorhinal cortex: a cytoarchitectonic analysis. *J. Comp. Neurol.*, 355:171–98.

[25] Bear, M.F. 1996. A synaptic bases for memory storage in the cerebral cortex. *Proc. Nat. Acad. Sci.*, 93:13453–9.

[26] Douglas, R.J. The development of hippocampal function: implications for theory and therapy. In: RL Issacson and KH Pribram (Eds) The hippocampus Vol 2: Neurophysiology and behavior, Plenum Press, New York 1975 327–61.

[27] Zaidel, D.W. 1999. Quantitative morphology of human hippocampus early neuron development. *Anat. Rec.*, 254:87–91.

[28] Seress, L. and Ribak, C.E. 1995. Postnatal development and synaptic connections of hilar mossy cells in the hippocampal dentate gyrus of rhesus monkeys. *J. Comp. Neurol.*, 355:93–110.

[29] Mathern, G.W., Pretorius, J.K. and Babb, T.L. 1995. Quantified patterns of mossy fiber sprouting and neuron densities in hippocampal and lesional seizures. *J. Neurosurg.*, 82:211–9.

[30] Garcia-Ojalvo, J. and Roy, R. 2001. Spatiotemporal communication with synchronized optical chaos. *Phys. Rev. Let*, 86:5204–7.

[31] Xu, H., Strauch, F.W., Dutta, S.K., Johnson, P.R., Ramos, R.C., Berkley, A.J., Paik, H., Anderson, J.R., Dragt, A.J., Lobb, C.J. and Wellstood, F.C. 2005. Spectroscopy of three-particle entanglement in a macroscopic superconducting circuit. *Phys. Rev. Lett*, 94:027003–4.

[32] Corson, D.R. and Lorrain, D. 1962. Introduction to electromagnetic fields and waves, W.H. Freeman, San Francisco 276–8, 294–5.

[33] Winch, D.E., Iver, D.J., Turner, J.P.R. and Stening, J. 2005. Geomagnetism and quasi-normalization. *Geophys. J. Int.*, 160:487–504.

[34] Persinger, M.A., Koren, S.A. and Lafreniere, G.F. 2008. A neuroquantological approach to how thought might affect the universe. *Neuroquantol.*, in press.

[35] Persinger, M.A. and Koren, S.A. 2007. A theory of neurophysics and quantum neuroscience: implications for brain function and the limits of consciousness. *Int. J. Neurosci.*, 117:157–75.

[36] Dunn, J.R., Fuller, M., Zoeger, J., Dobson, J., Heller, F., Hamman, J., Caine, E. and Moskowitz, B.M. 1995. Magnetic material in the human hippocampus. *Brain Res. Bul*, 36:149–53.

[37] Halgren, E., Squires, N.K., Wilson, C.L., Rohrbaugh, J.W., Babb, T.L. and Crandall, P.H. 1980. Endogenous potentials generated in the human hippocampal formation and amygdala by infrequent events. *Science*, 210:803–5.

[38] Jeffreys, J.G.R., Traub, R.D. and Whittington, M.A. 1996. Neuronal networks for induced "40 Hz" rhythms. *Trends in Neurosci.*, 19:202–7.

[39] Lisman, J.E. and Idiart, M.A.P. 1995. Storage of 7+/–2 short-term memories in oscillatory subcyles. *Science*, 267:1512–4.

[40] Llinas, R. and Ribardy, U. 1993. Coherent 40 Hz oscillation characterizes dream state in humans. *Proc. natn. Acad. Sci. U.S.A.*, 90:2078–81.

[41] Kahn, D., Pace-Schott, E.F. and Hobson, J.A. 1997. Consciousness in waking and dreaming: the roles of neuronal oscillation and neuromodulation in determining similarities and differences. *Neurosci.*, 78:13–38.

[42] Kavanau, J.E. 1997. Origin and evolution of sleep: roles of vision and endothermy. *Brain Res. Bul.*, 42:245–64.

[43] Fox, S.E., Wolfson, S. and Ranck, J.B. 1983. Investigating the mechanisms of hippocampal theta rhythms: approaches and progress, In: Seifert W (ed), Neurobiology of the hippocampus, Academic Press: New York, 303–19.

