The Influence Background Fluctuations of Electromagnetic Fields and Biophoton Emission has on Behaviour: A Correlational and Experimental Investigation

by

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Abstract

Nontraditional environmental factors such the geomagnetic field and background biophoton emission have the potential to influence human brain activity. The relationship between brain activity and geomagnetic field activity fluctuations as well as background photon emission were examined over the course of this study. An electroencephalographic database of 184 participants was amalgamated with a geomagnetic field database and a background photon emission database to be analyzed. The results showed that increased geomagnetic field activity was positively correlated with an increased alpha power from the right hemisphere of the brain and that as background photon emission increased, an increase in theta and alpha activity from the frontal lobe was observed. We further investigated the effect of geomagnetic fields by observing planaria behaviour after being exposed to one of six applied electromagnetic fields created to mimic a geomagnetic storm ranging in intensity from 0.1μT to 3.5μT. Planaria were split into two groups: control, and acute 10μM nicotine exposure 24 hours prior to behavioural observation. The behavioural observation results showed that planarian mobility increased when exposed to the synthetic geomagnetic storm electromagnetic field. Planaria experiencing nicotine withdrawal exhibited more aversive behaviour after being exposed to any intensity of the synthetic geomagnetic storm electromagnetic field. The data demonstrates that an electromagnetic field mimicking a geomagnetic storm can exacerbate aversive behaviour in planaria, especially in planaria experiencing nicotine withdrawal. In conclusion, both geomagnetic field and background photon emission correlated with brain activity. This research has given reason to consider how important non-traditional environmental factors are and how they factor into day-to-day life for biological individuals.

Keywords: Applied synthetic geomagnetic storm field, background photon emission, Electroencephalograph (EEG), planaria, nicotine withdrawal

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Table of Contents

List of Tables

List of Figures

List of Appendices

CHAPTER ONE:
INTRODUCTION

We are immersed in our environment and although it may appear consistent it is ever-changing. These changes are not always visible, invisible factors that affect our environment include: weather, heat, sunshine, humidity, atmospheric pressure, and even space weather. Another invisible factor that the general population may be unaware of is photon emission, specifically biophoton emission. While reading this paper, the electroencephalogram, the photomultiplier tube, photon emission, previous studies on weather affecting humans, as well as planaria and geomagnetic fields, will be introduced. Following the introduction, two separate experiments will be discussed to examine how all those topics are connected. Experiment one looks at the relationship between brain activity, background photon emission and geomagnetic field activity. Experiment two looks at the effect a synthetic geomagnetic storm electromagnetic field has on both a living organism and a living organism experiencing drug withdrawal.

In recent years, studies involving magnetic fields and electroencephalography has involved neurodegenerative diseases but have not identified what effects, if any, the geomagnetic field has on the general population (Riancho et al. 2021; Popovych et al. 2021). The same can be said for research regarding biophoton emission. The majority of studies have looked at biophoton emission produced by biological systems and have yet to examine specific relationship between the human brain and backround biophoton emission (Yearington, Hossack, and Dotta 2020; Li et al. 2021; Zapata et al., 2021). Understanding the kind of relationship, we as humans have with non-traditional environmental factors is important to help better understand our behaviour. As for current planarian research involving magnetic fields, the focus has mainly revolved around regeneration (Ermakov et al. 2022). Planaria as a preliminary animal model is very insightful as they have very similar nervous systems compared to mammals.

Electroencephalography

The normal functioning human brain generates both an electric and magnetic field. These fields are generated by firing action potentials from neurons in the cerebral cortex. The source is the millions of neuronal dipoles that are arranged in parallel within the cerebral cortex. The neuron contains dendrites on one side and the soma with axon on the other side. The dendrites are positively charged in comparison to the negatively charged axon, thus creating a surface potential. This potential is the source of smaller intensity, time-varying fields (Michael A. Persinger, 1997). These fields produced by the brain can be measured using an electroencephalogram.

German psychiatrist Hans Berger created and recorded the first electroencephalogram in 1924. The electroencephalogram, commonly referred to as EEG, measures the brain via scalp electrodes and an amplification device (Paranjape et al., 2001). The scalp electrodes are placed in standardized locations over the main anatomical structures of the brain, such as the frontal, temporal, and parietal lobes (Paranjape et al., 2001). The EEG is a complex signal representing brain electrical activity. The source of the EEG is the cerebral cortices, it does not necessarily reveal deep structure-activity. The data recorded from the EEG cap is passed through an amplifier and connected to a computer where it can be further organized into five specific frequency bands. Delta (1.5-4Hz) is associated with deep sleep; 1hz or less is correlated to a coma. Theta is in the range of 4-8Hz and is mainly generated from the temporal and parietal region; it is associated with altered states in adults. Alpha 1 ranges from 8-10 Hz, and alpha 2 ranges from 10-13Hz. Alpha is a sinusoidal pattern that occurs when the eyes are closed and is associated with suggestibility, imagery, and relaxation. Beta 1 ranges between 13-16.5Hz, beta 2 ranges from 16.5-20Hz and beta 3 ranges from 20-30Hz. Beta is associated with active mental processing. Gamma is anything greater than 30Hz. The EEG signal is recorded in real-time. As the participant thinks or moves, the EEG signal reflects the behaviours.

Weather and Mood

Climate plays a significant role in biology. Climate can influence individual fitness, population dynamics, species distribution and abundance, and ecosystem structure and function (Parmesan et al., 2000). Regional differences in climate create unique selective pressures for the evolution of locally adapted physiologies, morphological adaptations and behavioural adaptations (Parmesan et al., 2000).

Zhu and colleagues examined changes in EEG signals during cognitive activity at different humidity levels and temperatures. They found that at 70% humidity and warm temperatures, there was an increase in the relative power of the delta band and significantly decreased relative power of theta, alpha and beta (Zhu et al., 2020). Their finding suggests that participants were less alert and had trouble thinking clearly; however, they did not observe a change in cognitive performance (Zhu et al., 2020).

Schneider and colleagues analyzed the influence of weather on blood pressure, arrhythmia, and ischemia in cardiovascular patients. Women showed a decrease in systolic blood pressure on days with higher humidity, whereas men had a delayed 2-fold higher risk of ST-segment depression on days with lower temperatures. Their study found that weather induced changes in heart function which can ultimately lead to detrimental cardiovascular events, especially in susceptible individuals (Schneider et al., 2008).

Eklundh and colleagues examined the relationship between atmospheric pressure and levels of monoamines or their metabolites involved with the brain. In 1994 they found that atmospheric pressure significantly influenced 3-Methoxy-4-hydroxyphenylglycol in women not taking oral contraceptives (Eklundh et al., 1994). 3-Methoxy-4-hydroxyphenylglycol is a metabolite of norepinephrine. In the late '90s Eklundh and colleagues found that in high pressure, tyrosine concentration in the cerebral spinal fluid of participants decreased whereas the level of Cholecystokinin tetrapeptide increased (Eklundh et al., 2000). Cholecystokinin tetrapeptide acts primarily in the brain as an anxiogenic.

Hiltunen found a significant correlation between atmospheric pressure and suicide attempts in Helsinki, Finland (Hiltunen et al., 2012). Men were more likely to attempt suicide during low atmospheric pressure conditions, whereas women were more likely to attempt suicide during high atmospheric pressure. The tendency of genders to react in opposite ways towards weather variables has been found in prior studies. Temperature, wind, and humidity affect the rate of body cooling. Women sweat less than men and react to heat with a higher body temperature. Menstruation also has a role in thermoregulatory efficiency. Significant correlations between hospital visits and suicide attempts were seen on warmer, humid days with little wind (Barker et al., 1994). These factors may cause thermal stress resulting in physiological, psychological and behavioural changes (Barker et al., 1994).

Kööts and colleagues examined the relationship between affective experience and weather variables using an experience-sampling method. They found that luminance had the most noticeable influence on affective experience and that individuals' would have more intense feelings during warmer temperatures (Kööts et al., 2011). Weather significantly impacted the physiologically based feelings of sleepiness and tiredness. The fatigue score decreased as temperature or luminance increased. Denissen and colleagues also found that sunlight prevented tiredness; however, Howarth and Hoffman reported an increase in sleepiness in higher temperatures (Denissen et al., 2008; Howarth & Hoffman, 1984).

Regarding mental health, Beecher and colleagues examined the relationship between measured client distress and numerous weather variables that were concurrent with the location and time the participant filled out the questionnaire. At Brigham Young University, the counselling center requires every client to complete the Outcome Questionnaire 45 before each session. The Outcome Questionnaire is a 45-item self-report measure of psychological functioning; items are measured on a 5-point Likert scale. In addition, the physics department at Brigham Young University has been collecting meteorological data, minute by minute, since February 19, 2000. Using this data, they found that direct sun time significantly correlates with mental health (Beecher et al., 2016).

Lambert and colleagues measured neurotransmitter and metabolite levels via a percutaneously placed catheter positioned high in the internal jugular of participants. They found a correlation between exposure to sunlight and serotonin production in the brain. Increased sunlight exposure resulted in increased serotonin found in the participant's blood. Conversely, the turnover for serotonin was lowest in winter (Lambert et al., 2002).

Gillihan and colleagues created a weather-related "mood index" to examine the relationship between neural activity and weather-influenced mood. To create the index, they collected mood ratings from hundreds of people at the central train station in Philadelphia. They retrieved various weather variables from the National Weather Service Forecast Office. The variables they looked at were the amount of cloud cover, maximum, minimum and average temperature, dew point, wind speed, amount of precipitation, whether rain or fog was present, maximum, and minimum humidity and atmospheric pressure. They entered the weather variables into a forward stepwise regression model with mood as the dependent variable. The index was used as a covariate of interest in a general linear model using the data from arterial spin labelling functional magnetic resonance imaging from 42 different participants. They found that the resting cerebral blood flow activity in the left insula-prefrontal cortex and left superior parietal lobe were negatively correlated with the weather index. Their findings indicate that better mood-relevant weather conditions were associated with lower cerebral blood flow in these regions within the brain's emotional network (Gillihan et al., 2011).

Most of the previous research involving human mood and weather suggests a relationship between the two. However, with all the different experimental procedures, looking at general brain activity recorded via EEG and the weather variables before, during and after the recording have not been thoroughly investigated. A variable often forgotten that pertains to space weather is the Earth's geomagnetic field. This field has been shown to affect human mood and behaviour.

Geomagnetic Field

Earth's primary source of energy comes from the sun; it produces the heat and light required to maintain our planet as habitable (Babayev & Allahverdiyeva, 2007). However, the sun also produces various space weather, such as solar wind and cosmic rays. These types of space weather affect the Earth and Earth's space environment. The planet's iron core rotation is assumed to generate the Earth's magnetic field, also known as the geomagnetic field. The geomagnetic field helps to protect us from these effects. As a result, the geomagnetic field is affected by space weather causing variations in activity.

