Experimental and Correlational Evidence that Biological Systems are Influenced by Intensity and Variation of Geomagnetic Fields

by

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Abstract

Fluctuations in the Earth's geomagnetic environment have been implicated in numerous biological processes as small as ion transport across a cellular membrane to as gross as the activity and behaviour of an individual. Treatment of demyelinated planaria with a six minute exposure to a magnetic field which simulates the onset of a geomagnetic storm resulted in a reduction of atypical behaviours that mimics observations of planaria not treated with a demyelinating agent. There was also a strong correlation observed between the North/South component of the Earth's geomagnetic field and the prevalence of multiple sclerosis around the world. Increases in the local geomagnetic field strength due to geomagnetic disturbances can also influence the electrophysiological and negatively impact the sporting performance of athletes. These results indicate that biological systems are heavily influenced by changes in their geomagnetic environment, and certain disease acquisition and progression may be intrinsically tied to these energies.

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Chapter One: Introduction

Earth's Geomagnetic Field

The creation of magnetic fields is a by-product of the movement of electrons in a system. The magnetic field strength is directly proportional to the number of flux lines within a defined space and is commonly measured by the unit of Teslas (T). There are two main classes of magnetic fields; static or time-varying. The intensity and direction of static fields remain fairly constant over time, whereas time-varying fields are more dynamic.

This is relevant due to the fact that our planet is essentially a dipole magnet with two poles (North and South) where the strength of the field is the greatest (up to 67 μT), and gets smaller (as low as 22 μT) the closer we move to the middle of the magnet (the equator; Zhadin 2001). The Earth's magnetic field is primarily produced as a by-product of electrical current through the iron core with typical flux lines extending outward. Although this accounts for a large majority of the field; different mineral compositions and the flow of sea water around the world also have significant however more local effects on the geomagnetic field (Chulliat et al 2015). That being said, the field is not uniform for the entire planet and the dynamics of it are constantly changing with pole reversals, changes in the ion flow within the iron core as well as pockets of activity in the oceans caused by the flow of ion content within sea water (Heirtzler et al 1968). This is why attempts to produce an accurate and universal model for geomagnetic activity must be revisited on a regular basis (approximately every five years) to account for the changing global dynamics (Chulliat et al 2015).

This field also acts to protect the Earth from solar wind particles produced by the sun. Solar wind particles interact with the naturally produced geomagnetic field causing increased pressure periods known as geomagnetic disturbances (GMD; Palmer et al 2006).

Magnetospheric substorms are one example of a GMD which occur frequently in auroral zones and can cause a disturbance between roughly 50 nT 2000 nT increase in the strength of the background field (Lyons 2000). These disturbances, which occur exclusively above the 60th parallel, are the common causes of the aurora borealis, also known as the northern lights (Heppner 1954). Geomagnetic storms are a more global phenomena, however occur less frequently, and usually with a much lower intensity than the auroral magnetospheric substorms. During these periods, there is an increased pressure on the local field thereby increasing the local geomagnetic field strength. As described by Mayaud (1975), these disturbances have particular characteristics, including intensity fluctuating between 50-100 nT, and a typical onset of six minutes. The disturbances are measured as increases (in nT) from the background field, and can be categorized using a variety of scales including the Kp index which is quasi-logarithmic while values greater than 5 indicated a geomagnetic storm (Gmitrov & Gmitrova 2004).

Geomagnetic Variability and Biological Systems

Biological systems can be influenced by electromagnetic fields due to their similarity to a Faraday circuit. Any charged aqueous solution in the body (ie. ions flowing through the bloodstream, ions moving through a cellular membrane, etc.) are capable of inducing an electromagnetic field, and are therefore susceptible to changes in their local electromagnetic environment. In other words, changes in the electromagnetic dynamics that exert their energy on a biological system are capable of altering the normal operation of the system, perhaps altering the structure, function and behaviour of the system itself.

Many studies have demonstrated chemical changes in a biological system as a result of changes in a local geomagnetic field. For example, Tombarkiewicz (2008) demonstrated that deprivation from the natural geomagnetic field decreased the amount of multiple metals in the hair of rats, suggesting an increased storage internally, or enhanced excretion of these elements. Others have demonstrated significant changes in ion flux across the cellular membrane. For example, (Walleczek 1999) found changes in calcium ion regulation across the cell membrane of leukocytes thereby altering the local field produced by the flow of charged materials which changes the functionality of the cell itself. Other studies have noted changes in growth hormone and ketosteroids in peripheral blood (Stoupel 1999).

There has also been evidence to support the theory that fluctuations in geomagnetic activity can influence the physiology of an organism as a whole. Changes in geomagnetic field intensity has been shown to correlate better with symptoms for patients with heart disease two and a half times better than the physical increase in barometric pressure (Gurfinkel et al 1995). Increases in the local geomagnetic field have been correlated with increases in diastolic blood pressure in human subjects (Dmitrova 2008), and an increase up to 9% in arterial pressure in rats (Martinez-Breton & Mendoza 2016). Changes in local field dynamics have also been correlated with increased myocardial deaths (Stoupel 1999). Increased geomagnetic activity has been associated with decreased physiological melatonin levels (Weydal et al 2001) suggesting that melatonin can be influenced by a typical 24 hour light/dark cycle but also geomagnetic perturbations. Increases in geomagnetic activity also correspond to increased theta power in the right parietal (Mulligan & Persinger 2012), and field deprivation is linked to increased slow-wave activity (Stoilova & Zdravev 2000).

Interactions between the geomagnetic environment and biochemical and physiological processes internally can significantly impact human health, and behaviour on a larger scale. For example, it has been suggested that geomagnetic variation can directly account for up to 15% of adverse health effects in a population (Palmer et al 2006). Increased geomagnetic activity also correlates with the number of sudden infant death syndrome (SIDS) cases (O'Connor & Persinger 1997), and increased local field intensity has also been suggested to correlate to an increased risk of multiple sclerosis (Sajedi & Abdollahi 2012). Fournier and Persinger (2004) demonstrated an increased proportion of airplane crashes caused by pilot or computer error on days with greater geomagnetic activity than for those caused by mechanical failure. This suggests that hard-wiring of the human brain (neuronal networks) can be similarly affected by increased geomagnetic activity as the hard-wiring of a computer system.

Since biological systems are non-linear, one field may have differing effects on a separate system or individual just as drugs show individual effects. In fact, heart rate variability (HRV) data has allowed individuals to be separated into those who are sensitive to geomagnetic disturbances, and those who are not (Chernouss et al 2001). Those sensitive to fluctuations in geomagnetic activity can also be divided by into those who respond to these changes sympathetically or parasympathetically, perhaps providing an explanation as to why many biological effects of magnetic fields are not homogeneous across a population.

Present Study

In the present study, the biological effects of the Earth's geomagnetic field are investigated in relation to 1) the physical behaviours in planaria with a simulated form of multiple sclerosis, 2) the correlation with MS prevalence and 3) the effect on electrophysiological and sporting performance in humans.

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Chapter Two: Introduction of planaria as a new model for multiple sclerosis research: Evidence from behavioural differences in cuprizone treated planaria exposed to patterned magnetic fields.

Abstract

There has been a substantial history of correlative associations between subtle changes in geomagnetic intensity and the prevalence of multiple sclerosis. Several experiments have shown that rats in which experimental allergic encephalomyelitis had been induced respond to naturally-patterned weak magnetic fields. Exposures of only 6 min once per hour during the scotophase to a ~ 50 nT, 7 Hz magnetic field whose amplitude modulations simulated a sudden geomagnetic storm commencement markedly reduced both the behavioural symptoms and mononuclear cell infiltrations. In the present study planarian were exposed for only 6 min per day for three days to this same field pattern and intensities but with or without the presence of the demyelinating agent cuprizone. Behavioural analysis indicated a strong interaction after one day of exposure between cuprizone and field conditions for the numbers of “head whips” and an indicator of “unusual behaviours.” The 6 min exposures to the patterned magnetic field on the second and third days eliminated the effects of cuprizone upon the numbers of head whips and related anomalous behaviours. General activity was not affected. The specificity of the simultaneous exposure to the magnetic field and cuprizone for normalizing the planaria is consistent with the results of rodent studies involving one model of multiple sclerosis and suggests that this paradigm might be useful for examining the potential mechanisms for the correlation between prevalence of MS and geomagnetic variables.

Keywords: Planarian; Geomagnetic intensity; Cuprizone; Multiple sclerosis; Demyelination; Weak intensity

Introduction

Of the commonly used animal models for demyelination, the cuprizone (CPZ) model allows for direct investigation of myelin damage and resulting repair. In rat models, cuprizone first binds copper ions, disrupts the function of the cytochrome complex, reduces the membrane potential in the mitochondria, and creates an oxidative stress and energy shortage (Millet et al 2009, Pasquini et al 2012). This stress disturbs the normal functions of the endoplasmic reticulum in processing lipids and amino acids that contributes to oligodendrocyte degeneration and disintegration of the myelin sheath (Praet et al 2014). The damage then triggers an immune response including astrogliosis and subsequent micro gliosis to phagocytise the myelin debris (Chen et al 2004; Kotter et al 2006). Unlike human multiple sclerosis (MS), cuprizone induced models do not activate T and B cells. There has been no observable evidence of lymphocyte infiltration in damaged brain foci (Praet et al 2014). Cuprizone does not increase the permeability of the blood-brain barrier (BBB) which is often seen in MS which allows the auto-reactive T cells direct access to the CNS (McMahon et al 2001; Praet et al 2014).

It has been suggested that differential intensity of the earth's magnetic field is a correlative environmental risk factor in developing MS. In an extensive epidemiological review, Sajedi and Abdollahi found a positive correlation between geographic latitude and reported prevalence of multiple sclerosis around the world (Sajedia & Abdollahi 2012). A geographic (implicitly related to proportions of solar hours) is also central to the Vitamin D Hypothesis. However; when these authors compared the geographic latitude to the geomagnetic field strength of each study centre, they found a greater positive correlation between MS prevalence and geomagnetic field intensity, compared to geographic location alone. Time-varying magnetic fields generated by "cancelling" the background static field within the 50 nT range have previously been demonstrated to markedly attenuate Experimental Allergic Encephalomyelitis (EAE) in the Lewis rat (Cook & Persinger 2000; Kinoshameg & Persinger 2004; Persinger & Cook 2000). Weaker, more complex fields have been reported to treat some MS cases in human beings (Sandyk 1992).

The planarian flatworm has become popular for a multitude of human diseases due in part to their similarity to the human central nervous system. Physically, the planarian central nervous system is composed of a central cluster of ganglions with two ventral nerve cords with neurons and glial cells that resemble cytological structures in vertebrate nervous tissue (Biserova et al 2010). Chemically, they possess neurotransmitters and associated receptors found in vertebrates including acetylcholine, catecholamines, GABA, and serotonin (Buttarelli et al 2008). Perhaps the most exciting feature of these flatworms is their extensive ability to regenerate. Planaria possess an abundance of pluripotent stem cells (neoblasts) which give them the capability to fully regenerate all body parts including nervous tissue (Gentile et al 2011; Wagner et al 2011). A planarian can be segmented into 279 pieces and each fragment will regenerate into a full worm (Morgan 1901). All of these features have allowed researchers to study a variety of neurological disorders from addiction and withdrawal mechanisms to neurodegenerative disorders (Raffa et al 2013; Raffa & Valdez 2001).

The current investigation was designed to examine the planarian as a possible model to understand the potential geomagnetic contribution to the prevalence for multiple sclerosis (MS). We reasoned that if the geomagnetic effect was not a confounding association, then the effects of experimentally manipulating a natural intensity magnetic field upon planarian behaviour should interact with a more well known chemical treatment. One of these agents with potential application is cuprizone which has been considered a demyelinating agent. Since planaria lack an adaptive immune system, this experiment was designed to affect the pluripotent stem cells of planaria (Harshani Peiris et al 2014). We also planned to discern if magnetic fields that simulate a geomagnetic event could reduce behavioural symptoms in a cuprizone model as they did in prior studies which examined EAE in rats (Cook & Persinger 2000; Kinoshameg & Persinger 2004; Persinger & Cook 2000). Those experiments had simulated a "sudden storm commencement" or "sudden impulse" as outlined by Mayaud which exhibited an average duration of about six minutes and intensity fluctuating between 50-100 nT (Mayaud 1975). These field parameters were similar to those used in past studies. The primary difference was the rats had been exposed multiple times during the dark cycle whereas the planaria were exposed only once daily (Cook & Persinger 2000; Kinoshameg & Persinger 2004; Persinger & Cook 2000).

Materials and Methods

Planaria and Chemical Compounds

Brown planaria (*Dugesia tigrina*) were acquired from Carolina Biological Supply (Burlington, North Carolina) and housed in group containers containing fresh spring water in darkness until use (Murugan & Persinger 2014). Cuprizone (bis-cyclohexanone-oxaldihydrazone) was acquired from Sigma-Aldrich and dissolved in ethanol in spring water to the desired concentration of 0.5% w/w cuprizone (35 μM), 0.1% ethanol. This concentration is within the range of doses for cuprizone demyelination in rats and mice (Adamo et al 2006; Matsushima & Morell 2001).