[44] Richards, P.M., Persinger, M.A. and Koren, S.A. 1996. Modification of semantic memory in normal subjects by application across the temporal lobes of a weak (1 microT) magnetic field structure that promotes long-term potentiation in hippocampal slices. *Electro-Magnetobiol.*, 15:141–8.

[45] Kahana, M.J., Sekuler, R., Caplan, J.B., Kirschen, M. and Madsen, J.R. 1999. Human theta oscillations exhibit task dependence during virtual maze navigation. *Nature*, 399:781–4.

[46] Cherry, N. 2002. Schumann resonances, a plausible biophysical mechanism for human health effects of solar/geomagnetic activity. *Natural Haz.*, 26:279–311.

[47] Minakov, A.A., Nikolaenko, A.P. and Rabinovich, L.M. 1992. Gravitational-to-electromagnetic wave conversion in electrostatic field of earth-ionospheric resonator. Ivestiya Vysshikh Uchebnykh Zavedenii, Radiofiszika (translated) 35:488–97.

[48] Konig, H.L., Krueger, A.P., Lonag, S. and Sonning, W. 1981. Biologic effects of environmental electromagnetism, Springer-Verlag, New York, 28–9.

[49] Campbell, W.H. 1967. Geomagnetic pulsations. In Matushita S, Campbell WH. Physics of geomagnetic phenomena, Academic Press, New York, 821–909.

[50] Nunez, P.L. 1995. Towards a physics of the neocortex. In: Nunez PL (ed) Neocortical dynamics and human EEG rhythms, Oxford University Press, New York, 68–132.

[51] Millisecond by millisecond, year by year: 2002. Normative EEG microstates and developmental stages. *NeuorImage.*, 16:41–8.

[52] Efron, E. 1970. The minimum duration of a perception. *Neuropsychologica.*, 8:57–63.

[53] Kolb, B. and Wishsaw, I.Q. 1990. Fundamentals of human neuropsychology, W.H. Freeman, New York.

[54] Booth, J.C., Koren, S.A. and Persinger, M.A. 2005. Increased feelings of the sensed presence and increased geomagnetic activity at the time of the experience during exposures to transcerebral weak complex magnetic fields. *Int. J. Neurosci.*, 115:1039–65.

[55] Hu, J.H., Parker, G.H. and Persinger, M.A. Perinatal exposure to 0.5 Hz, 5 to 10 nT magnetic fields delays the ontogeny of right-left asymmetry of astroglia numbers in the parasolitary nucleus: implications for sudden infant deaths, in submission (2008).

[56] St-Pierre, L.S., Mazzuchin, A. and Persinger, M.A. 2008. Altered blood chemistry and hippocampal histmorphology in adult rats following prenatal exposure to physiologically-patterned, weak (50 to 500 nT) magnetic fields. *Inter. J. Rad. Biol.*, 84:325–35.

[57] Volchek, O.D. 1995. Influence of the cyclicity of the environment on the manifestations of functional asymmetry of the human brain. *Biophys.*, 40:1015–22.

[58] Gloor, P., Salanova, V., Olivier, A. and Quesney, L.F. 1993. The human dorsal hippocampal commissure. *Brain*, 116:1249–73.

[59] Volland, H. 1982. Quasi-electrostatic fields within the atmosphere. In: Volland H (ed) CRC Handbook of atmospherics Vol I, CRC Press, Boca Raton (Fla), 65–110.

[60] Hill, R.D. 1971. Spherical capacitor hypothesis of the earth's electric field. *Pure. App. Geophys*, 84:67–74.

[61] Bragin, A., Wilson, C.L., Straba, R.J., Reddick, M., Fried, I. and Engel, J. 2002. Interictal high-frequency oscillations (80–500 Hz) in the human epileptic brain: entorhinal cortex. *Annal. Neurol.*, 52:407–15.

[62] Breus, T.K., Pimenov, K.Y., Cornelissen, G., Halberg, F., Syutkina, E.V., Baevsky, R.M., Petrov, V.M., Orth-Gomer, K., Akerstedt, T., Otsuka, K., Watanabe, Y. and Chibisov, S.M. 2002. *Biomed. Pharmacother.*, 56:273s–83s.