The magnetic dipoles of the geomagnetic field are represented by the north and south poles, with flux lines running to and from both poles. The convergence of flux lines at the poles of the Earth generates a stronger geomagnetic field of about 70T, whereas the strength at the equator is only about 25T (M. A. Persinger, 1975). A geomagnetic storm is defined by extreme changes in geomagnetic disturbances. There are multiple indices to measure these disturbances. The K index is a measure of the disturbance level of the Earth's magnetic field. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a 3-hour interval (Morimoto, 2019). The antipodal index (aa) is a global geomagnetic activity index derived from the K indices from two approximately antipodal observatories. The aa-index, created in 1868, is one of the oldest planetary indices (Mayaud, 1972). The leading cause of geomagnetic storms is a sudden increase in charged particles originating from solar flares on the sun. Storms can last several hours and are global phenomena but with regional variation in intensity (Kay, 1994).

Living on Earth, we are affected by its geomagnetic storm activity (Kletetschka et al. 2021; Janashia et al. 2022; Erdmann et al. 2021). Only recently has research looked into how biological systems might be able to sense geomagnetic fields (Henderson 2021). However, the effects from geomagnetic field variation on human illness has been documented to range from cardiovascular to mental illness (Morimoto, 2019). Studies have found that geomagnetic variations of solar origin correlate with enhanced anxiety sleep disturbances, altered moods, and greater incidences of psychiatric admissions (M. A. Persinger, 1987). Palmer and colleagues (2006) found that during periods of severe geomagnetic disturbances, the number of hospitalized patients with nervous diseases significantly increased; cerebral insults, different paroxysmal conditions, nervous disturbance disorders, and suicidal attempts are reported more frequently, and psychoneurological diseases became more aggravated (Palmer et al., 2006). Hainsworth (1983) suggested that other factors affecting the apparent connection between geophysical parameters and biological effects are geographical (Hainsworth, 1983). There are regional differences regarding the effects of space weather just like climate. Habitants living at high geomagnetic latitudes experience geomagnetic disturbances with larger amplitudes (Babayev & Allahverdiyeva, 2007).

All human brains are immersed in the geomagnetic field, which has an average intensity of roughly 50,000 nT. This steady-state value, however, is subject to spatial and temporal variations, especially within the 1 nT to 500 nT range. The 1nT to 500nT range is remarkably similar to the range between the steady-state electric fields of human cerebral cortices (10 to 30 mV) and time-varying electroencephalographic fields (10 to 30 μV) (Dotta & Persinger, 2009). Geomagnetic activity measured between 15-20nT has been correlated with brain activity. Using quantitative EEG, Babeyev and Allahverdiyeva (2007) found that alpha and theta brain activity within the right hemisphere is affected during geomagnetic storms (Babayev & Allahverdiyeva, 2007). Inspired by their findings, in 2010, Mulligan and colleagues confirmed using EEG that increased geomagnetic field activity is correlated with changes in right hemispheric electroencephalographic activity, particularly in the gamma and theta frequency bands (Mulligan et al., 2010a). The hippocampal indexing theory suggests that gamma and theta oscillations coordinate the interaction between cortical structures and the hippocampus to encode and retrieve episodic memories (Nyhus & Curran, 2010). Interestingly, the right hemisphere is strongly correlated with hunches, intuition, and mood (Mulligan et al., 2010b).

The effects of geomagnetic field activity on the human brain can be observed in other measures other than EEG. For example, geomagnetic field variation has been shown to influence human brain photon emission.

Photon

The concept of what light is has been debated between classical physics and quantum physics for centuries. The 1700s brought the discussion of wave versus particle. In the 1800s, English physicist James Clerk Maxwell pioneered our modern understanding of the properties of light. In 1900, German physicist Max Planck mathematically described black body radiation explaining that the energy released was contained in small packages, or quanta (Planck, 1901). Albert Einstein later expanded on quanta to include the entire electromagnetic spectrum that he referred to as Lichtquant. In English, Lichtquant is known as the "photon." The photon is an elementary particle of electromagnetic radiation, it is the basic unit of light that possesses both characteristics of a particle and wave. In the late 20th century, technology advanced enough that single-photon experiments could be conducted and put to practical use. The total energy per photon is dependent on its frequency; this relationship is usually thought to be mediated by

Planck's constant and the speed of light. The energy of a photon can be calculated using the following equation:

$$E=hc/\lambda$$

Where "E" is energy, "h" is Planck's constant, "c" is the speed of light, and "λ" is the wavelength. Photons in the ultraviolet to infrared (~200nm to 1500 nm) spectrum range in energy from $2 \cdot 10^{-19}$ J to $6 \cdot 10^{-19}$ J. The ultraviolet range has higher power than the infrared range. Higher energy photons can affect surrounding tissues (Popp et al., 1994). Photons can behave like quantum particles allowing them to interact with other quantum particles via electromagnetic forces (Gabrielli et al., 2006). When a photon interacts with matter, energy and momentum are transferred, just like a collision (Walker et al., 2013). It has been demonstrated that biological systems release photons due to their oxidative metabolism; this release is termed biophoton emission (Popp et al., 1994).

Biophoton Emission

Biophoton emission was first studied by Russian scientist Alexander Gurswitsch. He proposed biological communication via photon emission in 1922 (Bischof, 2005). He found that root cells of one onion could stimulate the growth of root cells in a different onion when separated by quartz glass. However, the use of ordinary glass blocked this effect. Gurswitsch concluded that it must be "mitogenic radiation" in the UV range, but he could not measure this phenomenon reliably (Bischof, 2005). It was not until the production of photomultiplier tubes (PMTs) that researchers could measure a hundred times weaker photon emission and prove cell radiation exists (Bischof, 2005). This low-intensity light became known as ultra-weak photon emission (UPE) (Van Wijk & Van Wijk, 2005).

All living systems produce UPE. UPE differs from bioluminescence in that it does not require specialized organs or metabolic pathways. Photon emission without external stimulation by light is a feature that distinguishes ultra-weak photon emission from fluorescence and phosphorescence (Cifra & Pospíšil, 2014). It has since been ruled out that UPE is not a by-product of thermal radiation; inanimate objects heated to a temperature range of 30 °C to 90 °C produce no increase in UPE (Van Wijk & Van Wijk, 2005). Oxidative metabolic and stress processes are primarily thought to chemically generate UPE in biological samples and living organisms (Cifra et al., 2015). It is generally considered that photons are emitted at near ultra violet (350–400 nm), visible (400–750 nm) and near infrared (750–1300 nm) regions of the spectrum (Cifra & Pospíšil, 2014). There are two types of UPE: spontaneous and induced. Spontaneous UPE is the average photon emission generated by oxidative metabolism without any external influences. Induced UPE refers to excess photon emission produced by certain biotic or abiotic factors; these factors can include stress, mechanical damage, or ionizing radiation (Cifra & Pospíšil, 2014).

Originally it was thought that UPE was merely a by-product with no effect on biological processes. However, more and more research is proving that UPE plays a role in growth regulation and proliferation (Cohen and Popp 1997; Creath and Schwartz 2004; Rahnama et al. 2011; Moro et al. 2022). An experiment by Murugan and colleagues showed that cells can "store" and release photons (Murugan & Karbowski, 2016). Quantifying UPE factors, such as intensity and spectral distribution, could help further understand tissues and organisms' oxidative metabolism and stress. The information gained from UPE could be used as a diagnostic tool in biology and medicine (Cifra and Pospíšil 2014; Zapata et al. 2021). Murugan and colleagues developed an early detection protocol to test malignancy in vitro and in vivo systems. They found that tumour cells showed an increase in photon emission compared to non-malignant cells (Murugan et al., 2020). Using UPE as a diagnostic tool is ideal because it is non-invasive, has little to no energy input, is almost real-time and has low operation costs (Cifra & Pospíšil, 2014).

It has been hypothesized that photons may play a role in consciousness. During cognitive tasks, increased photon emission from the brain has been observed (Dotta, Saroka, and Persinger 2012; Zapata et al. 2021; Hunter et al. 2010; Dotta and Persinger 2011; Dotta, Saroka, and Persinger 2012; Saroka, Dotta, and Persinger 2013). Four separate studies (Hunter et al., 2010; Dotta and Persinger, 2011; Dotta et al., 2012; Saroka et al, 2013) have shown that when individuals sit in complete darkness and think about bright white light, there is a significant increase in photon emission recorded from the right hemisphere of the brain. Hunter and colleagues in 2010 found that as photon emission from the brain increased, the geomagnetic field in the horizontal plane decreased. Further experiments by Persinger and colleagues in 2013 concluded that the energies involved with the brain imaging white light and the changes in the intensity of the geomagnetic field around the brain are related (M. Persinger et al., 2013).

Planaria

An excellent animal model to work with is the planaria. The common brown planaria is an aquatic flatworm found in lakes, ponds, streams, and springs where they occupy bottom habitats (Barnes, 1980). Planaria have a solid body with sensory neurons that project from the sides of their head containing chemoreceptors that help locate food (Rawls & Raffa, 2008). On top of the head of the planarian are two eyespots known as ocelli that function as photoreceptors; these photoreceptors can detect light (Rawls & Raffa, 2008). The advanced nervous system of the planaria is separated into distinct sensory and motor pathways (Brusca & Brusca, 2003). Within the body of the planaria, the central nervous system forms the shape of an inverted U-shape creating a cephalic ganglion (Rawls and Raffa, 2008). The planarian central nervous system is similar to mammals regarding neurochemical and general metabolic characteristics (Brusca & Brusca, 2003). Planaria express and utilize neurotransmitters; when exposed to specific drugs or stimuli, they display mammalian-like responses. These responses include but are not limited to; a change in motility, behavioural sensitization, and drug-seeking and withdrawal (Zewde et al. 2018; Mohamed Haroon et al. 2021; Sal, Prados, and Urcelay 2021).

Electromagnetic fields have been shown to have an effect on planaria (Hossack, Persinger, and Dotta 2020; Ermakov et al. 2022; Gang and Persinger 2011; Murugan et al. 2013). In 2011, Gang and Persinger found that planaria placed in water that had been previously exposed to varying intensities of electromagnetic fields affected planaria mobility diffusion rates (Gang & Persinger, 2011). In 2013, Murugan and colleagues found that a tandem sequence composed of weak temporally patterned magnetic fields dissolved planaria in water. After five days of 6.5-hour exposures to a frequency modulated magnetic field immediately followed by an additional 6.5-hour exposure on the fifth day to a complex field with exponentially increasing spectral power would 100% dissolve the planaria within 24 hours (Murugan et al., 2013).

Conclusion

The aim of this thesis is to identify what types of naturally occurring environmental variables influences our brain activity. Our brains are electrochemical and geomagnetic fields have an electoral component, the hypothesis that there is a relationship between the two is highly likely. The same can be said for photon emission. Photons can behave like quantum particles; this allows the photon to interact with other quantum particles via electromagnetic forces. Every living thing emits ultra-weak photon emission, including the human brain. It is likely, that just like the geomagnetic field, background biophoton emission has a relationship with human brain activity. Having a greater understanding of how our environment affects human brain activity will help to better explain human behaviour and benefit our society.