Patterned Magnetic Fields

The magnetic field was generated using a digital to analog converter (DAC) and a coil with dimensions of 38 cm x 33 cm x 27 cm which was wrapped with 305 metres of 30 AWG wire as described by Murugan et al. (2014). A custom constructed digital-to-analogue converter transformed a series of 5,071 numbers each between 1 and 256 which were equivalent to voltages between -5 and +5 V. The numbers were contained within Complex Software formatted for an XT personal computer. The point duration of each voltage (number value) was 69 milliseconds such that one cycle completed through a series of numbers (1-256) formed a temporal pattern. The magnetic field pattern used simulated the typical onset of a geomagnetic storm (a sudden storm commencement or “sudden impulse”) whose duration was about 6 min. A diagram of the shape has been published several times.

Essentially it is a fundamental 7 Hz square wave containing two envelopes of increasing and decreasing amplitude modulations around 36 mHz and 71 mHz. The intensity fluctuated between 40 and 100 nT according to a power meter. A MEDA magnetometer verified the displacement in the x-axis only (the direction of the field from the coil) of about 40 nT. It is important to emphasize that when the field was generated by the equipment the static component of the x-axis of the static geomagnetic field decreased by a maximum of 40 nT during the peak components of the pattern. In other words the pattern was created within the increment between the diminished component of the geomagnetic field and the normal values for the field. We have found that this cancellation of a component of the local static field within which the experimentally generated temporally patterned field is then replaced produces the most robust biological and behavioural effects.

The exposure area for the planarian was 1.4 m from the center of the coil in order to obtain the required intensity to simulate that which produced the maximum reduction of EAE in rats. The orientation of the coil with respect to the earth's magnetic field was about 14° east of due magnetic north. The inclination was 71° and the resultant field was 49,080 nT (± 5 nT). The average static x, y, and z components (± 5 nT) were 14, 692, 3,857, and 47, 673, respectively. The surface upon which the containers for the planarian were placed was directly on the smoothed bedrock in the basement of the building.

Experimental Procedure

To establish a dosage curve, planaria (N=60) were divided into six treatment groups: a water control, a 0.1% ethanol control, and 0.1%, 0.2%, 0.5% or 0.8% cuprizone solution groups. Therefore, there were a total of 10 planaria per condition. Planaria were then placed into 1.5 mL plastic conical centrifuge tubes (Fisherbrand with dimensions of 10.8 x 40.6 mm). Each tube contained one worm and 1 mL of fluid. It was held upright in a plastic rack throughout the experiment. Behaviours were monitored daily after which the solutions were replaced for a total of three days.

To assess the effects of magnetic field treatment on cuprizone treated planaria, over three trials (weeks), on three separate days, planaria (N=60) were divided into four treatment groups: a water control, cuprizone treated, magnetic field treated water control and a cuprizone with magnetic field treatment group. Therefore, there were a total of 15 planaria per condition. Planaria were then placed into 1.5 mL plastic conical centrifuge tubes (Fisherbrand with dimensions of 10.8 x 40.6 mm). Each tube contained one worm and 1 mL of fluid and were held upright in a plastic rack throughout the experiment. On the first day of each trial, planaria were placed into their individual tubes along with 1 mL of either 0.5% cuprizone solution or spring water (Gang & Persinger 2011). Each subsequent day, the planaria were exposed to the magnetic field or a sham condition (no field). Their behaviours were monitored for five minutes .

Behavioural Paradigm

Planaria were placed in a small petri dish containing 3 mL of spring water on top of 0.5 cm grid paper. Over a five minute observation period, the numbers of gridlines crossed (known as the planarian locomotor velocity or pLMV) and frequency of atypical behaviours including head-whips, tail-twists, squirming and corkscrews were recorded as described by Raffa and Valdez (2001).

Statistical Analyses

The basic design was a four way analysis of variance with three between levels (magnetic field, cuprizone, replicate or weeks) and one within subject (trials). Statistical tests included multiple level analysis of variance, one-way analysis of variance and post-hoc Tukey tests to discriminate group differences. The mean of the three trials for each behavioural measure was analyzed for main effect comparisons. All statistical analyses were performed using PC IBM SPSS Statistics Version 20.

Results

The grand means and standard deviations (in parentheses) for behaviours during the dosage curve experiment were as follows: squares traversed: 58.5 (15.4), head whips: 31.0 (9.3), tail twists: 2.2 (1.6), cork screw: 1.3 (1.3), and squirming: 0.61 (0.75). Two way analysis of variance, as a function of treatment group and day, revealed strong group and day effects for the numbers of headwhips during the observation period. On day one, planaria displayed a lower amount of headwhips [F (2,177) = 3.34, p=0.038], while at days two and three were no statistically significant differences (p>0.05). Analysis of variance using only data from these two days demonstrated a significant difference between treatment groups for number of headwhips [F (5,117) = 30.7, p<0.001]. These results can be seen in Figure 2.1 with SEMs to demonstrate significance. A post-hoc Tukey test confirmed that all cuprizone treated groups varied significantly from the water control (p<0.05). Also, the ethanol control group displayed less headwhips than the 0.5% and 0.8% cuprizone groups. For this reason, the 0.5% concentration was used for further experiments to minimize the effect of the solvent.

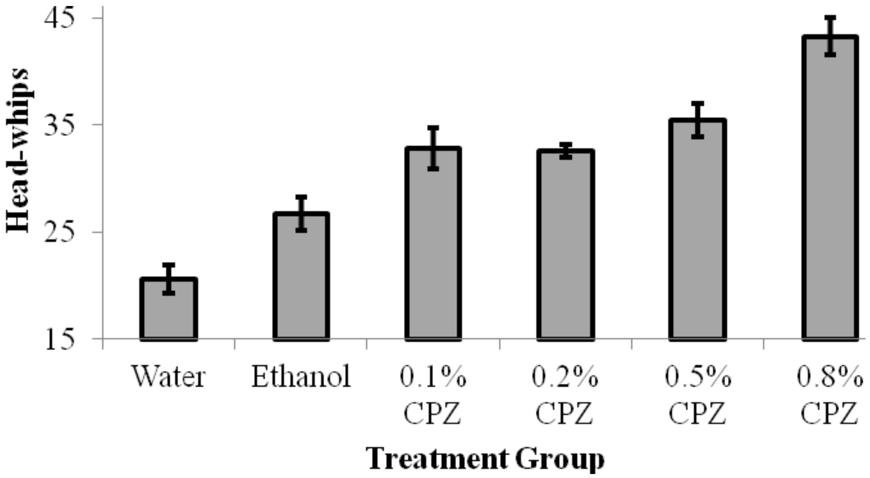

Figure 2.1 Number of head-whips during five minute observation period for varying concentrations of cuprizone. Results are displayed as Mean ± SEM.

The grand means and standard deviations (in parentheses) for the various measures were: squares traversed: 64.0 (11.6), head whips: 27.3 (7.9), tail twists: 0.25 (0.38), cork screws: 0.37 (0.47), and squirming: 0.15 (0.23). Four way analyses of variance as a function of field condition, cuprizone, replication and trial (within subject) for the five measures separately revealed multiple main effects for the three between subject measures. The planarian exposed to the magnetic field displayed significantly fewer headwhips [F (1,48)=20.15, $p<0.001$] compared to the no field conditions. There were no statistically significant treatment differences for any of the other four measures. On the other hand, the planarian exposed to the cuprizone solution displayed significantly (all dfs=1,48) more headwhips [F=30.71], more squares traversed [F=6.69] more tailtwists [F=12.25], more corkscrews [F (8.16) and more squirming [F=20.63] than the comparison groups. The gross influence of cuprizone upon numbers of squares traversed is shown in Figure 2.2. Standard errors of the mean (SEMs) are indicated to help demonstrate statistically significant differences between groups (treatments). There were statistically significant (all dfs=2,48) differences for all measures (except squirming) between the replicates, that is over the three separate weeks. Post hoc analyses indicated the planarian in the second block exhibited generally fewer responses for all behavioural domains.

Perhaps the most relevant result was the interactions between the simultaneous treatment by the cuprizone and the weak magnetic fields designed to simulate a sudden geomagnetic storm commencement or “sudden impulse.” Analysis of variance indicated statistically significant interactions (all dfs=1,48) between cuprizone and magnetic field treatments for numbers of head whips [F=9.84], twists [F=8.03] and corkscrews [F=9.88]. The significant interactions were not apparent for either the numbers of squares traversed or squirming. The typical pattern (as indicated by head whips) of these interactions is shown in Figure 2.3. Because there was a statistically significant interaction with trials (days) and the post-hoc analysis indicated that the major source of the interaction was for the second and third days of treatment, the means and dispersion measures reflect only those two days. The effects of the cuprizone upon the numbers of headwhips were eliminated if the planarian were simultaneously exposed for 3 days, 6 min per day to the magnetic field pattern.

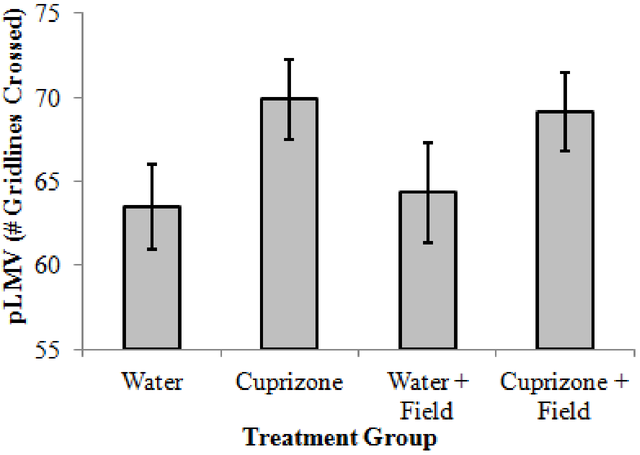

Figure 2.2. Mean planarian locomotor velocity (pLMV) during five minute observation period after field treatment. Results are displayed as Mean ± SEM.

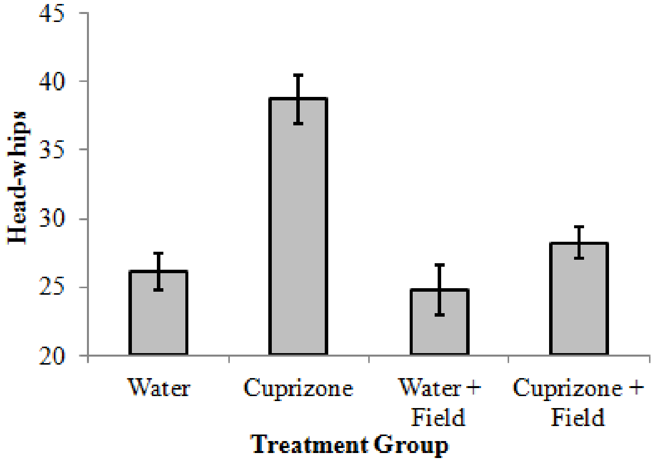

Figure 2.3. Number of head-whips during five minute observation period after field treatment. Results are displayed as Mean ± SEM.

Discussion

The results of these experiments indicated that brief exposures to a pharmacological treatment that may have relevance to processes contributing to myelinization and a complex amplitude-modulated weak (50 nT) magnetic field based upon a 7 Hz square wave fundamental pattern can produce specific and differential effects upon planarian behaviour. Whereas the cuprizone clearly affected gross movement behaviours as well as the qualitative patterns in which planarian engage, the effects of brief 6 min daily exposures to the magnetic field pattern only affected specific qualitative behaviours. Among the most robust was the numbers of head-whips which were not affected by the magnetic field only. The statistically significant main effect was confounded by the statistically significant interaction between curpizone and magnetic field treatments. However when the planaria were exposed to both treatments (Figure 2) the numbers of head-whips were reduced to control (water only) values.

These results suggest that the magnetic field pattern, even though the intensity was 50 nT and was presented for only 6 min, may have involved the same biochemical processes through which cuprizone mediates its effects. That weak magnetic fields can interact with pharmacological agents to ameliorate or exacerbate their effects has been shown by several researchers (Martin et al 2004). Recently Karbowski et al. (2015) showed that the relationship between molecular pathways related to receptor-ligand binding and electromagnetic resonance patterns could involve the coherent organization of de-localized electrons as predicted by Cosic's Molecular Resonance Recognition model (Cosic 1994; Karbowski et al 2015).

Although 50 nT (0.5 mG) might be considered minimal (and within the range of background 60 Hz power values in many habitats) changes within this range of intensity by diminishing the static geomagnetic field (rather than superimposing the experimental field) for more protracted periods has been shown to increase the rate of asexual reproduction (fission) in planarian by Novikov et al (2007). From a biophysical perspective the energy associated with this magnetic field strength within the volume (~ 10^{-11} m^3) according to the traditional relationship of $E=B^2 \cdot (2\mu)^{-1}$ m^3 where B is the field strength, μ is magnetic permeability and m3 is volume would be about 10^{-20} J. This is within the range of energy involved with sequestering ligands as well as the quantity associated with the distance between potassium ions that contribute significantly to the resting membrane potential of the plasma membrane (Persinger 2010). If the Cosic model is applicable, then once the energies for the applied and intraorganism conditions are matched, the critical determinant is the temporal pattern for the congruent “information”. We reiterate that our fields were created by diminishing the static geomagnetic field and generating the experimental pattern within this alteration.

