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Greater electroencephalographic coherence between left and right temporal lobe structures during increased geomagnetic activity

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HIGHLIGHTS

- Enhanced interhemispheric temporal lobe coherence occurred with increased geomagnetic activity.
- The threshold for electroencephalographic changes was similar to those associated with subjective experiences.
- Major coherence occurred within the alpha activity range.
- Differences in left/right parahippocampal activity were correlated with increased geomagnetic activity.

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ABSTRACT

Interhemispheric coherence for 19 channel EEG activity collected over a three year period from 184 men and women who relaxed in a quiet, darkened chamber showed significant increased coherence between caudal temporal regions for the 11 Hz frequency band during increased (>~8 nT) global geomagnetic activity at the time of measurement. Detailed analyses from source-localization indicated that a likely origin was the parahippocampal regions whose net differences at 10, 11 and 12 Hz intervals were significantly correlated with geomagnetic activity. Analyses of residuals to obtain a “purer” measure of parahippocampal contributions indicated that interhemispheric temporal lobe coherence across unit increments between 1 and 40 Hz revealed the most statistically significant peaks at 7.5 Hz and 19.5 Hz. These weak but reliable correlations between global geomagnetic activity and the degree of inter-temporal lobe coherence for normal people relaxing in a dark, quiet area are consistent with the results of multiple studies indicating that intrusive experiences such as “presences” or “hallucinations” are more frequent when global geomagnetic activity increases above ~15–20 nT.

Although the static magnetic field of the earth averages ~50,000 nT perturbations more than 1000 times smaller in magnitude are associated with significant changes in the incidence rates of broad classes of behavior [5,10,20,30]. Small increases (>20 nT) in global geomagnetic intensity have been correlated with increased display of epileptic convulsions in clinical patients [24] as well as rats in which epilepsy has been induced experimentally [15]. That the effects were associated with the magnetic field component rather than the multiple correlative variables such as proton flux and electric field changes was demonstrated with experimental simulations [10,26]. Human experiences, often described as hallucinations or “altered states” [14,25] that are consistent with increased electrical activity within the temporal lobes have also been correlated with increases in daily geomagnetic activity. Reports of bereavement apparitions occurred on days when the mean global perturbation was ~28 nT compared to days before or after (as well as monthly averages) that averaged 20–21 nT [14].

The development of easily available quantitative electroencephalographic (QEEG) techniques and the statistical software to effectively extract information concerning specific activity has shown that the human brains, or at least a subset of them, display clear changes in power within specific frequency bands over specific regions during very intense geomagnetic activity [2]. Mulligan et al. [11] showed that even daily global changes in aa (average antipodal indices) values of between 20 and 50 nT were associated with robust changes in electroencephalographic power in normal volunteers. Young adults whose whole bodies were exposed to experimental simulation of components of geomagnetic activity

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at natural intensities exhibited changes in QEEG patterns within a few minutes [12].

The preferential sensitivity of the right hemisphere to subtle increases in geomagnetic activity has been reported [4]. For decades neurosurgeons and epileptologists have reported that individuals who exhibit electrical foci within the right temporal lobe were more likely to report unusual experiences such as "sensed presences", detachment, and exotic experiences including frank hallucinations [1,21]. Over the last 20 years we have been examining the hypothesis that differential exposure of the right hemispheres of volunteers to physiologically patterned, weak magnetic fields followed by bilateral stimulation enhances the report of intrusive experiences of "presences" and other representations of the "right hemispheric sense of self" [18,22,27,29].

In other words the experimental protocol [28] produces a condition that is similar to that during enhanced geomagnetic activity which has been shown to be correlated with "out-of-body" experiences in certain populations [16]. Persinger and Richards [23] reported a threshold for the enhanced numbers of reports for a cluster of items which involved "vestibular themes", *i.e.*, detachment, floating. These experiences markedly increased when the global geomagnetic activity increased over a K_p ('kennziffer' or index of the logarithm of a number) of 3 or between 15 nT and 25 nT.

Within the last five years we have measured hundreds of subjects within various experimental setting by 19 channel QEEG and discerned source localizations with Low Resolution Electromagnetic Tomography (sLORETA). We reasoned that if increased geomagnetic activity was associated with enhanced coherence between the right and left hemispheres (and this condition was primarily involved with the report of vestibular experiences and often the "detection" of a sensed presence) then recent computational software with greater sensitivity that measures enhanced interhemispheric coherence should reveal a comparable threshold. Here we show that within a population of 184 subjects tested over a period of several years this coherence increased significantly when the global geomagnetic activity increased beyond 20 nT.

A total of 184 men and women, ages 20 through 80 years, were tested singly over a 3.5 year period as a part of a larger study involved with examining source localizations during periods of relaxation in quiet settings when the eyes were opened or closed. Because a subset of these subjects had been measured several times under different experimental conditions, 233 records were available for this study.