To investigate the impact of a synthetic geomagnetic storm electromagnetic field on a biological system, we conducted experiments utilizing a database consisting of 184 EEG baseline measures and average geomagnetic field activity and background biophoton data as well as planaria. We postulate that background geomagnetic field activity and background photon emission with brain activity are correlated as well as applied geomagnetic field activity and planarian behaviour.

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CHAPTER TWO:
THE RELATIONSHIP OF BACKGROUND GEOMAGNETIC FIELD ACTIVTY AND BACKGROUND PHOTON EMISSION WITH BRAIN ACTIVITY

Abstract

Humans are affected by the environment in which they live. Our environment consists of many visible and invisible factors. Geomagnetic field activity and ultra-weak background photon emission are two of these invisible non-traditional factors. Geomagnetic field activity is produced by the relationship between the Earth's magnetic field and space weather; the source is currently unknown for ultra-weak background photon emission. Can these invisible non-traditional environmental factors affect human brain activity? Electroencephalography readings from various participants were recorded over multiple years and corresponding ultra-weak background photon emission. Since then, we have compiled a database of geomagnetic field activity occurring 24 hours before the EEG reading, during the EEG reading and 24 hours after the EEG reading. After running statistics with this database, we found various correlations between brain activity, geomagnetic field activity, and background photon emission. As background photon emission increased, theta and alpha activity from the frontal lobe increased. As concurrent geomagnetic activity increased, we observed an increase in alpha power from the whole right hemisphere.

Introduction

Humans have always been mindful of their environment. We have particular needs, such as security and safety. Physical and psychological comfort are among the qualities we seek in our surroundings. Different environments produce different effects. It is well understood that a busier environment is much more likely to produce adverse effects such as stress than a quiet environment. Studies have shown biological differences in people simply between being in a city versus nature (Cho et al., 2017; Li, 2010; Mao et al., 2017; Park et al., 2010; Yu et al., 2017). For example, one study revealed that being in a forest environment resulted in lower concentrations of cortisol, lower pulse rate, lower blood pressure, greater parasympathetic nerve activity and lower sympathetic nerve activity than being in a city environment (Park et al., 2010). Some aspects of the measurable world are self-evident, such as how much busier a city is than a quiet forest. However, many people are unaware that these non-traditional factors in our environment may also influence our behaviour. Two non-traditional factors that our research has focused on are background photon emission and geomagnetic field activity.

The source of background photon emission is not fully understood. Photons are discrete packets of energy known as quanta, with properties of both particles and waves. Photon emission is the by-product of an electron changing energy levels. As an electron changes levels, its energy decreases, and the atom releases photons. The photon's energy is the same amount of energy lost by the electron as it moves to a lower energy level. There are various theories about where background photons originate. One theory states that background photon emission might be produced by silicates found within crustal structures of the Earth, specifically subtle mechanical forces or electromagnetic stimuli (Persinger, 2012). However, the atmosphere's dynamic pressure is the primary source of excitation of Earth's free oscillations (Nishida et al., 2000). Background photon emission recorded from a darkened basement room in the Sudbury Basin showed an annual variance of about 3 MHz, remarkably similar to the amplitudes of both free earth oscillations and infrared flux density (Persinger, 2012). All living biological systems emit ultra-weak biophoton emission. One theory suggests that background photon emission is the remnants from the biophoton emission produced by living systems within the environment; as we move around in space, we leave by ultra-weak biophotons in the background.

Previous studies have suggested that it is metabolic activity, specifically the oxidation of free radicals, that is the primary cause of biophoton emission (Dotta et al., 2012). This proposed mechanism applies to both spontaneous and induced biophoton emissions. An organism's regular metabolic activity produces spontaneous biophoton emission. However, exposure to one or more stimuli can produce an increase in biophoton emission in an organism (Yearington et al., 2020). Neuronal activity, cerebral energy metabolism, EEG activity, cerebral blood flow, and oxidative processes can influence biophoton emission rate (Rahnama et al., 2011). During cognitive tasks, it was observed that the biophoton emission coming off from the brain increased which may support the idea that photons have a role in the process of consciousness (Dotta et al., 2012). More specially speculated as a biproduct of consciousness. Four different studies (Dotta & Persinger, 2011; Hunter et al., 2010; Mulligan et al., 2010a; Saroka et al., 2013) have shown that when people sit in total darkness and imagine bright white light, UPE biophoton emission from the right hemisphere of the brain increased. Hunter and colleagues discovered in 2010 that as photon emission from the geomagnetic field decreased in the horizontal plane, photon emission from the brain increased (Hunter et al., 2010). In 2013, Persinger and colleagues concluded that there is a relationship between the energy involved in imaging white light and the strength of the geomagnetic field surrounding the brain (Persinger et al., 2013).

The Earth's magnetic field, also known as the geomagnetic field, is thought to be produced by the rotation of the planet's iron core. The north and south poles of the Earth represent the magnetic dipoles of the geomagnetic field, with flux lines running to and from both poles. The convergence of the flux lines at the poles produces a geomagnetic field with a strength of about 70μT, while the strength at the equator is only about 25μT (Persinger, 1975). The geomagnetic field has a time-varying feature of approximately 7.8Hz, an extremely low frequency (ELF). The 7.8Hz frequency produces resonance between the Earth and the ionosphere (Persinger, 1975). The ionosphere is responsible for the bulk of variations in the frequency of the geomagnetic field detected at Earth's surface (Mead, 1964). In addition, space weather can affect the strength of the geomagnetic field, such as solar wind. The solar wind is a stream of plasma produced by the sun resulting in a diurnal variation with intensities lowest during the night. When solar wind affects the geomagnetic field, we call this a geomagnetic storm (Mead, 1964). There are multiple indices used to describe the intensity of the geomagnetic field during a geomagnetic storm. The most well-known is the KP index, a semi-logarithmic scale invented in 1938 (Bartels et al., 1938). The AP index is derived from the KP index with units of nanotesla. The values recorded for these indices come from 13 observatories around the globe (Rostoker, 1972). The AA (antipodal) index is derived from two observatories, one in the northern hemisphere in the UK and the other in the southern hemispheres in Australia (Mayaud, 1972).

Studies have found that when global geomagnetic activity exceeds AA index values of about 20nT, there are increased occurrences of convulsive behaviours (Rajaram & Mitra, 1981), post-mortem hallucinations (Persinger et al., 1988; Randall & Randall, 1991) and vestibular experiences (Persinger & Psych, 1995) in humans as well as greater mortality rates in rats with acute epileptic limbic activity (Mulligan & Persinger, 2012). Furthermore, Babayev and Allahverdiveva found that severe geomagnetic disturbances would reliably change electroencephalography activity in normal individuals (Babayev & Allahverdiyeva, 2007). Inspired, Mulligan and colleagues (Mulligan et al., 2010b) found significant changes in the theta frequency (4-7Hz) over the parietal lobe and gamma frequency (>35Hz) over the prefrontal region of the frontal lobe, specifically in the right hemisphere that correlates with daily geomagnetic activity (Mulligan & Persinger, 2012).

The objective of this study is to examine human brain activity and non-traditional environmental factors. Starting with a database of 184 baseline EEG profiles, we amalgamated background geomagnetic field and background photon emission data corresponding with the time of each EEG profile recording. Using this compiled database, we were able to analyze the relationship between human brain activity with background geomagnetic field activity and background photon emission.

Methods

Electroencephalography

This research was approved by the Laurentian University Research Ethics board (LUREB), file number 6019407. Electroencephalogram (EEG) data was recorded from 184 individuals (some measured several times) in which eyes closed data was collected as part of the completion of various experiments within the laboratory for a total of 238 measurements (N=238). The EEG of these participants occurred over a total of about three years between 2009 and 2013. The EEG data was collected using a Mitsar 201 amplifier running under WinEEG, which monitored and recorded the series of voltages streamed through 19 different channels (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2) using the 19-channel Electro-Cap International. All impedances for each channel were maintained under 5 kOhms, and data was filtered between 1.5 and 50 Hz with a notch filter set to 35-55 Hz. While most of the data was obtained at 250 Hz, some records were sampled at 500 Hz, which were then resampled to 250 Hz for accuracy.

Sixteen-second lengths of eyes closed data were extracted from each of the available records. Raw EEG time-series data was entered into MATLAB software for spectral decomposition within 9 frequency bands (delta [1.5-4 Hz], theta [4-7.5 Hz], alpha-1 [7.5-10 Hz], alpha-2 [10-13 Hz], beta-1[13-20 Hz], beta-2 [20-25 Hz], beta-3 [25-30Hz], gamma-1 [30-35 Hz], gamma-2 [35-40 Hz]); for this we used the bandpower.m script available within EEGLab toolkit to decompose into frequency bands rather than discrete frequency bins (Makeig et al., 2004). Data was then consolidated into a singular dataset for importation into SPSS.

Background Photon Emission

To record daily average background photon emission, we used a photomultiplier tube (PMT). The sensor of the PMT was housed in a thick wooden black box covered with several layers of black terry cloth towels; this setup was created to avoid any light to get to the PMT and influence the recording of background photon emission. The room it was in was also kept dark. For the past eleven years, the PMT has been connected to a photometer (scale 1 to 100) with voltages measured once per minute for 24 hours per day by an IBM laptop computer. Two different methods of calibration have indicated that a 1-unit change is equivalent to ~5 x 10-11 W/m2 (Vares & Persinger, 2013). The typical range of background variation over several days is between 45 and 55 units unless. Within a single hour, the range variation around the central tendency was between 5 and 6 units. Spectral analyses were completed by SPSS PC-16 software and Plotter for confirmation (Vares & Persinger, 2013).

Statistical Analysis

One-way analysis of variance, t-tests, and non-parametric mean analyses was conducted to observe any group differences. All statistics were performed on Windows PC with SPPS 20.

Results

Brain activity and Background Photon Emission

Figure 2.1 shows the correlation between PMT and frontal alpha power, which was found to be statistically significant, r(216) = +.143, p < 0.05, two-tailed. Despite the fact that the rho coefficient is roughly 2%, it reflects a significant number of people in a large sample size.