The observation that the synergistic amelioration of the curpizone effect on head whips (and related behaviours) occurred after the first exposure would also suggest that at least 24 hr is required for a process to emerge that would facilitate the drug-magnetic field interaction. A single exposure of 6 min to a patterned magnetic field with which there would be energetic equivalents induced within the planarian is well within the physiological time range to produce profound changes in cellular systems. For example to produce long-term potentiation (LTP) in hippocampal slices from the rodent brain a stimulation for only about 0.5 s at 100 to 400 Hz is required (Greenough 1984). LTP is considered the primary mechanism by which experience is represented within neuronal arrays through alterations in protein sequences and depositions as (primarily) dendritic spines (Biscofberger 2006). In other studies LTP, assuming the pattern of the electrical or electromagnetic sequences are appropriate, requires less than 6 min to produce changes that are maintained for days to years (Whitlock et al 2006).

We are pursuing the concept that the cuprizone will produce a demyelination-like alteration in planarian that could be manifested in a variety of behavioural indicators. By understanding this process and how the applied magnetic field reduced specific components of this process, perhaps alternative treatments could be developed for patients who exhibit MS. Cook and Persinger showed remarkable diminishment of EAE in rats exposed to this same pattern of 6 min, intermittent stimulation (Cook & Persinger 2000). In a single case study we exposed (wholebody) a middle-aged woman diagnosed with MS who was displaying moderately severe impairment to the same pattern and intensity while she was sleeping (Persinger et al 2014). Before the treatment was terminated by request, she reported conspicuous reduction of the weakness and paraesthesia of the left side of her body.

The question then becomes why do we see these behavioural changes in planaria and not vertebrates? One plausible explanation is the mechanism for action of cuprizone itself. Cuprizone does not penetrate the blood-brain barrier (BBB) as it is not detected in brain tissue of treated animals (Praet et al 2014). Planaria on the other hand do not possess a BBB. Therefore, cuprizone would enter freely into nervous tissue, perhaps enhancing its chelating effect (Ragan et al 2008). These structural differences between species may explain why behavioural changes are observed more easily in the planarian model of cuprizone demyelination than in past studies. Given the potential for periodic or transient reduction of the efficacy of the BBB in patients who are prone to or develop MS, the cuprizone model might still be applicable.

Although at this point we cannot say for certain which cellular and molecular processes are underlying these distinct changes we can hypothesize that the cuprizone invokes the same damage in planaria as rat models by causing increased oxidative stress and apoptosis of oligodendrocyte equivalents. This results in damage to the myelin and gliosis. This damage could then be halted by the effect of the patterned magnetic field. However, unlike past hypotheses suggesting it had an effect on the immune regulation in rats, we propose instead it acts to promote regenerative processes which are exacerbated in planaria due to the large number of pluripotent stem cells they possess. These observations suggest that the planarian cuprizone model may offer new insights into remyelination in multiple sclerosis due to their easily classifiable behaviours and extensive network of stem cells. Future histological, regenerative and molecular analyses may verify planaria as a superb test animal for multiple sclerosis treatments

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Chapter Three: Geomagnetic Models for Global Multiple Sclerosis Prevalence

Abstract

There is a well documented positive correlation between geographic latitude and prevalence of multiple sclerosis; however recent work has shown that the Earth's geomagnetic field may provide a better explanation for this correlation. Over two hundred regional prevalence estimates were accumulated along with geographic and geomagnetic variables for each study region including individual components of the local field. We found that the North-South component of the Earth's geomagnetic field provided a better explanation for MS prevalence when comparing each individual continent. These results support past findings that the Earth's geomagnetic field is intrinsically linked to some process that increase the probability of developing MS. The importance of controlling for the timing of prevalence estimates was also stressed when comparing a large amount of epidemiological studies reported over a large temporal span. These results indicated that the addition of a temporal lag in this analysis significantly increased the strength of the predictive models. Taken together, these models may provide clues for the development and progression of future treatments for this disease.

Keywords: Multiple sclerosis; geomagnetic static field; north-south vector; multivariate analyses

Introduction

The positive correlation between the prevalence of multiple sclerosis (MS) and geographic latitude has been well documented in the past literature (Simpson et al 2011). The commonly drawn conclusion is that because regions closer to the equator receive a greater amount of annual sunlight and with it a greater opportunity for people to produce Vitamin D. It has been hypothesized these vitamin provides an immunological effect, thus reducing the risk for an individual to have MS (Cantorna 2008). Past studies have indicated that this is not a universally linear effect. Northern and Southern Hemispheres show different trends for increasing MS prevalence (Koch-Henriksen & Sorensen 2010; Sajedi and Abdollahi 2012). Sajedi & Abdollahi (2012) demonstrated that a greater and more consistent correlation exists between geomagnetic latitude and prevalence.

The main source of the Earth's geomagnetic field is produced beneath the Earth's surface by the liquid iron core, with smaller contributions arising from mineral composition in the crust and flow of sea water. The latter exhibits a more local effect on geomagnetic field properties (Chulliat et al 2015). This natural geomagnetic environment can be perturbed by sources outside of the Earth's static magnetic field where the magnetopause interfaces with the interplanetary magnetic field and solar wind. Changes in solar wind velocity and density can cause events known as geomagnetic disturbances (GMD; Hanslmeier 2007).

The Earth's geomagnetic field also has multiple components which add to create the total field strength (in the order of 50,000 nT) at any location around the world according to the World Magnetic Model (WMM). The WMM provides four main magnetic field elements: the X, Y, Z and Horizontal components as seen in Figure 3.1, each with distinct global trends (Chulliat et al 2015). In comparison geomagnetic activity amplitudes are in the order of 20 to 500 nT.

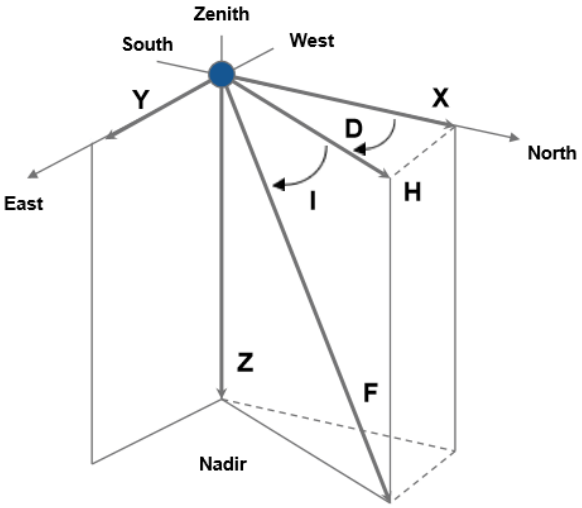

Figure 3.1. Representation of the components of the Earth's geomagnetic field. Reprinted from The US/UK World Magnetic Model 2015-2020, by Chulliat et al, 2015.

According to the WMM (Chulliat et al 2015) and data estimates from the National Oceanic and Atmospheric Association's (NOAA) online magnetic field estimate calculator, the X element refers to the North/South component of the field, which peaks roughly around the equator and declines towards the magnetic poles. The Y element refers to the East/West component of the field, whose intensity peaks towards the poles and decreases towards the equator. The Z element which corresponds to the Vertical component of the field whose intensity increases in the positive direction towards the north pole, and negatively towards the south pole. The H (horizontal) element is the resultant vector of the X and Y elements and whose intensity decreases towards the magnetic poles. Together, these components are used to estimate the total field intensity which ranges between 22 and 67 μT or 22,000 to 67, 000 nT. The values increase towards the magnetic poles of the planet (Zhadin 2001).

Knowing this, most researchers who assess biological effects of magnetic fields in a laboratory setting manipulate these components to achieve the desired physiological effect. For example, Mekers et al (2015) demonstrated that fluctuations as small as 40 nT, or approximately 0.1% of the background field intensity, in the X component of a patterned magnetic field which simulated a geomagnetic storm could reduce behavioural symptoms of cuprizone treated planaria. Similar results were found in rats using the Experimental Allergic Encephalomyelits (EAE), and in a single participant case study (Cook & Persinger 2000; Kinoshameg & Persinger 2004; Persinger et al 2000; Persinger et al 2014). GMD's have also been correlated with changes in hormone concentrations in blood serum, changes in brain and heart electrophysiology as well as cellular behaviour. There are several examples of direct correlates with multiple sclerosis. For example geomagnetic field activity alters leukocyte activation (Jandova et al 2005) and can enhance the production of reactive oxygen species (ROS) by immunologically active cells (Cocek et al. 2008; Simko et al 2004; Walleczek 1992). Both leukocyte activity and ROS production have been implicated in the display of multiple sclerosis. Therefore, the question arises if components of the natural geomagnetic field can be used as better predictors for global prevalence of multiple sclerosis than geographic or geomagnetic latitude.

To test this hypothesis, epidemiological reports since the year 2000 were accumulated along with geographical coordinates and local geomagnetic field strength estimates to see which component of the local field was the strongest predictor for global and regional MS prevalence. A secondary question to be investigated was the effect of temporal lags between the prevalence date and the date of analysis. Due to the fact that the prevalence of MS in populations has been on a steady incline over time (Alonso & Hernan 2008; Sumelahti et al 2001), this study also aimed to propose a new method for analyzing epidemiological meta-data by controlling for the added variability caused when including data points spread over multiple decades for a disease whose prevalence demonstrates a temporal increase.

Materials and Methods

Search strategy and selection criteria

Two separate research databases (Science Direct and Scholars Portal) were searched for English scientific papers published since the year 1995. This date was selected in an attempt to maintain consistent diagnostic criteria between studies. The keywords used in the searches were "prevalence" or "epidemiology" and "multiple sclerosis." Studies were deemed appropriate if they contained a clear prevalence date and estimate, geographic location which the study occurred and clear diagnostic criteria. Papers which did not meet these standards, focused only on a certain portion of society (race, gender, etc), or which generated an estimate based on five or less patients were excluded from the analysis. Papers were also visually examined for previous prevalence reports for the same study region, and this data was also recorded; however only the most recent estimate for each region was included in the main study. A summary of studies which included a previous prevalence estimate are outlined in Table 3.1.

Geographic and Geomagnetic Data

Geographical coordinates for each study centre were obtained from worldatlas.com. This geographic data was then entered into the National Oceanic and Atmospheric Association's (NOAA) online magnetic field estimate calculator (www.ngdc.noaa.gov/geomag-web), with elevation set to 0, and dates encompassing January 1st, 2015 to December 31st, 2015, thereby creating an annual estimate for the total magnetic field, and each of the four components (Horizontal, North/South, East/West and Vertical). The absolute values for each geographic and geomagnetic variable were used for this analysis. A summary of all included studies, along with the geographic variables can be found in Table 3.2.

Table 3.1. Summary of studies which included an earlier estimate of prevalence. Prevalence figures are reported as cases per 100,000.

			Current Estimate		Previous Estimate	
Reference	Country	Region	Year	Prevalence	Year	Prevalence
Barnett et al 2003	Australia	Newcastle	1996	59.1	1981	38
Cristiano et al 2016	Argentina	Buenos Aires	2010	38.2	1996	19.8
Simpson Jr et al 2011	Australia	Hobart Tasmania	2009	121.55	2001	110.4
Finkelsztejn et al 2014	Brazil	Sao Paula	1997	15	1990	4.27
Warren et al2008	Canada	Alberta	2004	357.6	2002	335
Hader & Yee 2007	Canada	Saskatoon	2014	298.3	1999	248
El Adssi et al 2012	France	Lorraine	2008	170.9	2004	123.7
Klupka-Saric & Galic, 2010	Herzegovina	Caplijina	2006	42.3	2003	36.1
Klupka-Saric & Galic, 2010	Herzegovina	Konjic	2006	27.5	2003	29.9
Klupka-Saric & Galic, 2010	Herzegovina	Ljubuski	2006	24.9	2003	22.6
Klupka-Saric & Galic, 2010	Herzegovina	Mostar	2006	35.05	2003	31.2
Klupka-Saric & Galic, 2010	Herzegovina	Posusje	2006	49.6	2003	55.8
Klupka-Saric & Galic, 2010	Herzegovina	Prozor	2006	36.7	2003	34.6
Klupka-Saric & Galic, 2010	Herzegovina	Siroki-brjeg	2006	26.8	2003	13.3
Zsiros et al 2014	Hungary	Csongrad	2013	89.8	1999	62
Lonergan et al 2009	Ireland	Wexford County	2006	290.26	2001	120.7
Alter et al 2006	Israel		2000	44.03	1995	40.15
Nicoletti et al 2005	Italy	Catania, Sicily	1999	91.81	1995	58.51
Solaro et al 2015	Italy	Genoa	2007	148.5	1997	94
Montomoli et al 2002	Italy	Provencia di Nuoro	1998	156.78	1994	151.9
Massa et al 2007	Italy	Sardinia	2005	171	1999	144.4
Houzen et al 2012	Japan	Tokachi Province	2011	16.22	2006	13.11
Alroughani et al 2014	Kuwait		2011	85.05	2000	18.54
Taylor et al 2008	New Zeland	Bay of Plenty	2006	48.79	2001	37.5
Grytten et al 2015	Norway	Hordaland	2013	210	2003	150.8
Grytten et al 2015	Norway	Nord-Trondelag	2013	225	2001	163.6
Grytten et al 2015	Norway	Oppland	2013	250	2002	174.4
Grytten et al 2015	Norway	Oslo	2013	209	2005	148
Grytten et al 2015	Norway	Troms and Finnmark	2013	207	1993	73
Kurtzke 2015	Qatar		2010	68	2002	24.12
Malkova et al 2006	Russia	Novosibirsk city	2003	54.4	1997	49.3
Mallada-Frechin et al 2008	Spain	Nlcoy	1997	41.29	1988	17.18
Aladro et al 2005	Spain	La Palma	2002	77.46	1998	42
Svenningsson et al 2015	Sweden	Vasterbotten	2010	215	1997	154
Simpson Jr et al 2015	UK	Isle de Man	2011	179.89	2007	142.4
Ford et al 2002	UK	Leeds	1999	108.7	1996	84
Mayr et al 2003	USA	Olmstead County	2000	176.6	1985	159.77
Neuberger et al 2004	USA	Sugarcreek	2001	115	2000	87

Table 2. Summary of epidemiological reports. Prevalence is reported as cases per 100,000.