Quantitative electroencephalographic (QEEG) recordings were collected with a Mitsar-201 amplifier connected to a Dell laptop equipped with WinEEG v. 2.8. Each subject wore a 19-channel Electro-Cap, which recorded activity from 19 sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2) commensurate with the International Standard of Electrode Placement. All electrode impedances were maintained below 5 kΩ. For each subject, sixteen-second segments of artifact free eyes closed data was extracted and filtered between 1.5 and 40 Hz.

Spectral analyses were completed with MATLAB software equipped with EEGLab [7]. We used the *bandpower.m* function to compute spectral power for each sensor within the delta (1.5–4 Hz), theta (4–7.5 Hz), low-alpha (7.5–10 Hz), high-alpha (10–13 Hz), beta-1 (13–20 Hz), beta-2 (20–25 Hz) beta-3 (25–30 Hz) gamma-1 (30–35 Hz) and gamma-2 (35–40 Hz) bands. Coherence analyses were also completed using the EEGLab toolbox. Specifically, we used the *coherence.m* function (script available at http://sccn.ucsd.edu/pipermail/eeglablist/2005/001056.html) to calculate coherence between the left (T5) and right (T6) posterior temporal sites. Both the spectral power and the coherence magnitudes for each individual were saved for further analysis with SPSS.

Source localization using sLORETA [13] software was employed to infer bilateral activation within the parahippocampal gyri. sLORETA software models the current source density ($\mu A/mm^2$) distribution [9] of activity recorded from scalp electrodes onto a 3D reconstruction of the human brain. For this study, we first translated the 19-channel time-series into the frequency-domain by means of cross-spectral analysis within discrete 1-Hz frequency bins from 1 to 40 Hz using the *EEG to Cross-Spectrum* function. Current source density was then computed using *Cross-Spectrum to sLORETA*. The results of this computation were then entered into the *sLORETA to ROI* function to obtain regional-specific activation of the bilateral parahippocampal gyri using its approximate MNI co-ordinates (right: $X = 28$, $Y = -40$, $Z = -12$; left: $X = -28$, $Y = -40$, $Z = -12$). As a result both left and right parahippocampal sLORETA activation scores were obtained for discrete 1-Hz frequency bins from 1 to 40 Hz. These scores were also saved and imported into SPSS for further analyses.

Considering the frequent occurrence of increased activation within the right parahippocampal region as inferred by source localization (sLORETA) during conditions associated with both sensed presences and increased geomagnetic activity [29], we computed net differences between the left and right parahippocampal scores as a function of 1 Hz increments by subtracting activation in the left parahippocampal gyrus from the right; therefore the scores reflected right parahippocampal activation with respect to the left and positive values indicated greater right parahippocampal involvement. Preliminary analyses of variance (described below) suggested similar effects for the 10, 11, and 12 Hz bands, which also comprise what is commonly known as the "high-alpha" band. Hence the sum of the activation of 10, 11, and 12 Hz bands for the net changes in parahippocampal activation was employed as the predictor and all channels and bands were employed as independent variables in a step-wise multiple regression. In order to discern the intrinsic activity in right parahippocampal regions after the removal of cortical components, the residuals were analyzed as a function of the different levels of *K* values at the time of the measurement. Because activation of intracortical regions inferred by sLORETA is ultimately based upon electrical activity derived from the outer surface of the brain, we reasoned that controlling for cortical activity by removing shared sources of variance contributed by the sensors would provide a more accurate representation of activity within the parahippocampal region. Finally the strength (r^2) of the correlations between this residual and the T5–T6 coherence values for each of the frequencies between 1 and 40 Hz were completed. All analyses involved PC SPSS 16 software.

The numbers of people (in parentheses) measured during times of various levels of geomagnetic disturbance were $K_p = 0$ ($N = 47$), $K_p = 1$ ($N = 105$), $K_p = 2$ ($N = 51$), $K_p = 3$ ($N = 23$) $K_p \geq 4$ ($N = 7$). The results of the coherence analyses are shown in Fig. 1. The mean coherence between the left (T5) and right (T6) posterior temporal regions significantly increased ($F_{4,228} = 4.97$, $p < .01$, Ω^2 estimate = .08) when the contemporary geomagnetic activity, as inferred by 3 h *K*-indices, was 2 or greater which is equivalent to >6 to 9 nT at the time of the measurement. The coherence was also specific to the 11 Hz frequency band and was not evident for increments below or above this value. The effect sizes for the correlations between the *K* indices and the net differences in current source density between the left and right parahippocampal regions for each 1 Hz increment are shown in Fig. 2. One way analyses of variance indicated statistically significant correlations only for the adjacent 10, 11, and 12 Hz bands as well as a smaller 30 Hz frequency.

The only variables that entered the equation for the sum of the activation within the 10, 11, and 12 Hz ($\Sigma_{10,12}$) bands were high-alpha from the right posterior temporal (RPT-α2) regions and the