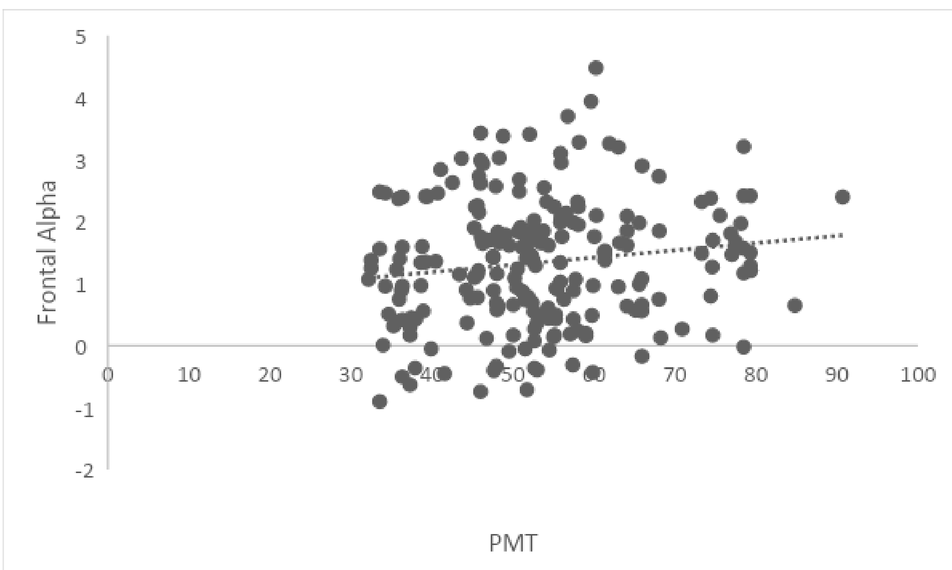

Fig. 2.1 Scatter plot (n=216) of relative power in the alpha frequency over the frontal lobe as a function of daily background photon measurements. The correlation between PMT and frontal alpha power was found to be statistically significant, r(216) = +.143, p < 0.05, two-tailed.

Figure 2.2 shows the correlation between PMT and frontal theta power, which was found to be statistically significant, r(216) = +.142, $p < 0.05$, two-tailed.

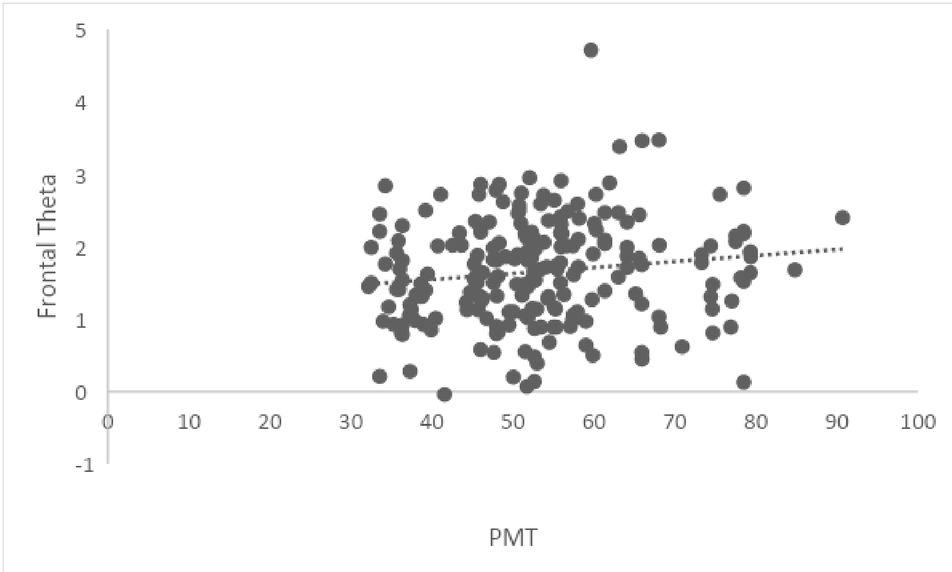

Fig. 2.2. Scatter plot (n=216) of relative power in the theta frequency over the frontal lobe as a function of daily background photon measurements. The correlation between PMT and frontal theta power was found to be statistically significant, r(216) = +.142, $p < 0.05$, two-tailed.

Figure 2.3 shows the correlation between PMT and FZ frontal low alpha power, which was found to be statistically significant, r(216) = +.165, $p < 0.5$, two-tailed.

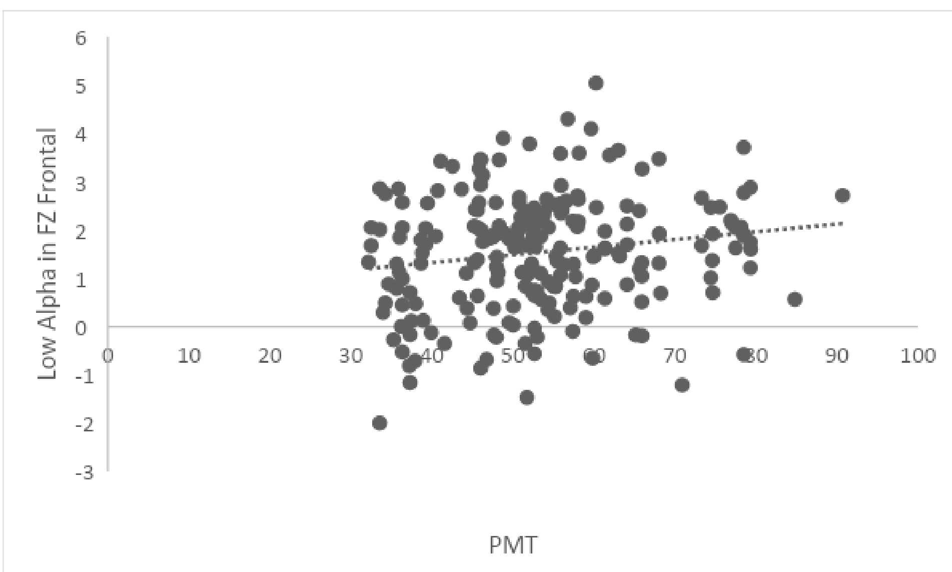

Fig. 2.3. Scatter plot (n=216) of relative power in the low alpha frequency over the central area of the frontal lobe as a function of daily background photon measurements. The correlation between PMT and FZ frontal low alpha power was found to be statistically significant, r(216) = +.165, $p < 0.5$, two-tailed.

Table 1 Factor Analysis

Rotated Component Matrix					
	Component				
	1	2	3	4	5
Temperature ℃ Average	0.082	-0.048	0.124	0.963	-0.012
Sea Level Pressure kPa Average	-0.011	0.047	0.021	-0.174	-0.811
Dew point ℃ Average	0.095	-0.079	0.093	0.919	0.121
Wind Speed kmh Average	-0.09	0.042	-0.049	-0.315	0.667
Total precipitation mm	0.056	-0.044	0.061	0.003	0.74
Humidity Monthly Average	0.045	-0.101	-0.1	-0.548	0.112
AA Before	0.03	0.937	0.049	-0.023	0.019
AA	0.174	0.041	0.953	0.104	-0.009
AA after	0.943	0.08	0.142	0.018	-0.008
KP Before	0.076	0.953	0.053	0.01	-0.026
KP	0.167	0.2	0.892	0.16	-0.005
KP After	0.946	0.066	0.14	0.08	0.024
AP Before	0.067	0.951	0.09	0.028	-0.067
AP	0.094	-0.016	0.956	0.115	0.023
AP After	0.961	0.031	0.131	0.02	-0.015

Figure 2.4 shows the correlation between factor 3 and right hemispheric low alpha power, which was statistically significant, r(216) = +.155, p < 0.05, two-tailed.

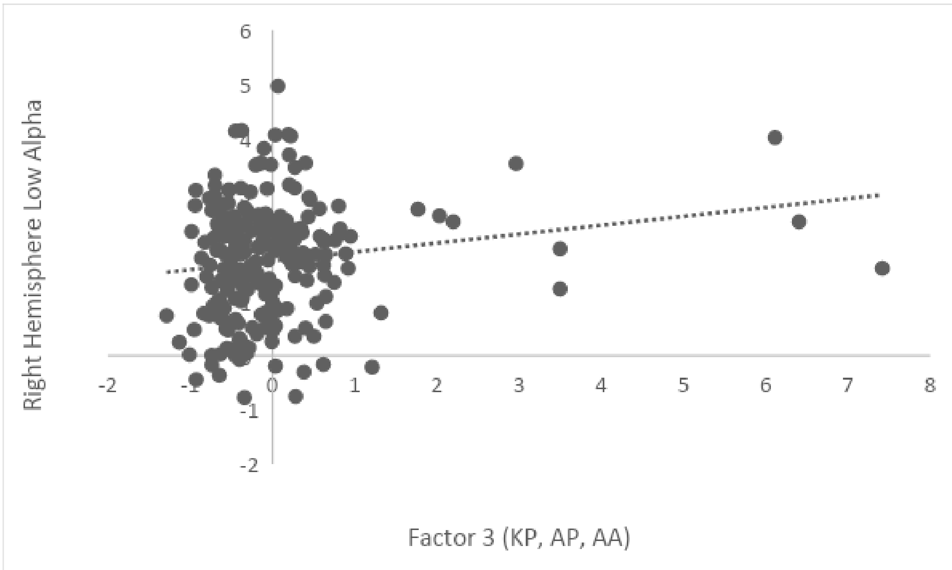

Fig. 2.4. Scatterplot (n=236) of relative power in the low alpha frequency over the right hemisphere as a function of factor 3; KP, AP, AA daily average. The correlation between factor 3 and right hemispheric low alpha power was statistically significant, r(216) = +.155, p < 0.05, two-tailed.

Figure 2.5 shows the correlation between factor 3 and right hemispheric high alpha power, which was statistically significant, r(216) = +.165, p < 0.05, two-tailed.

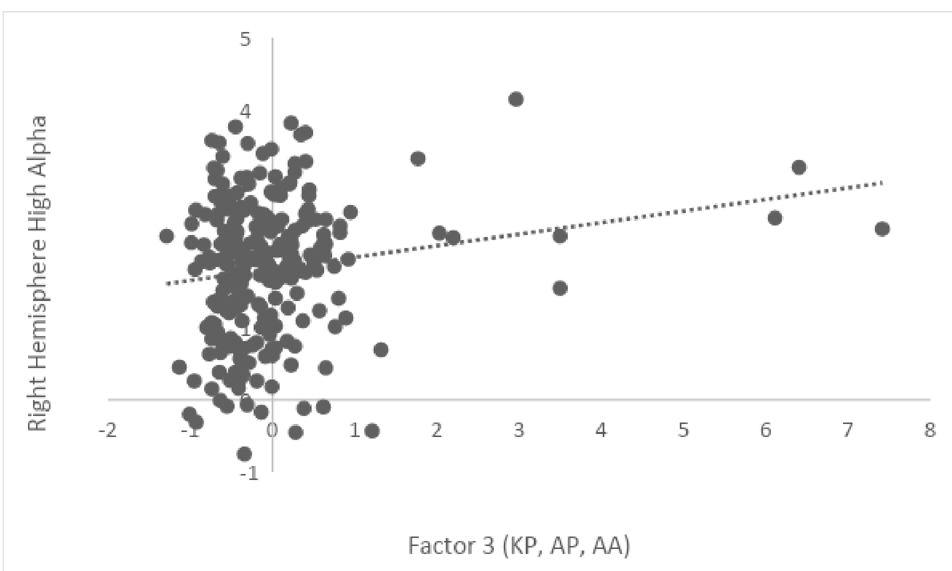

Fig. 2.5. Scatterplot (n=236) of relative power in the high alpha frequency over the right hemisphere as a function of factor 3; KP, AP, AA daily average. The correlation between factor 3 and right hemispheric high alpha power was statistically significant, $r(216) = +.165$, $p < 0.05$, *two-tailed.*

Discussion

We found a positive relationship between PMT and brain activity from the frontal lobe regarding background photon emission, specifically in the theta and alpha power. The most significant relationship was found in the central area of the frontal lobe in low alpha power. The spearman's rho analysis of the PMT and brain activity data was significant. Albeit the rho coefficient is small at only roughly 2%, in regard to a large sample size the small coefficient still represents a lot of people. In the grand scheme of things, 2% of the total population of the world represents around 150 million people. As for geomagnetic field activity, we found a positive relationship between the concurrent average KP, AP and AA activity and the corresponding right hemispheric brain activity in all lobes.