[63] Ruhenstroth-Bauer, G., Gunther, W., Hantschk, I., Klages, U., Kugler, J. and Peters, J. 1993. Influence of the earth's magnetic field on resting and activated EEG mapping in normal subjects. *Intern. J. Neurosci.*, 73:195–201.

[64] Subrahmanyam, S., Sanker Narayan, P.V. and Srinivasan, T.M. 1985. Effect of magnetic micropulsations on the biological systems-a bioenvironmental study. *Int. J. Biometeor.*, 29:293–305.

[65] Rajaram, M. and Mitra, S. 1981. Correlation between convulsive seizure and geomagnetic activity. *Neurosci. Lett.*, 24:187–91.

[66] Michon, A.L. and Persinger, M.A. 1997. Experimental simulation of the effects of increased geomagnetic activity upon nocturnal seizures in epileptic rats. *Neurosci. Lett*, 224:53–6.

[67] Burch, J.B., Reif, J.S. and Yost, M.G. 1999. Geomagnetic disturbances are associated with reduced nocturnal excretion of a melatonin metabolite in humans. *Neurosci. Lett*, 266:2090212.

[68] Babayev, E.S. and Allahverdiyeva, A.A. 2007. Effects of geomagnetic activity variations on the physiological and psychological state of functionally healthy humans: some results of Azerbaijani studies. *Advan. Space Res.*, 40:1941–51.

[69] Mulligan, B., Hunter, M. and Persinger, M.A. Enhancement of coherence of theta activity within the right hemisphere during real-time periods of atmospheric power and geomagnetic activity. In submission (2008).

[70] Adey, W.R. 1981. Tissue interactions with nonionizing electromagnetic fields. *Physiol. Rev.*, 61:435–509.

[71] Jenrow, K.A., Zhang, X., Renehan, W.E. and Liboff, A.R. 1998. Weak ELF magnetic field effects on hippocampal rhythmic slow activity. *Exper. Neurol.*, 153:328–34.

[72] Ahmed, Z. and Wieraszko, A. 2008. The mechanism of magnetic field-induced increase of exctiability in hippocampal neurons. *Brain Res.*, 1121:30–40.

[73] Kinoshameg, S.A. and Persinger, M.A. 2004. Suppression of experimental allergic encephalomyelitis in rats by 50 nT, 7 Hz amplitude modulated nocturnal magnetic fields depends on when after the inoculation the fields are applied. *Neurosci. Lett*, 370:166–70.

[74] Aczel, A.D. 2002. Entanglement: the greatest mystery in physics, Raincoast Books, Vancouver.

[75] Prosen, T. 1994. Exact quantum surface of section method. *J. Phys. A: Math. Gen.*, 27:L709–L14.

[76] Petkov, V. 2007. On the reality of Minkowski space. *Found Phys.*, 37:1499–502.

[77] Imry, Y. and Webb, R.A. 1989. Quantum interference and the Aharonov-Bohm effect. *Scientific. Amer.*, April:56–62.

[78] Furusawa, A., Sorensen, J.L., Braunstein, C.A., Fuchs, C.A., Kimpble, H.J. and Polzik, E.S. 1998. Unconditional quantum teleportation. *Science*, 282:706–9.

[79] McFadden, J. 2007. Conscious electromagnetic field theory. *Neuroquantol.*, 3:262–70.

[80] Jibu, M. and Yasue, K. 1995. Quantum brain dynamics and consciousness: an introduction, John Benjamins Publishing, Amsterdam.

[81] Beck, F. 2008. Synaptic quantum tunnelling in brain activity. *NeuroQuantol.*, 6:140–51.

[82] Mach, Q.H. and Persinger, M.A. Behavioral changes with brief exposures to weak magnetic fields patterned to simulate long-term potentation. in submission.

[83] Chiron, C., Jambaque, I., Nabbout, R., Lounes, R., Syrota, A. and Dulac, O. 1997. The right brain hemisphere is dominant in human infants. *Brain*, 120:1057–65.

[84] Persinger, M.A. 1995. On the possibility of directly accessing every human brain by electromagnetic induction of fundamental algorithms. *Percep. Mot Skills*, 80:791–9.