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Melcon et al 2008	Argentina	Argentinian Patagonia	-41.81	68.91	2002	17.2
Cristiano et al 2016	Argentina	Buenos Aires	-34.6	58.38	2010	38.2
Risco et al 2011	Argentina	Oliva	-32.04	63.57	2003	88
Risco et al 2011	Argentina	Trelew	-43.25	65.31	2002	13.4
Simmons et al 2001	Australia	Canberra	-35.28	149.13	1996	70.6
Simmons et al 2001	Australia	Capital Territory	-35.47	149.01	1996	57.14
Simpson Jr et al 2011	Australia	Hobart Tasmania	-42.88	147.33	2009	121.55
Barnett et al 2003	Australia	Newcastle	-32.93	151.78	1996	59.1
Milanov et al 1997	Bosnia	Trojan	44.24	18.47	1995	39.14
Risco et al 2011	Brazil	Arapongas	-23.42	51.43	2003	14
Finkelsztejn et al 2014	Brazil	Belo Horizonte	-19.92	43.94	2001	18.1
Finkelsztejn et al 2014	Brazil	Botucatu	-22.88	48.44	2001	17
Risco et al 2011	Brazil	Londrina	-23.3	51.17	2003	13.8
Finkelsztejn et al 2014	Brazil	Recife	-8.05	34.88	2002	1.36
Finkelsztejn et al 2014	Brazil	Santos	-23.96	46.33	2005	14.1
Finkelsztejn et al 2014	Brazil	Sao Paula	-23.55	46.63	1997	15
Finkelsztejn et al 2014	Brazil	Uberaba	-19.75	47.94	2008	12.5
Milanov et al 1999	Bulgaria	Samkov	42.34	23.55	1998	38.1
Milanov et al 1999	Bulgaria	Sofia	42.7	23.32	1998	43.1
Milanov et al 1997	Bulgaria	Svoge	42.96	23.34	1995	39.28
Warren et al 2008	Canada	Alberta	51.05	114.07	2004	357.6
Kingwell et al 2015	Canada	British Columbia	49.28	123.12	2008	194.9
Marrie et al 2010	Canada	Manitoba	49.9	97.14	2006	226.7
Sloka et al 2005	Canada	NL	53.14	57.66	2001	94.4
Marrie et al 2013	Canada	Nova Scotia	44.65	63.58	2010	266.9
Widdifield et al 2015	Canada	Ontario	43.65	79.38	2010	207.3
Beck et al 2005	Canada	Quebec	45.5	73.57	2000	180
Hader & Yee 2007	Canada	Saskatoon	52.13	106.67	2014	298.3
Cheng et al 2007	China	Shanghai	31.23	121.47	2004	1.39
Lai & Tseng 2009	China		35.86	104.2	2005	2.96
Cristiano et al 2008	Colombia	Antioquia	7.2	75.34	2000	1.48
Risco et al 2011	Colombia	Bogota	4.71	74.07	2002	4.41
Cristiano et al 2008	Colombia	Caldas	5.3	75.25	2000	1.58
Cristiano et al 2008	Colombia	Risarala	5.32	76	2000	4.98
Cristiano et al 2008	Colombia	Santander	6.64	73.65	2000	2.53
Glavic et al 2001	Croatia	Dubrovnik-Neretva	42.65	18.09	2001	26.86
Peterlin et al 2006	Croatia	Gorski	45.32	14.82	1999	151.9
Materljan et al 2009	Croatia	Istria	45.13	13.9	2001	61.01
Materljan et al 2009	Croatia	North Adriatic Islands	43	15	2001	56.07

Table 2 Continued

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Cabadaj 1998	Czech republic	Okres Teplice	50.66	13.75	1998	130.53
Eaton et al 2010	Denmark		56.26	9.5	2006	189
Risco et al 2011	Ecuador	Cuenca	-2.9	79	2006	0.75
Risco et al 2011	Ecuador	Guayaquil	-0.12	79.92	2006	2.26
Risco et al 2011	Ecuador	Quito	-0.18	79.47	2006	5.05
Kurtzke 2015	Egypt	Red Sea	27	30	2012	14
Sarasoja et al 2004	Finland	Central (Jyvaskyla)	62.24	25.75	2000	105
Tienari et al 2004	Finland	Seinajoki-North	63	22.5	1993	136
Tienari et al 2004	Finland	Seinajoki-South	62	23.4	1993	219
Tienari et al2004	Finland	Vassa	63.1	21.62	1993	107
Formont et al 2010	France	Alsace	48.32	7.44	2004	112
Formont et al 2010	France	Aquitaine	44.7	0.3	2004	87.9
Formont et al 2010	France	Auvergne	45.7	3.34	2004	101.5
Formont et al 2010	France	Basse Normandie	48.89	0.52	2004	98
Formont et al 2010	France	Bourgogne	47.05	4.38	2004	116.2
Formont et al 2010	France	Bretagne	48.2	2.93	2004	94.7
Formont et al 2010	France	Centre	47.75	1.68	2004	103.1
Formont et al 2010	France	Champagne-Ardenne	48.79	4.47	2004	122.9
Formont et al 2010	France	Corse	42.04	9.01	2004	81.1
Formont et al 2010	France	Franche Comte	47.13	6.02	2004	115.3
Formont et al 2010	France	Haute Normandie	49.52	0.88	2004	94.7
Sagnes-Raffy et al 2010	France	haute-garonne	43.4	1.14	2005	106.07
Formont et al 2010	France	Ile de la France	48.3	2.3	2004	84.3
Formont et al 2010	France	Languedoc Roussillon	43.59	3.26	2004	83.1
Formont et al 2010	France	Limousin	45.89	1.57	2004	93.2
El Adssi et al 2012	France	Lorraine	48.87	6.21	2008	170.9
Formont et al 2010	France	Midi Pyrenees	44.09	1.52	2004	87.4
Formont et al 2010	France	Nord pas de Calais	50.48	2.79	2004	113.3
Formont et al 2010	France	PACA	43.94	6.07	2004	84.1
Formont et al 2010	France	Pays de Loire	47.76	0.33	2004	86.7
Formont et al 2010	France	Picardie	49.66	2.53	2004	116.8
Formont et al 2010	France	Poitou Charente	45.9	0.31	2004	85.5
Formont et al 2010	France	Rhone Alpes	45.17	5.45	2004	87.3
Piperidou et al 2003	Greece	Evros Prefectur	41.1	26.05	1999	38.9
Ntaleva-Parcharidou et al 2009	Greece	Nomos Kavalos	40.94	24.4	2008	38.6
Papathanasopoulos et al 2008	Greece	Western	38.51	21.57	2006	119.61
Cabre et al 2005	Guadeloupe		16.27	61.55	1999	8.5
Klupka-Saric & Galic, 2010	Herzegovina	Caplijina	43.11	17.71	2006	42.3

Table 2 Continued

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Klupka-Saric & Galic, 2010	Herzegovina	Konjic	43.65	17.96	2006	27.5
Klupka-Saric & Galic, 2010	Herzegovina	Ljubuski	43.2	17.55	2006	24.9
Klupka-Saric & Galic, 2010	Herzegovina	Mostar	43.34	17.81	2006	35.05
Klupka-Saric & Galic, 2010	Herzegovina	Posusje	43.47	17.33	2006	49.6
Klupka-Saric & Galic, 2010	Herzegovina	Prozor	43.82	17.61	2006	36.7
Klupka-Saric & Galic, 2010	Herzegovina	Siroki-brjeg	43.38	17.59	2006	26.8
Cseh & Valikovics 2007	Hungary	Borsod-abauj-zemple	48.29	20.69	2006	68
Zsiros et al 2014	Hungary	Csongrad	46.42	20.26	2013	89.8
Benedikz et al 2002	Iceland		64.96	19.02	1999	119.12
Kurtzke 2015	Iran	E Azerbajan Pr	37.9	46.27	2009	28
Izadi et al 2015	Iran	Fars Province	29.1	53.05	2013	72.1
Etemadifar & Maghzi 2011	Iran	Isfahan	32.65	51.67	2010	73.3
Kurtzke 2015	Iran	Kerman	30.28	57.08	2013	32
Kurtzke 2015	Iran	Mazandran Pr	36.23	52.53	2007	20
Kurtzke 2015	Iran	N. Khorasan Pr	37.47	57.1	2011	13
Kurtzke 2015	Iran	Qom	34.64	50.88	2011	50
Moghtaderi et al 2013	Iran	Sistan Province	27.53	60.58	2010	13.96
Kurtzke 2015	Iran	Tehran	35.69	51.69	2011	74
Al-Himyari 2009	Iraq		33.22	43.68	2008	43.8
McGuigan et al 2004	Ireland	Donegal County	54.65	8.1	2001	184.6
Lonergan et al 2009	Ireland	Dublin	53.35	6.26	2006	127.8
Lonergan et al 2009	Ireland	Wexford County	52.34	6.46	2006	290.26
Alter et al 2006	Israel		31.05	34.85	2000	44.03
Salemi et al 2000	Italy	Bagheria City (Sicily)	38.08	13.51	1994	49.4
Nicoletti et al 2005	Italy	Catania, Sicily	37.51	15.08	1999	91.81
Valiani et al 1998	Italy	Cava de Tirreni	40.7	14.71	1998	54.55
Grimaldia et al 2007	Italy	Commune di Caltanissetta	37.49	14.06	2002	165.79
Grimaldo et al 2001	Italy	Enna, Sicily	37.52	14.38	1995	120.2
Granieri et al 2007	Italy	Ferrara	44.84	11.62	2004	120.93
Millefiorini et al 2010	Italy	Frosinone	41.66	13.63	2007	95
Solaro et al 2015	Italy	Genoa	44.41	8.95	2007	148.5
Totaro et al 2000	Italy	L'Aquilla	42.35	13.4	1996	53
Bargagli et al 2016	Italy	Lazio	41.66	12.99	2011	130.5
Nicoletti et al 2005	Italy	Linguaglossa, Sicily	37.84	15.14	2001	203
Ragonese et al 2004	Italy	Monreale	37.92	13.24	2000	71.2
Valiani et al 1998	Italy	Napoli	40.85	14.27	1998	25