The right hemisphere of the human brain, which is significantly more activated during REM states, appears to be more sensitive to increased geomagnetic activity (Dotta & Persinger, 2009). Biological systems have evolved within and are constantly immersed in a geomagnetic environment; it makes sense that that biological systems would be responsive to minute changes (Mulligan et al., 2010a). The right hemisphere, in particular, is the part of the brain responsible for the perception of our environment (Kimura, 1973). While the two hemispheres tend to have virtually similar macrostructures, variations in neuronal network composition allow for unique function in each. For example, blood flow and the white to grey matter ratio in the right hemisphere are about 10% higher than in the left hemisphere (Kolb & Whishaw, 1990). In addition, the right hemisphere excels at simultaneous nonverbal representations of spatial patterns, whereas the left hemisphere excels at serial sequencing associated with temporal information in language (Dimond & Beaumont, 1974). The right hemisphere's unique susceptibility to heightened geomagnetic activity has far-reaching implications for human behaviour, both individually and in groups (Davidson & Hugdhal, 1995). Studies have shown that both experimentally applied and physiologically patterned magnetic fields increased right-hemispheric alpha activity (Persinger, 1999).

Alpha activity is the most visible rhythm in the adult human, occurring between 8 and 12 Hz. Alpha activity was previously thought to represent cortical idling (Pfurtscheller et al., 1996). This interpretation was based on discovering that alpha activity increased when subjects were awake but not engaged in any task. Lately, studies have shown evidence against the idling hypothesis suggesting that the function of alpha has been misunderstood (Jensen & Mazaheri, 2010). Instead, it is more likely that an increase in alpha activity reflects either active processing related to memory preservation (Palva et al., 2005; Palva & Palva, 2007) or inhibition of posterior regions that are not required for the task at hand (Klimesch et al., 2007). Inhibition is an essential factor in the development of the exact timing of an oscillation. As a result, inhibition plays a significant role in developing highly selective activation patterns (Klimesch et al., 2007).

Magnetic fields resembling geomagnetic patterns can entrain EEG behaviour after a 15-minute exposure (Persinger et al., 1997). Right hemispheric arousal is thought to produce periods of increased vigilance, panic attacks or a "sensed presence." Booth and colleagues found that an increase in magnetic field intensity increased the chance of experiencing a "sensed presence" in experimental and correlation studies (Booth et al., 2003, 2005). A “sensed presence” is when an individual believes that they are being visited by another worldly being such as an angel or ghost. The sensation of a "sensed presence" is thought to be caused by the intrusion of right hemispheric "information" into left-hemispheric consciousness during altered states (Persinger, 2003; Persinger & Healey, 2002). If geomagnetic activity can affect the right hemisphere of the human brain, then it can affect the behaviour of the human population (Healey et al., 1997; Ross et al., 2008). Although most individuals would not be conscious of these changes, geomagnetic field activity could influence decision-making. Right hemispheric processes are strongly linked to intuition, hunches, and mood, particularly when faced with new information with no prior verbal labels.

Biophoton emission from the human brain is thought to be the product of the active process of cognition (Dotta et al., 2012). Our study has shown that not only does our brain activity produce biophotons, but that background photons in the environment can affect our brain activity. This is not the first time a study has shown an effect correlated with background photon emission. Vares and Persinger (2013) discovered that discrete energies from entropic-like processes immersed in background photon densities of 10-11 Wm-2 were coupled to the occurrence of changes in random events that resulted in real consequences two days later. Our study showed that background photon emission is positively correlated with theta and alpha brain activity in the frontal lobe. The frontal lobes are involved in executive function. It facilitates the beginning of tasks, organizing and storing vital information, shifting mental sets from one line of thought to another, inhibiting unsuccessful or self-defeating actions, mapping the emotional meaning of stimuli, and encoding sense and perspective (Sira & Mateer, 2014).

The exact alpha frequency, as discussed earlier, may be associated with Schumann resonances. The Schumann resonances are a series of spectrum peaks in the Earth's electromagnetic field spectrum at extremely low frequencies. Frequencies in the range of 7-8Hz are caused by global lightning strikes between the ionosphere and Earth's surface. The fundamental frequency of ~7.5 Hz reflects the ratio of the velocity of light and the Earth's circumference. Interactions with seismic energy, the height of the ionosphere, and the time of year can all cause changes in the resonant frequencies (Persinger, 2014). Schumann resonances have been correlated with electroencephalograph activity in humans (Persinger, 2014). Thus, there may be a relationship between brain activity, the Schumann resonances and background photon emission that could help explain the results we have found in our study.

Theta activity is widely distributed in the primate brain. It is thought to represent active operations, such as memory encoding and retrieval, working memory retention, novelty detection, and recognizing the need for top-down control (Cavanagh & Frank, 2014). Cognitive load and executive control may be influenced by theta activity. According to Sauseng and colleagues, theta activity from the midline frontal lobe localized to the anterior cingulate was correlated with a general degree of cognitive demand, whereas theta activity from the frontal-parietal region was stimulated during greater memory-based executive functions requiring visuomotor integration (Sauseng et al., 2007). While studying willed attention, Rajan and colleagues found that theta oscillations play a role in indexing frontal conflict resolution and decision-making and facilitating reciprocal communication between frontal executive structures and parietal attention control regions. Using simultaneous EEG-fMRI technology, they found that the dorsal anterior cingulate and the default mode network may represent the neuroanatomical substrate of frontal theta oscillations in willed attention (Rajan et al., 2019).

Our most significant finding was from the FZ electrode, in which low alpha had the greatest positive correlation with the PMT values. FZ records from the superior frontal gyrus as well as the motor and premotor areas. The primary motor region consists of the precentral gyrus and the anterior bank of the central sulcus, where all parts of the body are portrayed in a distorted yet topographic manner (Ball, 1983). The Premotor and prefrontal regions are areas of the frontal lobe that are rostral to the primary motor region. In sensory-driven movements, the premotor region plays a key role. In response to visual, auditory, and somatosensory stimuli, premotor area units are activated. Regarding the low alpha power, studies have shown that it may represent various types of attentional demands (C. Cajochen et al., 1995; Christian Cajochen et al., 1996; Klimesch, 1999; Torsvall & åAkerstedt, 1987). Increased lower alpha power may indicate increased effort and, most likely, difficulties maintaining a state of alert wakefulness in subjects. (Torsvall & åAkerstedt, 1987). Subjects with low sustained attention that fail to avoid distracting environmental stimuli have a significantly greater portion of lower alpha power than subjects with high sustained attention (Klimesch, 1999).

Previous studies have shown that experimentally applied synthetic geomagnetic storm electromagnetic fields can affect brain activity; our current study has further supported the correlation between geomagnetic field activity and brain activity. This study has also provided evidence that there is a correlation between background photon emission and brain activity. How brain activity is influenced by geomagnetic activity and background photon emission is currently unknown as there are various cellular, bimolecular, and membrane mechanisms as to how it can occur. EEG activity is merely the by-product of brain activity. Why this phenomenon occurs is an even bigger question. If our physical environments can influence our behaviour, why not the intangible environment? Further studies will need to prove whether these non-traditional environmental factors truly influence human behaviour or if it is all just correlational.

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CHAPTER THREE:
APPLIED SYNTHETIC GEOMAGNETIC STORM ELECTROMAGNETIC FIELD INFLUENCE PLANARIAN BEHAVIOUR

Abstract

Previous research has shown that there is a correlation between geomagnetic field activity and human brain activity. Working with planaria, we examined how an applied synthetic geomagnetic storm field with varying intensities affects planaria behaviour. Planaria were either kept in spring water as control or experienced acute nicotine exposure 24 hours prior to behavioural observation to illicit withdrawal behaviour. Results showed that exposure to varying intensities of the synthetic geomagnetic storm electromagnetic field increased planaria mobility and increased aversive behaviour only in planaria exhibiting nicotine withdrawal. The results provide further support that there is a correlation between synthetic geomagnetic storm field activity and brain activity that can be observed through behaviour.

Introduction

Electromagnetic fields (EMF) consist of an electrical and magnetic component that forms a force or field. These fields can be both static and dynamic. Dynamic fields consist of temporal fluctuations in intensity, ranging from a few cycles per second (Hz) to 1043 cycles per second. These temporal fluctuations can be symmetrical, like sinewaves, or complex, like those produced by cells. The Earth's magnetic field is the most prominent local EMF.

Scientists have debated the relationship between human health and solar activity for decades (Morimoto, 2019). Solar wind and solar flares can disrupt the Earth's magnetic field resulting in a "geomagnetic storm." Extreme changes in geomagnetic disturbances define a geomagnetic storm. The K index is a tool used to measure disturbance levels, derived from the maximum fluctuations of horizontal components observed on a magnetometer during a 3-hour interval (Morimoto, 2019). The frequency of geomagnetic storms fluctuates with the sunspot cycle. Changes in geomagnetic activity have been correlated to a variety of health effects, including epileptic seizures, heart attacks, strokes, SIDS, suicide, and depression (Berk et al., 2006; Dimitrova et al., 2004; Feigin et al., 1997; Gmitrov & Gmitrova, 2004; Kay, 1994; Michon et al., 1996; O'Connor & Persinger, 1997; M. A. Persinger & Psych, 1995; E. Stoupel et al., 2002; E. Stoupel, 2006; Eliahu Stoupel et al., 1995).

In this work, we studied the effect of magnetic fields, including a range of intensity of the geomagnetic field, has on planaria exhibiting nicotine withdrawal behaviour by monitoring the mobility and aversive behavioural responses.