Table 2 Continued

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Ranzato et al 2003	Italy	Padova	45.41	11.88	1999	80.5
Bergamaschi et al 2006	Italy	Pavia	45.18	9.16	2000	94
Montomoli et al 2002	Italy	Provencia di Nuoro	40.33	9.46	1998	156.78
Luliano & Napoletano 2008	Italy	Salerno	40.67	14.81	2005	71.62
Granieri et al 2008	Italy	San Marino	43.56	12.27	2005	166.7
Massa et al 2007	Italy	Sardinia	40.12	9.01	2005	171
Valiani et al 1998	Italy	Sorrento Province	40.37	14.22	2009	53.33
Gajofatto et al 2013	Italy	Verona	45.44	10.99	2001	106.6
Itoh et al 2003	Japan	Asahikawa	43.77	142.36	2002	102
Houzen et al 2012	Japan	Tokachi Province	42.55	143.12	2011	16.22
El-Salem et al 2006	Jordan		30.59	36.24	2004	39.21
Alroughani et al 2014	Kuwait		29.31	47.48	2011	85.05
maclcience 2004	lithuania	Kaunas	54.9	23.9	2002	55.2
Dean et al 2002	Malta		35.94	14.38	1999	16.7
Cabre et al 2005	Martinique		14.64	61.02	1999	21
Taylor et al 2008	New Zeland	Auckland	-36.85	174.76	2006	56.4
Taylor et al 2008	New Zeland	Bay of Plenty	-37.68	176.19	2006	48.79
Taylor et al 2008	New Zeland	Canterbury	-43.75	171.16	2006	108.11
Taylor et al 2008	New Zeland	Hawkes Bay	-39.77	176.74	2006	58.82
Taylor et al 2008	New Zeland	Otago	-44.83	169.63	2006	134.19
Taylor et al 2008	New Zeland	Tasman	-41.21	172.73	2006	87.21
Graw et al 2008	North ireland	Moyle	55.2	6.25	2004	230.6
Grytten et al 2015	Norway	Akershus	60	11.37	2013	142
Grytten et al 2015	Norway	Buskerud	60.48	8.7	2013	229
Grytten et al 2015	Norway	Hordaland	60.27	5.72	2013	210
Grytten et al 2015	Norway	More and Pomsdal	62.97	8.02	2013	275
Grytten et al 2015	Norway	Nordland	67.1	14.57	2013	190
Grytten et al 2015	Norway	Nord-Trondelag	64.44	11.75	2013	225
Grytten et al 2015	Norway	Oppland and Hedmark	61.54	9.72	2013	250
Grytten et al 2015	Norway	Oslo	59.91	10.75	2013	209
Grytten et al 2015	Norway	Ostfold	59.26	11.33	2013	201
Grytten et al 2015	Norway	Rogaland	59.15	6.01	2013	176
Grytten et al 2015	Norway	Sogn and Figordane	59.96	10.75	2013	242
Grytten et al 2015	Norway	Sor-Tronderlag	63.01	10.35	2013	242
Grytten et al 2015	Norway	Telemark	59.39	8.32	2013	206
Grytten et al 2015	Norway	Troms and Finnmark	69.65	18.96	2013	207
Grytten et al 2015	Norway	Vest-Agder	58.37	6.9	2013	230
Grytten et al 2015	Norway	Vestfold	59.17	10.11	2013	196
Al-Hashel et al 2008	Oman		21.51	55.92	2000	4
Risco et al 2011	Panama		8.54	80.78	2005	5.24

Table 2 continued

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Risco et al 2011	Peru	Lima	-12.05	77.04	2007	7.69
Lobinska & Stelmasiak 2004	Poland	lublin	51.25	22.57	1997	57.29
De Sa et al 2006	Portugal	Santarem	39.24	8.69	1999	46.3
Kurtzke 2015	Qatar		25.35	51.18	2010	68
Balasa et al 2007	Romania	Mures judet	46.56	24.67	2006	26.1
Karnaukh 2009	Russia	Amur oblast	54.6	127.48	2005	32.3
Bakhtiiarova & Magzhanoc 2006	Russia	Bashkortostan	54.23	56.16	2004	31.3
Malkova et al 2006	Russia	Novosibirsk city	55.01	82.94	2003	54.4
Goncharova & Baliazin 2007	Russia	Rostov	47.24	39.7	2007	22.84
Sivertseva et al 2006	Russia	Tiumen	57.16	65.53	2002	22.4
Dokuchaeva & Boiko 2006	Russia	Volgograd	48.71	44.51	2000	31.9
Visser et al 2012	Scotland	Aberdeen	57.15	2.09	2009	229
Grant et al 1998	Scotland	Fife	56.21	3.15	1996	143
Murray et al 2004	Scotland	Glasgow	55.86	4.25	1998	144.97
Rothwell & Charlton 1998	Scotland	Lotham and Border	55.95	3.19	1995	187
Visser et al 2012	Scotland	Orkney	58.98	2.96	2009	248
Visser et al 2012	Scotland	Shetland	60.53	1.27	2009	295
Forbes et al 1999	Scotland	tayside	56.28	2.58	1996	184
Hirst et al 2008	SE Wales	Cardiff	51.48	3.18	2005	146
Pekmezovic et al2001	Serbia	Belgrade	44.79	20.45	1996	41.5
Mallada-Frechin et al 2008	Spain	Alcoy	38.7	0.48	1997	41.29
Modrego & Pina, 2003	Spain	Baja Aragon	41.05	0.11	2003	75
Pina et al 1998	Spain	calatayud	41.35	1.65	1995	58
Moral et al 2003	Spain	costa de ponent	38.54	0.12	2001	53.82
Aladro et al 2005	Spain	La Palma	28.71	17.91	2002	77.46
Fernandez et al 2012	Spain	Malaga	36.72	4.42	2008	125
Garcia-Gallego et al 2002	Spain	Marina alta	38.78	0.04	2001	41.72
Casquero et al 2001	Spain	Menorca	39.95	4.11	1996	68.65
Benito-Leon et al 1998	Spain	Mostoles	40.32	3.87	1996	43.37
Candeliere-Merlicco et al 2016	Spain	Murica	37.99	1.13	2010	71.9
Izquierdo et al 2015	Spain	Northern Seville	37.39	5.99	2011	90.2
Otero-Romero et al 2012	Spain	Osona, Catalania	41.98	2.22	2008	49.9
Ares et al 2007	Spain	Santiago de Compostela	42.88	8.54	2003	79
Mondrego Pardo et al 1997	Spain	Tereul province	40.35	1.11	1996	32.02
Tola et al 1999	Spain	Valladolid	41.65	4.72	1997	58.3

Table 2 continued

Reference	Country	Region	Latitude	Longitude	Year	Prevalence
Sundstrom et al 2003	Sweden	Arjong	59.23	12.1	2002	277
Sundstrom et al2003	Sweden	Arvika	59.65	12.59	2002	183
Sundstrom et al 2003	Sweden	Eda	59.89	12.11	2002	150
Sundstrom et al2003	Sweden	Filipsted	59.71	14.17	2002	152
Sundstrom et al 2003	Sweden	Forshaga	59.53	13.49	2002	131
Sundstrom et al 2003	Sweden	Grums	59.35	13.11	2002	150
Sundstrom et al2003	Sweden	Hagfors	60.03	13.69	2002	152
Sundstrom et al 2003	Sweden	Hammaro	59.31	13.53	2002	119
Sundstrom et al 2003	Sweden	Karlstad	59.4	13.51	2002	182
Sundstrom et al 2003	Sweden	Kil	59.59	13.24	2002	160
Sundstrom et al 2003	Sweden	Kristinehamn	59.31	14.11	2002	113
Sundstrom et al 2003	Sweden	Munkfors	59.84	13.53	2002	171
Sundstrom et al 2003	Sweden	Saffle	59.13	12.93	2002	246
Sundstrom et al 2003	Sweden	Sotrfors	59.53	14.27	2002	130
Sundstrom et al 2003	Sweden	Sunne	59.84	13.14	2002	214
Sundstrom et al 2003	Sweden	Torsby	60.14	13.01	2002	134
Sundstrom et al 2003	Sweden	Varmland	59.73	13.24	2002	170.07
Svenningsson et al 2015	Sweden	Vasterbotten	65.33	16.52	2010	215
Celik et al 2003	Turkey	Edine City	41.68	26.56	2003	29.6
Inshasi & Thakre 2011	UAE	Dubai	25.2	55.27	2007	54.77
Spilker et al 2009	UK	Bradford	53.8	1.76	2008	334
Fox et al 2004	UK	Devon	50.72	3.53	2001	87.39
Simpson Jr et al 2015	UK	Isle de Man	54.24	4.55	2011	179.89
Ford et al 2002	UK	Leeds	53.8	1.55	1999	108.7
MacDonald et al 2000	UK	London	51.51	0.13	1996	200
Korniychuk & Zheliba 2005	Ukraine	Vinnytsia Oblast	49.23	28.47	1994	30.8
Noonan et al 2010	USA	El Paso	31.76	106.49	2003	49.4
Turabelidze et al 2008	USA	Jefferson County	39.58	105.27	2002	105
Cowen et al 2007	USA	Lawson	39.44	94.2	2002	166.9
Noonan et al 2010	USA	Lorrain County	41.41	82.13	2000	112.4
Williamson et al 2007	USA	Lubbock County	33.68	101.8	2003	71.5
Mayr et al 2003	USA	Olmstead County	44	92.38	2000	176.6
Neuberger et al 2004	USA	Sugarcreek	40.5	81.64	2001	115
Noonan et al 2010	USA	Texas	29.76	95.37	2000	47.2

Statistical analyses

To observe how the prevalence of MS has increased temporally, studies which listed a current and past prevalence date and value were accumulated, and the number of prevalent cases per year increase were noted. From this value, a percent increase in prevalence between the two epidemiological studies was found by using Equation 1 below. The percent increase was then divided by the number of years between prevalence dates to obtain an estimation of the percent increase in prevalence per year for that study region.

Equation 1:

$$\text{\% Increase in Prevalence} = \frac{(\text{Current Estimate} - \text{Previous Estimate})}{\text{Current Estimate}} \times 100\ \%$$

The main statistical test used in this analysis was the multiple regression using either a geographic (latitude) or geomagnetic (Total Field, Horizontal, North/South, East/West or Vertical) variable as the first dependent variable, along with the variable representing the number of years since the last epidemiological report as the second independent variable, and the prevalence estimate as the dependent variable. Fisher Z Tests were then used to compare the strength of the resulting correlation coefficients between regression models. One sample t-tests were also used to compare Z scores against the predicted value of zero difference between Z scores to assess model improvements. All statistical analyses were performed using IBM SPSS Version 19.

Results

Global Trends of MS Prevalence

Linear Regression models using prevalence as the dependent variable and each geographic and geomagnetic variable one at a time along with the number of years since the last prevalence date and 2016 to control for the global increase in multiple sclerosis cases around the world were created. A summary for global models can be found in Table 3.3. Regional models for the Americas can be found in Table 3.4, while models for the rest of the world can be found in Table 3.5.

Table 3.3. Results of global (N = 221) multiple regression analysis to predict prevalence using each geographic or geomagnetic variable along with the number of years since the prevalence date as independent variables.

	Global		
	R^2	F	p
Latitude	0.502	110.29	<0.001
Total	0.305	48.19	<0.001
Horizontal	0.443	87.64	<0.001
North/South	0.422	80.28	<0.001
East/West	0.147	18.97	<0.001
Vertical	0.404	74.44	<0.001

Table 3.4. Results for North America (n = 15) and South and Central America (n = 23) multiple regression analyses to predict prevalence using each geographic or geomagnetic variable along with the number of years since the prevalence date as independent variables.

	North America			South and Central America		
	R^2	F	p	R^2	F	p
Latitude	0.652	12.18	0.001	0.336	5.32	0.013
Total	0.721	16.79	<0.001	0.150	1.85	0.183
Horizontal	0.678	13.68	0.001	0.240	3.32	0.056
North/South	0.671	13.26	<0.001	0.209	2.77	0.085
East/West	0.396	4.27	0.038	0.012	0.13	0.878
Vertical	0.714	16.25	<0.001	0.026	0.28	0.759

Table 3.5. Results from Western Europe (n = 117), Eastern Europe and Russia (n = 32), Asia and the Middle East (n = 16) and Australia and New Zealand (n = 10) multiple regression analyses to predict prevalence using each geographic or geomagnetic variable along with the number of years since the prevalence date as independent variables.

	Western Europe			Eastern Europe and Russia			Asia and the Middle East			Australia and New Zeland		
	R^2	F	p	R^2	F	p	R^2	F	p	R^2	F	p
Latitude	0.549	70.02	<0.001	0.003	0.05	0.956	0.096	0.74	0.495	0.819	15.83	0.003
Total	0.539	67.22	<0.001	0.028	0.44	0.650	0.100	0.78	0.478	0.780	12.41	0.005
Horizontal	0.551	70.70	<0.001	0.004	0.06	0.947	0.094	0.73	0.500	0.877	25.06	0.001
North/South	0.551	70.51	<0.001	0.005	0.07	0.930	0.094	0.73	0.500	0.909	34.95	<0.001
East/West	0.265	20.73	<0.001	0.142	2.49	0.100	0.097	0.75	0.489	0.340	1.80	0.233
Vertical	0.536	66.51	<0.001	0.021	0.32	0.730	0.094	0.72	0.503	0.814	15.27	0.003

Increases in MS Prevalence

The percent increase in prevalence data was grouped into regions, and a one-way analysis of variance (ANOVA) revealed no significant differences between regions as demonstrate in Figure 3.2. To confirm that temporal lags can influence prevalence estimates, the strength of the two models were compared using the Fisher Z-Test, with positive Z scores indicating that using the two variables resulted in a greater R value. Results for the global data can be found in Figure 3.3. Since there were consistent (however insignificant) differences between R values for the entire globe, the same analysis was done for each of the six study regions. Fisher Z scores for each group were then compared with a one sample t-test to measure the deviation from the predicted value of zero between the models. A summary of results are found in Table 3.6.