Planaria, free-living flatworms, are an ideal animal model to examine the relationship between geomagnetic fields and adverse health effects. They exhibit a body common to all vertebrates and many invertebrates, often referred to as "the earliest brain and spinal cord," due to their integrated neural network (Rawls et al., 2011). The planarian body is bilateral rather than radially symmetric, with dorsal and ventral surfaces and a rostro-caudal axis containing a head and tail. They also contain specialized sense organs and an aggregate of nerve cells in the head (Buttarelli et al., 2008). For decades, scientists have known that planaria are sensitive to weak static magnetic fields. Low-power frequency magnetic fields and frequencies adjusted to calcium resonance affect planaria's ability to regenerate and reproduce asexually (Murugan et al., 2013). In addition, neurochemical and histochemical studies have shown that planaria have neurotransmitters and receptors. Other research investigated the behavioural responses of planaria when exposed to substances that acted on neuronal transmission. Planaria respond to drug exposure or withdrawal with dose-related behavioural changes. For example, dopamine D1- and D2-receptor agonists, antagonists, and inhibitors can influence planarian locomotor activity. Planaria mobility and hyperkinesia activity are easily quantifiable and have been used to study the behavioural effects of a wide range of psychoactive agents and abused substances, including cocaine, amphetamines, nicotine, and opiates (Pagán et al., 2015).

Nicotine addiction is a major preventable cause of death in humans and is characterized by multiple unsuccessful attempts to quit smoking cigarettes. Like addiction to other drugs of abuse, nicotine addiction appears to be driven by a combination of the rewarding effects of nicotine, the development of tolerance, and the occurrence of withdrawal symptoms following continuous exposure to the drug (Sal et al., 2021). Acute nicotine administration in planaria has been observed to steadily modify the animals' movement, which has been interpreted as evidence of tolerance and withdrawal effects (Sal et al., 2021). Nicotine withdrawal can cause many negative symptoms; however, withdrawal-related cognitive abnormalities are becoming more well-known as a core dependent phenotype and target drug research (Ashare et al., 2014). These withdrawal-related cognitive deficits can be objectively evaluated in animals and people (Ashare et al., 2014).

Nicotine primarily interacts with ligand-gated ion channels known as nicotinic acetylcholine receptors in vertebrates. These receptors are divided into two main classes: muscle-type and neuronal type. In 2015, Pagan and colleagues studied the effect of cocaine and nicotine on planaria undergoing regeneration. They discovered that cocaine causes hyperkinesia in planaria via targets in the cephalic ganglia. In contrast, nicotine can cause similar behaviour in the absence of the planarian brain, implying extracephalic binding sites (Pagán et al., 2015). Pagan and colleagues did not characterize the specific nature of the pharmacological targets for cocaine or nicotine within the planaria, but their results are consistent with the operational definition of receptor targets; a receptor must recognize a distinct chemical entity and translate information from that entity into a form that the cell can read to alter its state accordingly (Kenakin & Bond, 1992).

The objective of this study is to examine the relationship between an applied electromagnetic field created to mimic geomagnetic storm activity and the behaviour of a biological system. Working with the animal model planaria and a Helmholtz coil connected to a computer, we applied the synthetic geomagnetic storm field to groups of planaria and following exposure, recorded their behaviour. To examine the effect of the applied synthetic geomagnetic storm field on withdrawal behaviour, we created a group of planaria exposed to 10μM solution of nicotine 24 hours prior to the applied synthetic geomagnetic storm field exposure.

Methods

Planaria

A total of 509 planaria were used for the experiment. Planaria (Dugesia tigrina) were housed in a fridge at 4 degrees Celsius and fed calf liver weekly. Housing planaria at such a low temperature is not common practice, but we have found that it effectively prevents mass mortalities. They were always kept in President's Choice spring water. Before any experimentation began, planaria were given 5–10 min to acclimatize to room temperature and were not used within three days of being fed. All experiments were completed between 10 am and 10 pm.

Nicotine Exposure

Planaria in the nicotine-exposed group were exposed to a 10μM solution of nicotine within a cuvette for 5 minutes. After exposure, the planaria were stored in 20mL of President's Choice spring water in a dark cupboard for 24 hours to elicit nicotine withdrawals. Following the 24 hours wait period, planaria then underwent behavioural measures.

Behavioural Measures

Each planarian was observed for 3 minutes within a petri dish filled with 20mL of spring water on top of 1 cm grid paper following a one-hour field exposure. For an example image of the observation setup please refer to Appendix A. To measure mobility, each time a planarian crossed a 1cm grid, that would be recorded as one movement commonly referred to as grids crossed. The other behaviour that we observed is categorized as aversive behaviour. Aversive behaviour only occurs when planaria are exposed to endangering environments and are rarely if ever observed when the planaria is in water. The three types of aversive behaviour measured was a corkscrew, "c" shape and head whips. A corkscrew behaviour is observed when the body of the planaria twists overtop itself to form a coil like shape. A "c" shape behaviour is observed when the head and tail of the planaria curve tightly towards one another to form the shape of "c" compressing the length of the body to less than half of its original length. Head whipping behaviour is observed when the planaria shakes its head from left to right, the motion is quick and distinctive compared to the planaria turning its head to move.

Electromagnetic Field (EMF) Application

The magnetic fields were generated within a Helmholtz coil (30 ohms, 20 AWG wire). The magnetic field pattern was produced by converting a column of numbers between 0 and 257 to –5 V to + 5 V (127 = 0 polarity) through a custom constructed digital-to-analogue converter. These values were controlled by a Zenith ZF 148-42 (Intel 8008 16bit CPU with 4.7 MHz or 8 MHz operations) computer and custom-designed software (Complex-2). For a visual mockup of what this setup entails, refer to Appendix B.

Complex Field Generation

The synthetic geomagnetic storm field pattern used consisted of 5072 points (Mulligan & Persinger, 2012). Each point occurred for 69 msec to produce a 7 Hz square wave magnetic field pattern that was amplitude-modulated from 0nT to the maximum value set by the experimenter for 1-hour intervals. A figure of this wave pattern has been published previously (Cook & Persinger, 2000). The concept of this field was derived from the average value and characteristics of sudden geomagnetic impulses. The amplitude of the maximum peak of the intensity was controlled by computer software. It could range between 0 to 900nT as measured by a Metex multimeter and a magnetic sensor in the center of the coil (Mulligan & Persinger, 2012). A Helmholtz coil, a device used for producing an area with a nearly uniform magnetic field, was used to generate the synthetic geomagnetic storm field.

Symmetrical Field Generation

The symmetrical field used was a sinewave. The sinewave was used as an electromagnetic field control. Research has shown that temporary symmetrical magnetic fields, such as the sinewave, have no statistically significant influence on behaviour (McKay et al., 2000). Therefore, waveform, rather than wave intensity, might be the significant factor causing the effects of weak EMF (McKay et al., 2000).

Sham Generation

Planaria that received the sham condition were placed within the Helmholtz coil with the computer turned on and no field running. The sham is to reassure that it is a field that creates the affect and not simply the environment in which the experiment occurs.

Statistical Analysis

One-way analysis of variance, t-tests, and non-parametric mean analyses was conducted to observe any group differences. All statistics were performed on Windows PC with SPSS 20.

Results

A paired-samples t-test was conducted to compare the mobility of planaria from the control condition and the nicotine exposed condition. On average, planaria crossed more grids when exposed to nicotine compared to the control condition ($t(507)=10.5$, $p<0.001$). Results are shown in Figure 3.1.

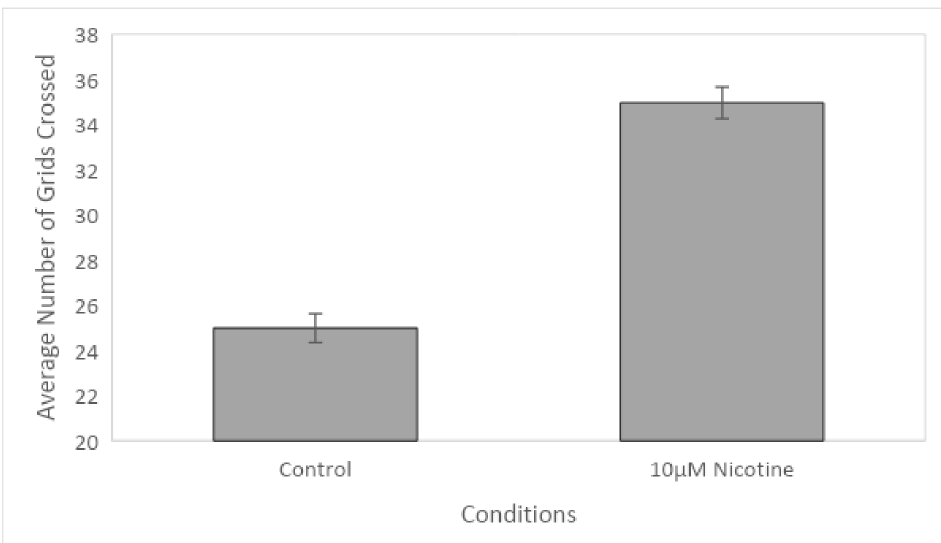

Fig. 3. 1. Bar graph (n=507) comparing the average number of grids crossed by planaria in the control and nicotine exposed conditions. The error bars represent the standard error of the mean (SEM). ($t(507)=10.5$, $p<0.001$).

Figure 3.2 shows the results of a paired samples T-test comparing total aversive planaria behaviour from both the control condition and nicotine exposed condition. The aversive behaviour entails: corkscrew, "c" shape and head whips. When exposed to nicotine, planaria, on average, significantly exhibited more aversive behaviour ($t(507)=10.8$, $p<0.001$).

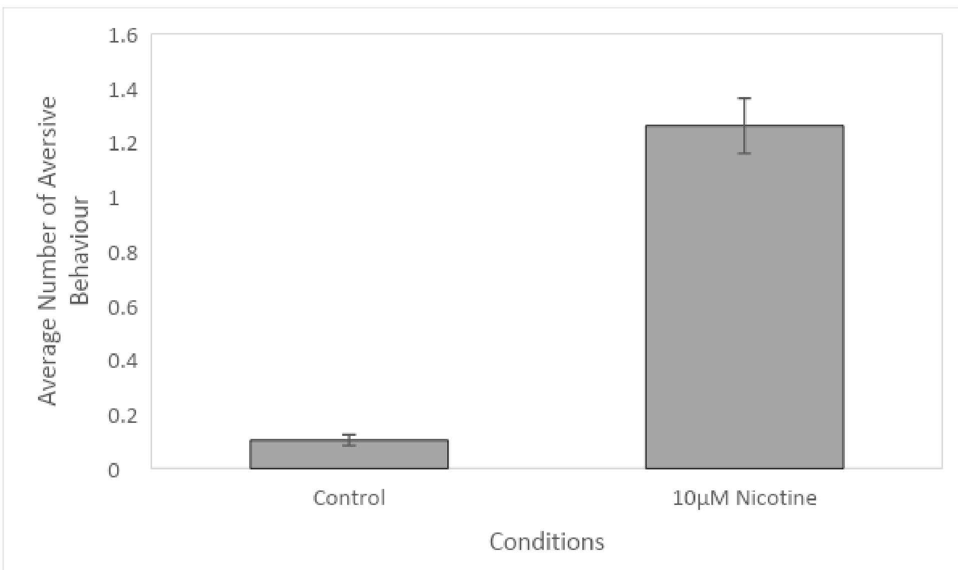

Fig. 2.2. Bar graph (n=507) comparing the average number of aversive behaviours exhibited by planaria in the control and nicotine exposed conditions. Error bars represent SEM. ($t(507)=10.8$, $p<0.001$).