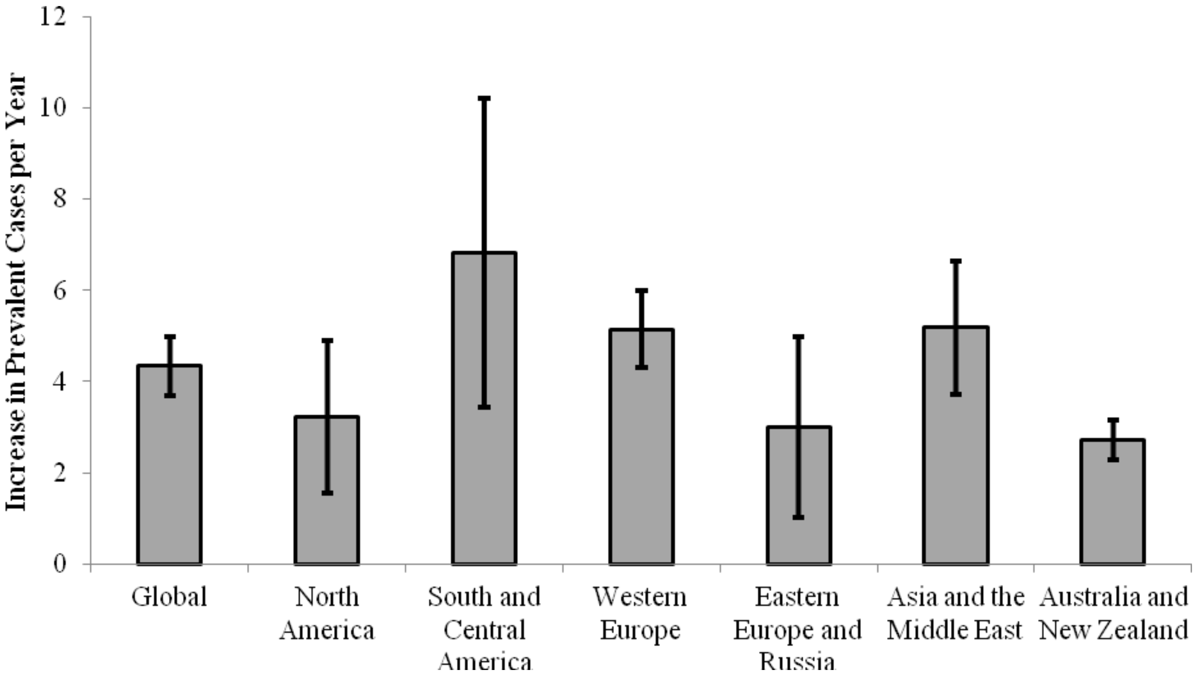

Figure 3.2. Mean percent increase of prevalent MS cases per year for the globe and each geographic region. Results are displayed as Mean ± SE.

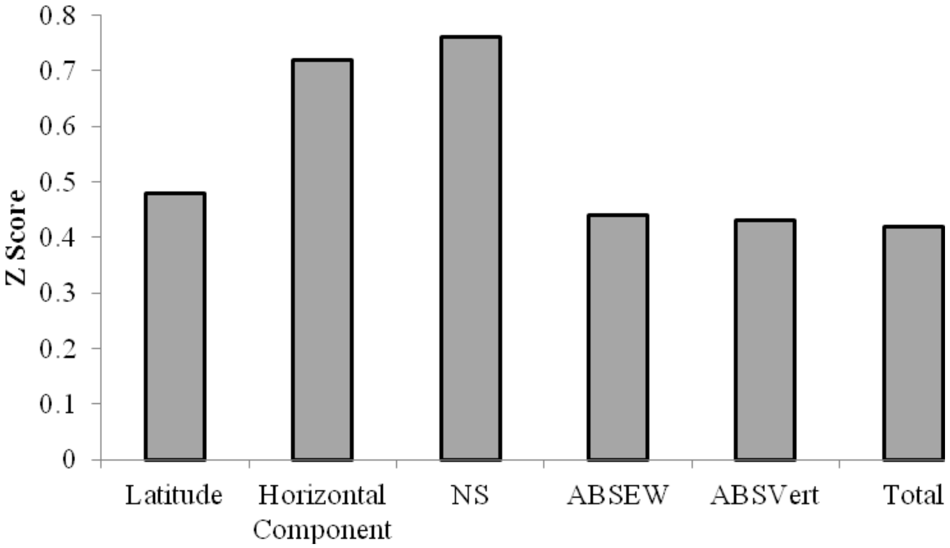

Figure 3.3. Increase in correlation strength by accounting for the temporal lag between the last prevalent estimate and 2016.

Table 3.6. Significant increases in model strength for various geographic and geomagnetic variables.

	t(6)	*p*
Latitude	2.66	0.045
Horizontal	2.38	0.063
North/South	3.31	0.021
East/West	1.86	0.123
Vertical	3.43	0.019
Total	2.48	0.056

Geomagnetic Variable vs Latitude

Geomagnetic variable correlation coefficient (R) values for prevalence from the above multiple regression analysis for each study region were compared against the correlation coefficient for latitude and prevalence using the Fisher Z-Test. The results from the Fisher comparisons were grouped for each geomagnetic variable, and then compared to a predicted value of zero using a one sample t-test. The results of this analysis can be found in Table 7, demonstrating the raw effect, as well as effect after the removal of the outlier data point of South and Central America.

Table 3.7. Difference between latitudinal and geomagnetic correlation strengths. t(6) includes all study regions while t(5) excludes an outlier.

	t(6)	p	t(5)	p
Total	-0.32	0.759	0.72	0.513
Horizontal	0.24	0.821	1.46	0.217
North/South	0.32	0.763	1.28	0.269
East/West	-1.62	0.167	-1.15	0.314
Vertical	0.66	0.540	0.92	0.411

Discussion

Although the latitudinal gradient has been well established for MS prevalence on a global scale, some more regional studies have demonstrated contradictory evidence against this theory (Forbes et al 1999; Pugliatti et al 2006). The above analysis indicates that geomagnetic activity as a global model for MS prevalence accounts for less variance than the typical latitudinal gradient; however, it can be a better predictor for MS prevalence on a more local scale. This relationship provides an explanation as to why epidemiological studies completed for a smaller geographical region have demonstrated mixed results of an established prevalence gradient. This thereby supports the idea that local latitudinal gradient has a lower impact on the prevalence of this disease than another environmental variable. While the results of the t-tests comparing the differences in correlation strengths between latitudinal and geomagnetic models were insignificant, one must remember that these two variables share a high degree of inter-correlation ($p < 0.001$). The additional variance explained by the geomagnetic component variables should not be considered trivial. The possibility that this component's actual effects may be masked by geographical confounds cannot be excluded.

This analysis also stresses the importance of controlling for the timing of an epidemiological report when comparing multiple studies, especially for those completed over a span of decades. For example, multiple sclerosis has been increasing temporally for a large number of possible reasons. One reason for the increased prevalence estimates is the changing of diagnostic criteria. This sensitivity has increased with the advent of new diagnostic tools such as Magnetic Resonance Imaging (Macdonald et al 2001). It is for this reason that many correlations reported by past epidemiological reports may not be an accurate representation of present day latitudinal trends. The increase in crude prevalence of the disease also points to improvements in the treatment of the disease thereby prolonging the lives of patients. Increased environmental risks for the disease would support the hygiene hypothesis for the development of autoimmune diseases and would add additional variability that could attenuate the apparent contribution from geomagnetic latitude.

The hygiene hypothesis posits that due to increased vaccination and sanitation in our industrialized societies children are no longer required to overcome as many illnesses during their youth (Rook 2012). This increase in immunity at an early age prevents the complete development of networks of our immune system (Correale 2009), thereby increasing the prevalence of numerous autoimmune diseases in society including allergies, asthma and of course multiple sclerosis. Rook (2012) outlined a timeline of organism removal from the human body that are thought to be implicated in immune regulation. When considering the timeline of societal industrialization, the time in which helminthes and nematodes were evicted from their resident human hosts, corresponds exactly to the time of a drastic increase in prevalence of multiple sclerosis across the globe (Rook 2012). A similar trend was noted for the increase in global allergies to pollens. This important facet in the history of multiple sclerosis lays the basis for helminth therapy to treat the disease by re-establishing the presence of these parasitic worms in the host (Weinstock & Elliott 2009). This form of therapy has been shown to decrease the exacerbation of the disease symptoms, as well as lessen the amount of brain lesions in both human as rat studies of experimental allergic encephalitis (EAE; Schwartz & Westbrook 2000; Weinstock & Elliott 2009).

The evidence of the correlation between the Earth's geomagnetic field and prevalence as well as the increased prevalence of multiple sclerosis over time suggest there may be an advantage to combination therapy to treat this disease based on two natural environmental approaches. Consider for a moment the model organism used by Mekers et al (2015) – the planarian flatworm. This organism has an extensive network of pluripotent stem cells (neoblasts) which give them an incredible ability to regenerate damaged body parts (Gentile et al 2011; Wagner et al 2011). It appears that changes in the geomagnetic field activated these cells to repair damage caused by cuprizone. An extension of this would imply that in previous EAE rat studies, the applied weak 7 Hz, 40 nT field worked to restore damaged myelin to reduce motor symptoms, not as an influence on the immunological attack of nervous tissue. Perhaps by reducing the immunological disequilibrium via helminth therapy in combination with activating repair mechanisms through magnetic field treatment, progression of the disease could be more significantly slowed by this dual system approach.

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Chapter Four: Geomagnetic Influences on Curling Performance: Evidence from Physiological and Performance Measurements

Abstract

Geomagnetic activity has been correlated with physiological changes in humans including alterations in heart rate variability and brain activity. These fluctuations can cause an effect on the individual as a whole including risk for cardiovascular disease or motor/cognitive control. This case study aimed to investigate the effect of geomagnetic disturbances on the performance and electrophysiology of a curling athlete. We found that performance was negatively correlated with geomagnetic activity, as well as heart rate variability. We also confirmed electroencephalographic changes in the right temporal lobe (parahippocampal gyrus) during geomagnetic disturbances which have been reported in previous correlational studies. These clear changes in athlete physiology and the resultant effect on performance may be the basis for new performance enhancement and training avenues in sport.

Keywords: *geomagnetic activity; athletic performance; curling; quantitative electroencephalography.*

Introduction

The Earth's geomagnetic field is generated by electrical currents in the Earth's core with flux lines which extend to form the magnetosphere around the globe. The geomagnetic field acts as a shield protecting the Earth from a majority of the solar wind produced by the sun. During times of high solar activity, there is a greater variable pressure exerted on the geomagnetic field which increases and decreases a small proportion of the strength of the local geomagnetic field on the Earth's surface. Theses changes are in the order of 0.1 to 1% the intensity of the static field component which is about 50,000 nT. The temporal components of these shifts in magnitude are in the order of minutes to tens of minutes.

The enhanced magnetic field has been shown to effect communication and computer systems around the world (Fournier & Persinger 2004; Pirjola & Viljanen 2000). There are two common scales for defining geomagnetic field strengths, the Ap and Kp index (Palmer et al 2006). The Kp index is measured in three hour intervals throughout the day on a scale of 0-9 where 0 is very low geomagnetic activity and 9 presents extremely high activity. The Ap index is a daily measurement which is derived from the Kp index and represents an entire days worth of geomagnetic activity (Gmitrov & Gmitrova 2004).

Although often not thought as an environmental factor which influences human behaviour, fluctuations in the earth's geomagnetic field have been suggested to influence human activity both directly and indirectly. From one perspective the human brain can be considered an "electrical system" similar to that of computers and electronic aggregates. For example, perturbations in the magnetic field strength as small as 20-100 nanoTesla (approximately 0.1% of the total geomagnetic field intensity) have been shown to be correlated with emotion (Babayev & Allahverdiyeva 2007), motor and cognitive skills (Alania et al 2001; Fournier &

Persinger 2004), the report of psi phenomena (Arango & Persinger 1988; Krippner & Persinger 1996; Schaut & Persinger, 1985) which is strongly associated with temporal lobe electrical sensitivity, physiological measurements such as electroencephalographic (EEG; Mulligan & Persinger 2012; Sastre et al. 2002), electrocardiographic (ECG) variations (Dimitrova 2008; Dimitrova & Stoilova 2003) and biochemical fluctuations such as melatonin secretion (Weydahl et al 2001). For the most part the effective component is the pattern of the extremely low frequency variation whereas changing the intensity of the pattern has a smaller effect.

Most of the current research focuses on how geomagnetic variations can influence human health (primarily vascular diseases). Very little work demonstrates how geomagnetic activity affects human activities such as athletic performance. The field of neurofeedback training has dominated the scientific branch of sport psychology over the past few decades. There is also evidence that local geomagnetic activity can cause similar changes in electrophysiological recordings in human brains that are targeted in some of these training regimes. Besides neurofeedback EEG training, there has recently been an emphasis in biofeedback training using heart rate variability (HRV) including reducing competition anxiety (Paul & Garg 2012), to decreasing the recovery time in athletes by training an athlete to increase their parasympathetic activation (Nolan et al 2005). In addition, electroencephalographic changes and enhanced parasympathetic activation have been correlated with geomagnetic activity (Otsuka et al 2000). Therefore, one may hypothesize that there may be an intrinsic relationship between our neurological, and cardiovascular systems with global geomagnetic activity. In fact, Reid et al. (2013) have demonstrated increases in the sensiromotor Rhythm (SMR) which is a marker of a relaxed cortical state in athletes, by using biofeedback HRV training. Through both of these relationships, it can be expected that an athlete's performance should vary depending on the geomagnetic activity through the interactions of the cortex with the magnetic environment.

The following longitudinal case study of a varsity athlete aimed primarily to experimentally verify previously reported relationships between electrophysiological measurements and global geomagnetic activity, and secondly to assess how changes in geomagnetic, electrophysiological and mood disturbance might influence sporting performance using curling as a model.

Materials and Methods

Participant

The participant in this study (BM) was a 23 year old right handed male university student who was also a varsity athlete. He was an experienced curler having curled for fifteen years, ten of which were at a competitive provincial level. He had no history of neurological or cardiological illnesses which would have influenced electroencephalographic (EEG) or electrocardiographic (ECG) recordings.

Experimental Procedure

The varsity team which the participant curled played in a local competitive league which occurred every Tuesday of the week at 1830 h local time. The afternoon of each game day between 1230 – 1400 h local time, the participant went into the laboratory for both electroencephalographic and electrocardiographic baseline recordings. That evening the athlete also completed the Profile of Mood State (POMS) short form prior to the start of the game. Throughout the game, performance statistics were recorded using Curlbook software.

EEG Measurements

EEG data were recorded using a Mitsar-201 portable QEEG equipped with an electrode cap (Electrode-Cap International) which had 19 channels following the International 10-20 System (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2). Impedance was kept under 10 kΩ and electrophysiological data was sampled at 250 Hz and acquired using WinEEG software. Five minutes of eyes open recordings were taken simultaneously with the ECG recording followed by three minutes of eyes closed recordings. Data were corrected for eye-blink artefacts using ICA in WinEEG and three clean, thirty second epochs were spectrally analyzed for raw power in μV^2 for the main frequency bands (theta, alpha, beta1, beta2, and gamma) and exported to statistical software for further analysis.

ECG Measurements

Electrocardiograph (ECG) samples of 5 minutes each were recorded at a sample rate of 250 Hz using single lead (two sensors) Covidien Kendall H135SG disposable ECG electrodes connected to a Mitsar-201 amplifier. Data were recorded with WinEEG v2.103.7 software and exported for additional processing. Automatic QRS peak detection was carried out with ARTiiFACT v2.05 software (Kaufmann et al., 2011) for calculation of R-R intervals in ms. Any artefacts were corrected using a cubic spline interpolation. Standard time domain descriptors of heart rate variability (HRV) were calculated for each time series including the mean R-R interval (*mNN*), standard deviation of R-R intervals (*SDNN*), and the root mean square of successive differences between R-R intervals (*RMSSD*). Additionally, time series were resampled (4 Hz interpolation) within ARTiiFACT for fast Fourier transform (FFT) from which popular frequency domain measures of HRV were derived including very low frequency (*VLF* = 0.003 to

0.04 Hz), low frequency (*LF* = 0.04 to 0.15 Hz), and high frequency components (*HF* = 0.15 to 0.40 Hz), along with the ratio of low frequency to high frequency power (*LF/HF*).

Profile of Mood States

The POMS-SF was utilized for this experiment. This questionnaire consists of 30 words which the subject is instructed to rate how accurate the word describes their current mood state on a likert scale where 0 = not at all to 4 = Extremely. Data were accumulated and grouped into six subscales (tension, depression, anger, vigor, fatigue and confusion) to analyze total mood disturbance on that day.

Curling Performance

Overall shooting accuracy was differentiated into multiple categories based on the type of shot (draw or takeout), and the direction the rock is rotated (in-turn = clockwise rotation and out-turn = counter-clockwise rotation). The type and direction for each shot was recorded as well as a performance rating which was scored on a four point scale where zero represents a complete miss and a score of four represents a perfect shot. The numbers of shots which fall into the respective performance categories were accumulated for each game, and the shooting accuracy was found by dividing the number of performance points by the number of possible performance points and multiplying by 100% to get a shooting percentage. For example, if an athlete threw five out-turn takeouts during a game, and the statistician scored him 4/4, 2/4, 3/4, 2/4 and 0/4 for these shots, then the shooting percentage for out-turn takeouts would be 11/20 x 100% or 55%.

Activity Measurements

The subject wore an activity tracker wristband throughout the course of the experiment which recorded ambulatory data as well as sleep patterns for the subject. Variables from the wristband which were included in this study were distance travelled day of and day prior to a game, time asleep the night before and the night two days prior to the game, as well as the times awoken the night before and the night two days prior to the game day.

Geomagnetic Activity

The daily global Ap index was recorded for the day of the game as well as four days prior to the day was retrieved from the National Oceanic and Atmospheric Administration (NOAA) data site (ftp://ftp.swpc.noaa.gov/pub/indices/old_indices). The eight 3-hour kp index measures for the day of the game were also retrieved from the same location.

Statistical analyses

This study is a longitudinal correlational case study of one participant. Statistical analyses included correlations between the geophysical and biological variables mentioned above, as well as linear regression models to predict performance measures. All statistical analyses were performed using IBM SPSS Version 19.

Results

Shooting Accuracy

Performance was broken down into five measures; overall, in turn, out-turn, takeout and draw percentages. Means and standard deviations for each of the performance measures from all fourteen games are summarized in Table 4.1.

Table 4.1. Mean shooting accuracies for all five categories of performance.

Performance Measure	Mean Percentage	Standard Deviation
Overall	60.00	11.35
In-turn	59.96	13.27
Out-turn	60.39	17.70
Takeout	66.63	18.09
Draw	55.70	21.09

Geomagnetic Activity and Performance

There was a significant negative correlation between the 8-hour kp index within the time of the game and in turn performance (R = - 0.550, $p = 0.042$) as seen in Figure 4.1. There was also a similar correlation between the Ap index two days prior and in turn performance (R = -0.643, p = 0.013).

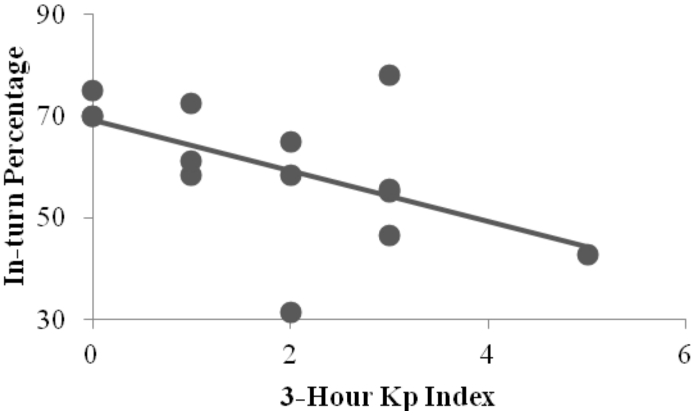
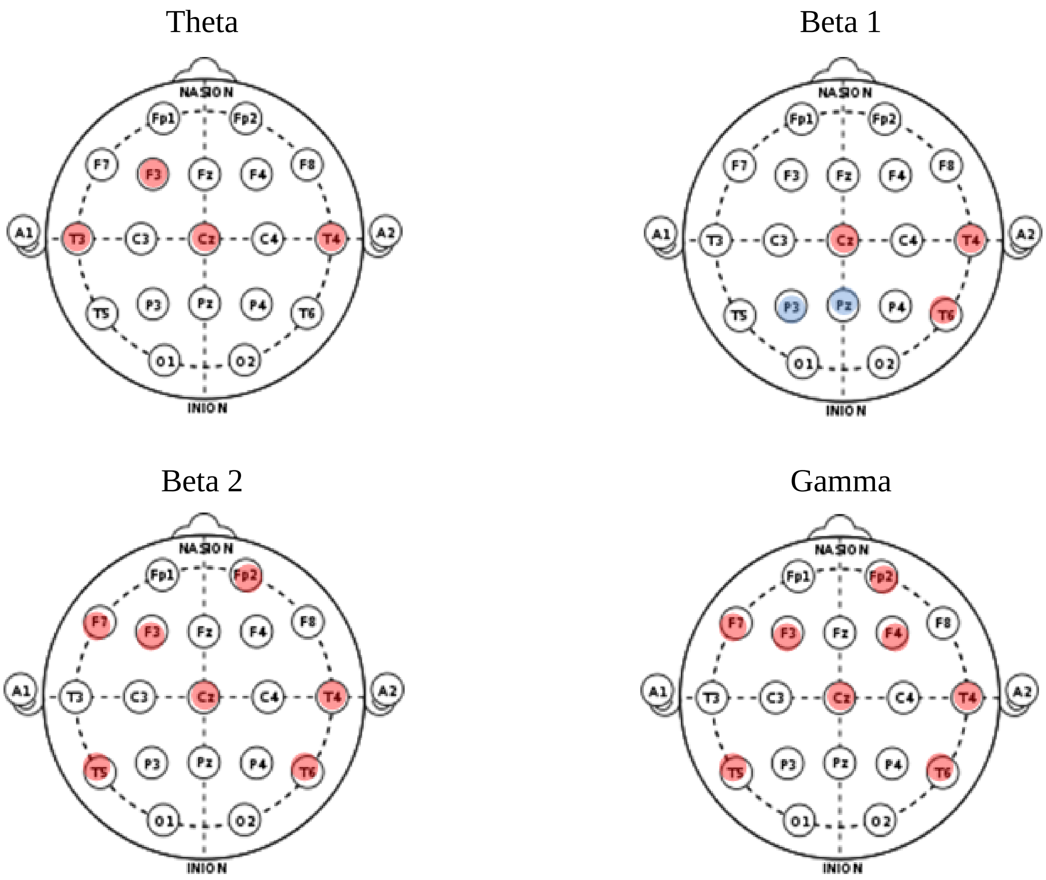


Figure 4.1. Relationship between the global geomagnetic activity during the game and in-turn shooting performance.

Geomagnetic Activity and EEG

There were multiple significant ($p < 0.05$) correlations between electroencephalographic activity and the Ap index the day of the game. There were no significant correlations in the alpha frequency band. The only negative relationships were in the beta1 frequency band over the parietal lobe. A summary of all relationships is found in Figure 4.2. The most frequent locations associated with geomagnetic activity involved T4 (the right temporal lobe) and Cz (central) which was evident for theta, beta1, beta2 and gamma activity. The second most frequent regions


Theta

Beta 1

Beta 2

Gamma

Figure 4.2. Significant correlations between the daily global Ap index and electrophysiological measures. Positive correlations are indicated by red markers whereas negative correlations are represented by blue markers.

involved T6 (right caudal temporal lobe) and F3 (left prefrontal region). The only cerebral areas associated with bilateral representations in both hemispheres occurred across the temporal lobes for theta (T3-T4), beta2 (T5-T6) and gamma (T5-T6) bands. Such synchrony sets the conditions for intercalation between the two hemispheres.

Geomagnetic Activity and ECG

There was a negative correlation between the NN50 (number of pairs of successive heart beats that differ by more than 50 ms) and the Kp index during the game (R = - 0.696, $p = 0.006$) and a weak negative correlation between the NN50 and the daily Ap index (R = - 0.490, $p = 0.075$). It appears that the variation in NN50 was mainly due to the High Frequency (HF) component of the rhythm, as HF also negatively correlated with geomagnetic activity during the event (R = - 0.561, $p = 0.037$). However; when controlling for either HF or NN50, it appears that NN50 was the driving variable for the effect between HF and geomagnetic activity. It was eliminated when controlling for NN50 (R = -0.048, p = 0.875).

POMS

There were no significant relationships between the POMS and any geomagnetic variable included in this study. There were however significant correlations between multiple POMS subscales and electroencephalographic spectral power. Significant correlations between mood subscale and EEG sensor location are summarized in Table 4.2. In comparing Figure 4.2 and Table 2 for overlap between relationships between POMS and EEG and geomagnetic activity, it was noted that F7 and T6 were significant for both relationships in the gamma frequency band. Partial correlation controlling for either geomagnetic activity or EEG spectral power demonstrated that it was the cortical activity which drove these relationships for when they were the control variables, the correlations became insignificant ($p > 0.10$).

Table 4.2. Significant correlations between POMS subscales and frontal or temporal sensors in the theta and gamma frequency bands associated with personality and geomagnetic liability.

Subscale	Sensor	Hemisphere	Lobe	BA	Frequency	Pearson R	*p*
Tension	Fp1	Left	Frontal	10	Theta	0.525	0.054
	Fz	Mid	Frontal	10	Theta	0.478	0.084
Depression							
Anger	F7	Left	Frontal		Gamma	-0.464	0.095
	T3	Left	Temporal		Gamma	-0.533	0.050
	T6	Right	Temporal		Gamma	-0.553	0.041
Vigor	Fp2	Right	Frontal		Theta	0.673	0.008
	Fp2	Right	Frontal		Gamma	0.525	0.054
Fatigue	F4	Right	Frontal		Theta	0.692	0.006
	T6	Right	Temporal		Theta	0.613	0.020
Confusion	F4	Right	Frontal		Theta	0.489	0.076
	F8	Right	Frontal		Theta	0.634	0.015
	F8	Right	Frontal		Gamma	-0.491	0.074

Models of Performance

Stepwise linear regression models with a maximum number of steps set to five were used to assess which physiological and geomagnetic factors could best predict shooting performance. Increases in overall performance were modelled by decreases in theta power in the T5 sensor. Greater in-turn performance was predicted by decreases in geomagnetic activity two days prior to the event as well as decreases in theta power in the T5 sensor. Increase in out-turn performance occurred on days where they subject had less sleep the night before, less spectral power in the beta-2 frequency in the O1 sensor and decreased alpha power in the CZ region. Days with increased takeout performance was associated with decreases in alpha power in CZ sensor and in the Fp1 gamma power, increases in F7 theta power and O2 beta-2 power and increases in the NN50 (number of pairs of successive heart beats that differ by more than 50 ms). Lastly, draw performance was predicted by increases in P4 beta-1 power, decreases in Pz theta power and F7 beta-1 power, increases in geomagnetic activity between 0900-1200 h local time the day of the game, and increases in P3 alpha power. A summary of coefficients for each regression model can be found in Table 4.3.