A one-way ANOVA was performed to compare planaria aversive behaviour from both the control and nicotine exposed groups across the three different EMF conditions; sham, sinewave, and synthetic geomagnetic storm field. Results showed that there is no difference in aversive behaviour between the sham and sinewave exposure groups. However, there is a significant increase in aversive behaviour in the synthetic geomagnetic storm field condition, $f(2,508)=5.8$, $p=0.003$ compared to the sham ($t(415) = -2.78$, $p<0.05$) and sinewave ($t(403) = -2.36$, $p <0.05$) EMF exposures. The results are shown in Figure 3.3. It is interesting to note that this increase does not occur when comparing grids crossed across the three different EMF conditions. A non-parametric test was conducted to confirm that this is a main effect and not an interaction between the EMF and nicotine-exposed planaria.

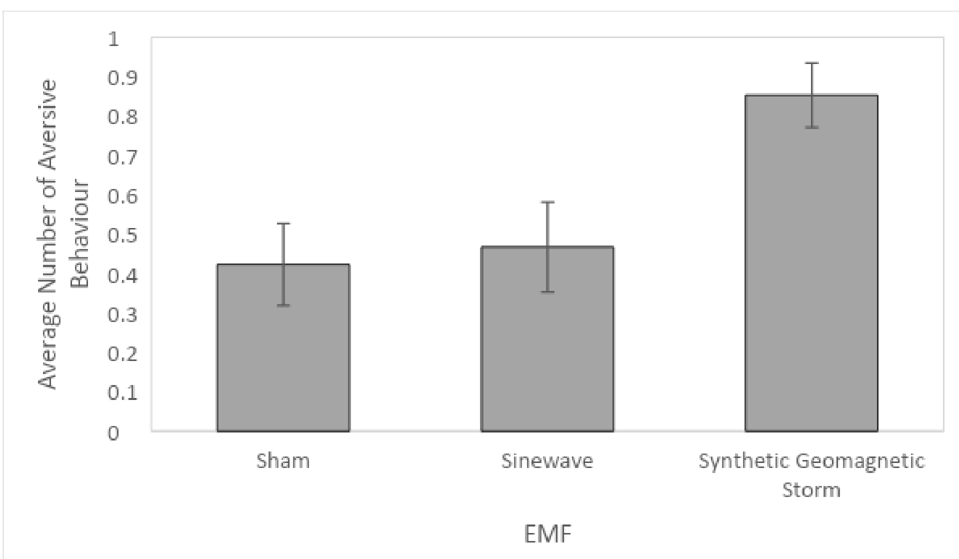

Fig. 3.3. Bar graph (n=508) comparing the average number of aversive behaviours exhibited in planaria across the three EMF conditions; sham, sinewave and geomagnetic field. The error bars represent SEM. sham (t(415) = -2.78, p<0.05), sinewave (t(403) = -2.36, p <0.05) and geomagnetic field condition (f(2,508)=5.8, p=0.003).

A one-way ANOVA was completed to compare the number of grids crossed from both the control and nicotine exposed planaria groups with the six intensities of synthetic geomagnetic storm field exposures: 0μT, 0.1 μT, 0.9 μT, 1.8 μT, 2.6 μT and 3.5μT. There is a significant difference of the amount of grids crossed between groups (f(5,415)=3.5, p=0.004). 0.1μT is significantly different from sham (t(162)=3.47, p=0.001), 0.9μT (t(122)=3.47, p=0.001), 1.8μT (t(120)=2.55, p<0.05) and intensity 2.6μT (t(120)=2.85, p<0.05). The results are shown in Figure 3.4.

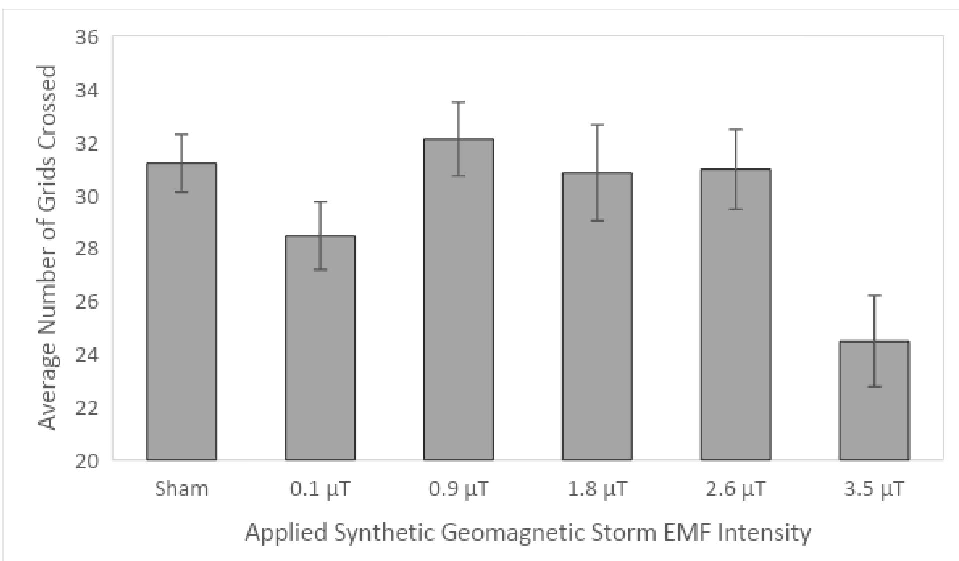

Fig. 3.4. Bar graph (n=415) comparing the average number planaria crossed grids in ranging geomagnetic intensity; 0μT, 0.1 μT, 0.9 μT, 1.8 μT, 2.6 μT and 3.5μT. The error bars represent SEM. There is a significant difference of the amount of grids crossed between groups (f(5,415)=3.5, p=0.004). Intensity 0.1μT is significantly different from sham (t(162)=3.47, p=0.001), 1.8 μT (t(122)=3.47, p=0.001), intensity 2.6μT (t(120)=2.55, p<0.05) and intensity 2.6μT (t(120)=2.85, p<0.05).

A one-way ANOVA was completed to compare the aversive behaviour seen in nicotine exposed planaria across the six varying synthetic geomagnetic storm field intensity conditions; 0μT, 0.1 μT, 0.9 μT, 1.8 μT, 2.6 μT and 3.5μT. A significant difference in aversive behaviour was observed between the groups $f(5,213)=2.5$, $p=0.03$. The results are shown in Figure 3.5. The sham exposure is significantly different from intensity 0.1 μT ($t(166)=2.08$, $p<0.05$), intensity 0.9 μT ($t(166)=2.92$, $p=0.004$), intensity 1.8 μT ($t(164)=2.09$, $p<0.05$) and intensity 2.6 μT ($t(164)=2.64$, $p<0.05$). Interesting enough, sham is not significantly different from intensity 0.1 μT.

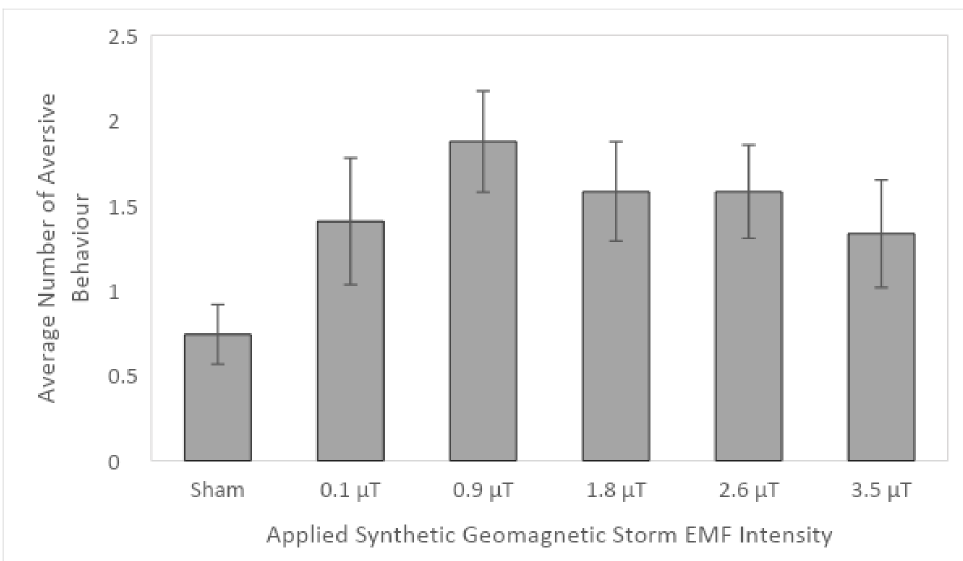

Fig. 3.3. Bar graph (n=415) comparing the average number of aversive behaviour exhibited in planaria across a range of geomagnetic field intensity; 0μT, 0.1 μT, 0.9 μT, 1.8 μT, 2.6 μT and 3.5μT. The error bars represent SEM. The results are shown in Figure 3.5. The sham exposure is significantly different from intensity 0.1 μT (t(166)=2.08, p<0.05), intensity 0.9 μT (t(166)=2.92, p=0.004), intensity 1.8 μT (t(164)=2.09, p<0.05) and intensity 2.6 μT (t(164)=2.64, p<0.05). Interesting enough, sham is not significantly different from intensity 0.1 μT.

Discussion

Overall, we found differences in behaviour exhibited from planaria exposed to nicotine compared to control groups and that EMF exposure does influence these behavioural differences. Planaria exposed to nicotine crossed more grids and exhibited significantly more aversive behaviour than control planaria. Regardless of whether they were exposed to nicotine or were in the control group, they exhibited significantly more aversive behaviour when exposed to the synthetic geomagnetic storm field than the sham or sinewave field exposure. We broke down the synthetic geomagnetic storm field condition into five different intensities, 0.1 μT, 0.9 μT, 1.8 μT, 2.6 μT and 3.5μT, to explore a dose curve. The intensity of the synthetic geomagnetic storm field did influence the number of grids crossed in planaria from both the control and nicotine exposed condition. Regarding aversive behaviour, only planaria exposed to nicotine showed differences in the number of aversive behaviours exhibited depending on the synthetic geomagnetic storm field intensity.

The difference in movement and aversive behaviour in planaria previously exposed to nicotine compared to planaria in the control condition provides further evidence that nicotine elicits mammalian-like effects in planarians. After a five-minute exposure to nicotine and a twenty-four-hour withdrawal period, planaria mobility and aversive behaviour significantly increased which can be compared to withdrawal symptoms in humans. The increased mobility mirrors a pacing-like behaviour in humans while the increased aversive behaviour mirrors the jumpy and restlessness behaviour observed in humans going through nicotine withdrawals (*7 Common Withdrawal Symptoms*, n.d.). Planaria are a cheap and effective animal model that can help further study the effects of nicotine and withdrawal that can be applied to human behaviour.