Table 4.3. Multiple regression analyses for all performance measures with physiological and geomagnetic independent variables.

Performance Measure	R^2	F Statistic	*p*	Variable	B	SE of B
Overall	0.586	17.00	< 0.001			
				Constant	76.860	4.565
				T5 Theta	-2.725	0.661
In-turn	0.642	9.85	0.004			
				Constant	89.408	7.113
				ApLag2	-1.804	0.491
				T5 Theta	-1.991	0.752
Out-turn	0.747	9.85	0.002			
				Constant	187.006	31.559
				Sleep Night Before	-0.186	0.066
				O1 Beta-2	-6.42	2.424
				CZ Alpha	-0.693	0.279
Takeout	0.965	44.30	< 0.001			
				Constant	77.543	5.978
				CZ Alpha	-1.645	0.125
				Fp1 Gamma	-37.204	4.523
				F7 Theta	4.816	0.942
				NN50	0.122	0.032
				O2 Beta-2	4.077	1.637
Draw	0.973	56.96	< 0.001			
				Constant	2.063	8.090
				P4 Beta-1	52.246	3.764
				PZ Theta	-8.105	1.165
				F7 Beta-1	-22.534	3.181
				kp 4	4.81	1.092
				P3 Alpha	1.322	0.421

Discussion

Past studies have demonstrated how electroencephalographic activity can be influenced by not only applied time-varying magnetic fields but also by variations in the Earth's natural geomagnetic field as manifested through geomagnetic activity. Our results support the literature in that there were consistent relationships between activity in the right temporal (primarily) and frontal lobes during athletic performance and daily geomagnetic activity (Babayev & Allahverdiyeva 2007; Mulligan et al 2009). It has been suggested that these effects due to geomagnetic activity can explain uncharacteristic human behaviours since the prefrontal cortex is considered to be the representation of the personality of an individual and also has numerous connections which the limbic system for controlling emotional experiences.

The propensity for more right temporal lobe regions to be correlated with the geomagnetic activity at the time of performance is consistent with other research results which have strongly indicated the enhanced sensitivity of the right temporal region to geomagnetic activity. For example Persinger (1988) reported increased incidences of spontaneous bereavement hallucinations (a traditional temporal lobe phenomenon) during increased global geomagnetic activity. Persinger and Richards (1995) showed that the increased vestibular experiences reported by subjects sitting blind folded in a quiet chamber while low intensity, physiologically patterned magnetic fields were presented across the temporal lobes in order to produce “experimental temporal lobe sensitivity” occurred only when the global activity exceed 20 nT. It was clearly an all or none response. The bilateral intercalation, particular for the theta band measured in this study may be one means through which “information” from the geomagnetic fluctuations might affect the experiences and performance of specific individuals engaged in specific tasks.

The stem of the temporal lobe also borders the insular cortex which may add to its liability to mood disturbance as this area of the cortex is activated during times of social emotions such as disgust, which may further explain why this sensor significantly correlated with the anger subscale of the POMS. One result that was not found in the previous literature was the negative correlation between beta-1 power in the left and central parietal cortex and geomagnetic activity suggesting that there is greater power in this region on days with lower geomagnetic activity. This may be a result of having an athlete as a participant and would likely be evident in other skilled performers. This beta-1 activity may be representative of sensor motor rhythm (SMR) that is often the focus of neurofeedback training in athletes (Reid et al 2013).

These results also suggest that local geomagnetic activity influenced heart rate variability measurements. Days with high geomagnetic activity were associated with a lower number of pairs of beats that differ more than 50 ms. This is consistent with the results of other work which has extensively compared HRV and geomagnetic activity (Otsuka et al 2000). Most heart rate variability often reflects differences between high frequency and low frequency spectral values. They have been suggested to represent both branches of the autonomic nervous system. Sympathetic activity modulated by the neurotransmitter norepinephrine is said to primarily be reflected by low frequency spectral power whereas parasympathetic activity modulated by acetylcholine release is reflected by high frequency spectral power.

Work by Mietus et al. (2002) suggested that the NN50, or the beat variability, was just as if not a better diagnostic tool to assess parasympathetic activity. Some researchers have hypothesized that low frequency spectral power does not solely reflect one branch of the ANS but rather a mixture of both. Current biofeedback training for elite athletes has focused on controlling the high frequency power. The presumption is parasympathetic activation controls the vasodilatation of certain organs throughout the body. The net effect is a decreasing heart rate in an attempt to reach homeostasis. Taken together with past findings, it appears that parasympathetic sensitivity to geomagnetic disturbance is a global phenomenon. Otsuka et al. (2000) reported a 25.2% decrease in HF during high geomagnetic activity.

Grouping the data in this study into low (kp 0-2) or high (kp values 3-5) geomagnetic activity indicated that the participant in this study displayed more than a 200% decrease in both high frequency spectral power and in the NN50. Perhaps this suggests that athletes are more parasympathetically sensitive to geomagnetic disturbances than the normal population. It would appear that more proficient athletic performance would likely occur during geomagnetically quiet periods. Therefore, these results support the use of the NN50 for parasympathetic assessment. Even though both correlated significantly with geomagnetic activity, partial correlations revealed that the NN50 was the dominant variable driving the effect.

Although geomagnetic activity has been associated with multiple facets of human behaviour from pilot error (Fournier & Persinger 2004) or motor vehicle incidents (Alania et al 2001), its direct involvement with sports performance has not been significantly assessed. It is apparent that left temporal theta power was significantly correlated with curling performance for this athlete's overall shooting accuracy. This particular sensor (T5) is also usually associated with contributions from the left parahippocampal gyrus, a structure that has been suggested to be intrinsically correlated with geomagnetic activity as well as components of the Schumann Resonance.

As described by Saroka and Persinger (2014), the parahippocampal region in the temporal cortex contains a large amount and variety of cortical projections. It is well known that activity in this region could have an influence upon the entire cortex. The authors also mention that this region processes spatial information for memory consolidation which could have a direct impact on curling performance. For example, consider a golfing green. To make a successful putt the golfer must remember the varied elevations on the green. This process would rely upon the parahippocampal gyrus to encode this spatial memory. Curling ice is comparable to a golfing green. The curler must recall the speed of the ice and how much it may curl in various spots in the ice. This process must be dynamic enough to track these changes throughout an entire two hour game in order to be successful. Saroka and Persinger (2014) also mentioned the numerous connections between the parahippocampal gyrus and the prefrontal cortex. The latter regions are involved with executive processes such as decision making. This skill is directly tied to strategic processes in curling which is called by many as a “game of chess on ice.”

It also appears that decreased geomagnetic activity enhances curling performance, as activity during the game, the day of the game as well as geomagnetic activity two days prior to the event all negatively correlated to at least one performance measure. Lower geomagnetic activity has also been shown in the past to enhance telepathic experiences (Arango & Persinger 1988) paranormal reports (Schaut & Persinger 1985), distant dream congruence (Krippner & Persinger 1996) and has also been suggested that lower activity can help facilitate entanglement. Taken together, it seems that lower geomagnetic activity enhance the effects of the parahippocampal gyrus by increasing the influence of the Schumann Resonance on the entire cortex, a hypothesis which has been presented before by Saroka & Persinger (2014)

The authors suggest that these results demonstrate that geomagnetic influences can have a significant impact on human behaviour, specifically sporting performance. Knowing this, athletes in the future may consider utilizing this information to enhance performance during competition. For example, these practices could replace current biofeedback techniques. It is much more difficult to train your brain to activate these cortical patterns than to simply immerse yourself in an energy (magnetic) field which can facilitate the same activation. Being cognizant of the influence of geomagnetic fluctuations might facilitate performance.

This would be analogous to athletes who train at higher altitudes in preparation for major competition. By subjecting themselves to the magnetic field which represents their peak performance state these athletes may have a significant advantage over others during competition. These “training fields” may extend beyond the natural geomagnetic field to those which are known to target certain receptors in our body. For example Murugan & Persinger (2014) demonstrated how the “Thomas pulse” resulted in the same behavioural changes in planaria as those who were treated with an analgesic such as morphine. These electromagnetic fields may create a condition for athletes to “push through the pain” without risking ingestion of a banned chemical substance. Although this may create new ethical concerns in the sporting world, it could offer a non-chemical method for athletes to perform at their best more consistently.

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Chapter Five: General Discussion

Fluctuations in the geomagnetic environment, whether it is on a global or local scale, correlate with significant changes in human health and behavior. As introduced in the first chapter, these changes exert their effects on a cellular level, which in turn affects the relevant tissues and organs, and continues to proceed through the levels of spatial organization. Eventually the entire organism is affected.

Consider the evidence that the prevalence and treatment of the demyelinating disease multiple sclerosis has an intrinsic relationship with the Earth's geomagnetic environment. As demonstrated in chapter two, planaria which were treated with the demyelinating agent cuprizone, but then exposed to only a six minute exposure to a patterned magnetic field simulating the onset of a geomagnetic storm behaved no differently than planaria which were not demyelinated. This suggests that the field exposure had a regenerative effect on the planarian nervous system. Additionally, chapter three demonstrated that components of the Earth's geomagnetic field can be better predictors for the prevalence of multiple sclerosis in local study regions, accounting for more variability than the common latitudinal model. From an inverse perspective one could argue that if MS was a default condition then certain intensities of magnetic fields attenuate its manifestation. Although these results may seem counter-intuitive of one another, one must consider that the Earth's magnetic field and geomagnetic storms are two separate entities. Whereas the Earth's magnetic field can be viewed as a constant environmental risk factor where increases in its strength increase an individual's susceptibility to multiple sclerosis, geomagnetic storms (although also an increase in local magnetic field intensity) act as fluctuations in this background environment, the pattern of which may infer a protective effect against multiple sclerosis

If the evidence that geomagnetic storms are a protective agent against multiple sclerosis along with the indications from the epidemiological models is assumed, one can create a more accurate hypothesis for the trends of multiple sclerosis epidemiology around the globe. Because past literature has shown that the prevalence increases towards 60° latitude from the equator and then decreasing again towards the poles, a geomagnetic model can better account for this non-linear trend. Due to the fact that geomagnetic storms were attributed to a protective effect from multiple sclerosis in rat and planarian populations, perhaps the auroral magnetospheric substorms provide the greater protection for these northern regions.

This form of geomagnetic disturbances occurs exclusively in the auroral zones. Here there is a greater frequency, duration and intensity of geomagnetic storms than elsewhere on the planet. In other words, although moving further away from the equator increases the susceptibility to MS based on changes in the North/South component of the field, individuals residing in the auroral region may be given extra protection from developing multiple sclerosis due to the protective effect of the magnetospheric substorms. This would therefore explain how prevalence begins to decrease after 60° latitude in the northern hemisphere, a trend that cannot be accounted for in the latitudinal or Vitamin D hypothesis for MS prevalence.

This research also demonstrates the possibility that geomagnetic fields can influence more than just human health. It can also affect the dynamics of performance in a quantitative manner. As shown in the chapter four case study of a curling athlete, geomagnetic field intensity can have a significant impact on the sporting performance, electroencephalographic power, electrocardiographic peaks, and the mood of an individual. Similarly to the possibility that geomagnetic storm activity influences symptoms in multiple sclerosis, they can also influence gross motor and cortical activity. Although it is unknown how these geomagnetic perturbations influence every type of cell in our body, one can infer that changes in one system will influence alterations in function in another physiological mechanism as our body constantly attempts to reach a state of homeostasis. One change in function can affect an entire system.

The environment in which we inhabit plays a significant role in our development. This includes some variables over which we have minimal control such as the geomagnetic field and the disturbances which are in large part caused by energy releases from the sun. By understanding the correlations between these environmental variables and human health and behavior, perhaps we can manage and utilize this information to improve the physiology of our species.

Appendix – Summary of Published Work

Mekers WFT[1], Murugan NJ[2] & Persinger MA[3]. Introduction of planaria as a new model for multiple sclerosis research: Evidence from behavioural differences in cuprizone treated planaria exposed to patterned magnetic fields. Journal of Multiple Sclerosis (Foster City). 2:156, 1000156.

Author Contributions

- Conceptualization: 1, 2, 3
- Data curation: 1
- Formal analysis: 1, 3
- Investigation: 1, 2, 3
- Methodology: 1, 2
- Supervision: 3
- Writing: 1, 3