When exposed to the synthetic geomagnetic storm field, mobility in planaria from both the control and nicotine exposed groups increased. Whether this behaviour resulted from the water being affected by the field or the planaria being affected by the field is currently inconclusive. However, in 2011, Gang and Persinger conducted a study to examine the effect of geomagnetic fields on water and planaria; they exposed a geomagnetic field to water for 24 hours then housed planaria in the exposed water (Gang & Persinger, 2011). The aim of the study was to rule out that the affects observed in planaria were not caused by changes made to the water but rather the field itself. Planaria housed in the field exposed water showed increased mobility compared to the control group-housed in regular water. These results imply that nonlinear biophysical effects may emerge under specific conditions of intensity ranges for particular volumes of water (Gang & Persinger, 2011).

Regarding aversive behaviour, the synthetic geomagnetic storm field exposure exacerbated the withdrawal-like symptoms from the planaria exposed to nicotine; we saw an apparent increase. There was no observable difference in aversive behaviour between any of the EMF exposures in the planaria control group, including all the synthetic geomagnetic storm field intensities, sinewave, and sham. In humans, geomagnetic disturbances have been associated with mood disturbances at a level that would not lead to admission except in those predisposed to developing severe depressive illness. One study has described up to 40% of daily mood variation being accounted for by the daily mean AP index of geomagnetic disturbance (Michael A.

Persinger & Levesque, 1983). Strong geomagnetic disturbances can negatively affect an individual's ability to handle mental and physical stress; this effect is hazardous for individuals who work in high-stress environments (Babayev & Allahverdiyeva, 2007). The complexity of the temporal form of the applied magnetic fields might allow significant biological effects at intensities lower than a simple form such as a sinewave. While sinewave fields do not affect contextual fear conditioning, precise patterns of magnetic fields when applied for 30min to adult rats affected specific behaviours strongly correlated with similar patterns endogenously generated within different brain structures (Cook & Persinger, 2000; McKay et al., 2000; M. A. Persinger, 2003). The effective intensities were between 20 and 2,000 nT, or 0.2 to 20 mG, well within the range of routine human exposure. These results further support the idea that there is not only a correlation between geomagnetic field activity and brain activity but a correlation between geomagnetic field activity and behaviour in various species (Cherry, 2002; Michon and Persinger, 1997).

Overall, the intensity of the synthetic geomagnetic storm field influenced planaria behaviour; the relationship between the two seems to be nonlinear. It was neither the lowest intensity nor the highest intensity of a synthetic geomagnetic storm field that created the most prominent effect in an organism but rather somewhere in between; intensity 0.9 μT seems to be around the peak of activity influence as it is the most significantly different from sham. These results could be an example to support Cosic's Resonant Recognition Model for Macromolecules (Cosic, 1994). According to Cosic's hypothesis, particular macromolecules are linked to an optimal spectrum. Thus, the particular cellular process that affects planaria activity might be associated with a specific intensity of geomagnetic field exposure that results in increased behaviour (Rouleau & Dotta, 2014). Further research will need to look deeper into more discrete intensities to discover the optimal intensity for maximum planaria activity influence; hopefully, such research will find the optimal intensity for other desired effects.

Understanding the relationship between space weather and human health is crucial, especially in mitigation and prevention, particularly for people who reside at high geomagnetic latitudes where geomagnetic disturbances are severe. If further research can identify how space weather affects the human body, we may be able to predict how society will react to such environmental factors and better prepare and help those who are sensitive to mental and emotional changes brought on by such factors.

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CHAPTER FOUR:
GENERAL DISCUSSION

Overall, this thesis encompasses how non-traditional environmental factors can affect brain activity; Specifically, background photon emission and geomagnetic field activity.

We examined the relationship between background biophoton emission and geomagnetic field activity with human brain activity. We utilized a database comprising of EEG activity from various participants over several years. We included the daily background photon emission that corresponded with the day the EEG activity was recorded for each participant and gathered the geomagnetic field K index for the time during the recording. We analyzed the brain activity with the background photon emission data and geomagnetic field data. Regarding background photon emission, our research found that increased background photon emission corresponds with increased theta and alpha activity from the frontal lobe. Regarding geomagnetic field activity, we found that as concurrent geomagnetic activity increased, we saw an increase in alpha power from the whole right hemisphere. Concluding that background photon emission and the geomagnetic field activity correlates with human brain activity.

We also studied the effect that an applied synthetic geomagnetic storm field has on normal planaria behaviour and planaria withdrawal behaviour. Planaria were either briefly exposed to nicotine then observed following 24 hours or were solely kept in spring water. The nicotine exposure created withdrawal behaviour. Our results showed that an applied synthetic geomagnetic storm field increased overall planaria movement. Regarding the nicotine-exposed planaria, we found that an applied synthetic geomagnetic storm field exacerbated withdrawal behaviour. Concluding that a synthetic geomagnetic storm field affects planaria behaviour, we can speculate that with further experimentation the same can be said to human behaviour, particularly populations struggling with drug addiction and withdrawal.

This research further supports the hypothesis that there is a correlation between background photon emission, geomagnetic field activity and the human brain activity (Dotta et al., 2012; Mulligan et al., 2010a; Persinger & Lavallee, 2010; Rouleau & Dotta, 2014).

This thesis demonstrates the importance of considering how non-traditional environmental factors, specifically background photon emission and geomagnetic field activity, could be influencing human behaviour. One important result that was consistent across the experiments discussed in this thesis, is that geomagnetic field activity does correlate with brain activity and behaviour. The first experiment shows a linear increase in right hemisphere brain activity and geomagnetic field activity and the second experiment shows that an applied synthetic geomagnetic storm field increased planarian mobility and aversive behaviours in planaria exhibiting withdrawal behaviour.

The majority of society is unaware of photon emission and electromagnetic fields, let alone background photon emission and geomagnetic fields. Knowing that these environmental factors can influence everyday brain activity could help individuals understand their emotions since the right hemisphere of the brain is correlated with mood (Mulligan et al., 2010b). These results give an important insight to not only how the general population may react to non-traditional environmental factors but also populations who struggle with drug withdrawal. For example, individuals struggling mentally on regular days may be worse off on days that correspond to geomagnetic storm activity. This research is valuable to health care providers and those who work at places that support mentally ill individuals. If we can predict when there might be an influx of people who need help, these organizations can be better prepared to have the proper care and staffing to help all those in need.

The database created for this thesis can be utilized for future studies. We can further examine correlations between brain activity, background photon emission and geomagnetic field activity, and more categories can be included, such as various weather variables. As our lab collects more EEG data from participants, we can include their recordings in the curated database. We can add the corresponding background photon emission and geomagnetic field activity data to new EEG data to continue looking at the effects this thesis found and perhaps uncover future correlations.

As discussed earlier, working with planaria as an animal model has plenty of benefits, but they are still a rudimentary comparison to humans. However, since planaria are cheap and easy to house compared to other animal models, we can use a significantly larger sample size of planaria to test out different hypotheses. Research utilizing planaria is a good preliminary study to uncover results without expending expensive animal models. When planaria studies conclude with significant results, further experiments can occur with higher-order animals such as rats without the fear of wasting an animal model that costs more and takes up more time to care for just to end with a null experiment.

Overall, our research has provided further evidence of a correlation between background photon emission, geomagnetic field activity and brain activity. As geomagnetic field activity or background photon emission increased, we saw an increase in brain activity. As background photon emission increased, theta and alpha activity from the frontal lobe increased. As geomagnetic field activity increased, alpha power from the whole right hemisphere of the brain increased. We also found a correlation between geomagnetic field intensity and planarian behaviour. Depending on the intensity of the synthetic geomagnetic storm field, mobility in planaria from all conditions increased and aversive behaviour in planarian exhibiting nicotine withdrawal increased. As we begin to understand how invisible non-traditional environmental factors correlate with brain activity, we can use what we know about these non-traditional environmental factors to help society. As seen with the planaria study, there is evidence of a correlation between a synthetic geomagnetic storm field and behaviour. If further research uncovers a true relationship between human behaviour and geomagnetic field activity, we can utilize the predicted changes in the geomagnetic field activity to predict how humans may react to these changes behaviourally. Increased geomagnetic field activity has been correlated to increased mental and physical health issues. Such predictions could help prepare different aspects of society such as health care for the influx of susceptible individuals to such changes in the geomagnetic field.

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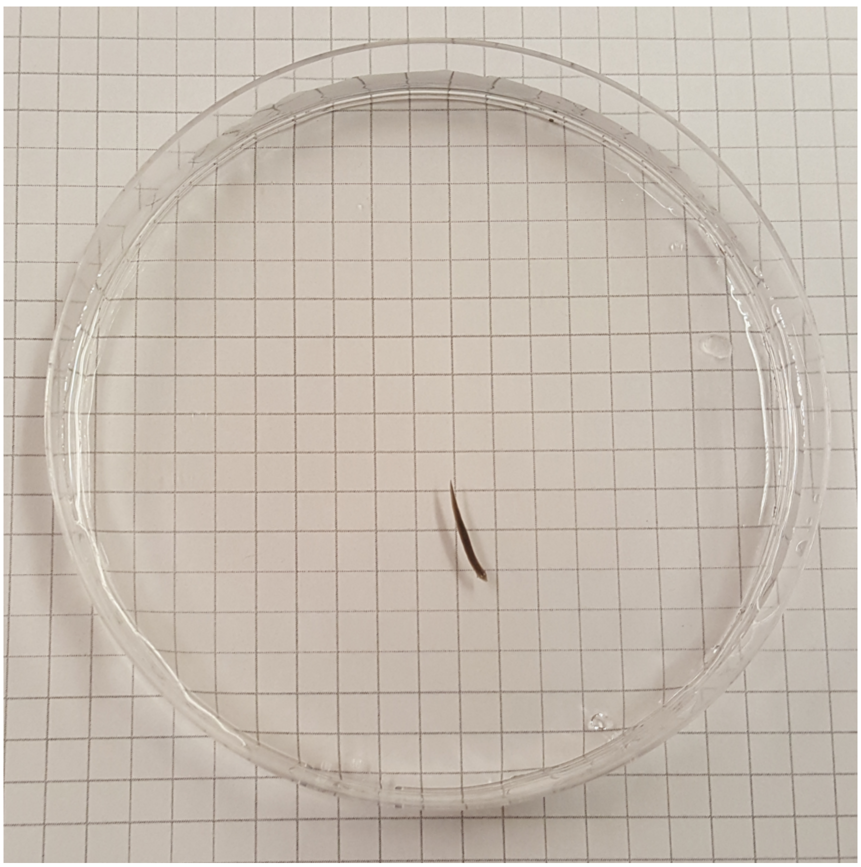
https://doi.org/10.3389/fnint.2014.00084

Appendix

Appendix A: Image of a single planaria in a petri dish filled with water, placed on top of 1cm grid paper.



Appendix B: Graphic created to represent the setup of for applying electromagnetic fields.