NATURAL VARIATION IN GEOMAGNETIC PULSATIONS AND PRESCHOOL CHILDREN'S SLEEP DISTURBANCE AND MOTOR ACTIVITY LEVELS

by

Gen Mitsutake

A thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

Master of Arts

Department of Psychology
University of Manitoba
Winnipeg, Manitoba

National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisitions et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

0-612-62799-3

Canada

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

NATURAL VARIATION IN GEOMAGNETIC PULSATIONS AND PRESCHOOL CHILDREN'S SLEEP DISTURBANCE AND MOTOR ACTIVITY LEVELS

BY

GEN MITSUTAKE

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

Manitoba in partial fulfillment of the requirement of the degree

of

MASTER OF ARTS

I hereby declare that I am the sole author of this thesis.

I authorize the University of Manitoba to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Gen Mitsutake

I further authorize the University of Manitoba to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Gen Mitsutake

Table of Contents

Acknowledgements

I would like to thank Dr. Warren O. Eaton for his persistent and invaluable help, Dr. Ian J. Ferguson for his kind and useful advice on the analysis of geophysical data, and Dr. Jim Nickels for his precious advice on the research design. I would also like to thank the 'Eaton lab' for their support and friendship. Thank you as well to my family for their patience. Finally, thank you to the children and their parents who contributed their precious time and effort to this study.

Abstract

This study evaluated the putative association between fluctuations in preschool-aged children's motor activity level (AL) and fluctuations in the intensity of the earth's magnetic field, referred to as geomagnetic pulsations. A sample of 32 preschoolers wore two different types of activity monitors on their right ankles for five hours once a week for ten weeks. A measure of child's sleep was completed by each child's parent on the morning of each activity assessment. It was hypothesized that high-amplitude pulsations in the intensity of the earth's magnetic field would, by disturbing their sleep the night before, decrease children's AL. Sleep disturbance and AL measured on geomagnetically active days were contrasted with the same measures on geomagnetically quiet days. Three different thresholds for defining geomagnetically active days were evaluated. Regardless of threshold used, sleep disturbance was unrelated to differences in geomagnetic activity. However, when the highest threshold was used to define a geomagnetically active day and contrasted with the quietest day, AL was significantly lower on the geomagnetically active day. It is concluded that the evidence provides some tentative support for a link between geomagnetic disturbances, which are "rapidly varying perturbation to Earth's magnetic field" (National Academies, 2001), and activity level, but this link does not appear to be mediated by sleep disturbance.

Introduction

On March 13, 1989, in Montreal, Quebec, 6 million people were without electric power for 9 hours because a strong magnetic disturbance on the earth disrupted a major electric power grid (Rostoker, 1998; Space Environment Center, 1998a). Power grids may not be alone in their susceptibility to such influences. Scientists in the fields of biology, psychology, and medicine have postulated that living cells are acutely sensitive to the earth's magnetic field, referred to as the geomagnetic field. Such a magnetic disturbance on the earth is harmful not only to electrical transmission equipment but also to life on the earth (Space Environment Center, 1998a). According to work by Becker, Brown, Marino and others (as cited in Savage, 1994), "delicate magnetic fluctuations may affect some basic biological functions such as metabolic rates, immune response, orientation systems and sleep-and-wake cycles."

Cases for linking changes in the geomagnetic field to observable changes, particularly in higher life form behavior, can be found in the scientific literature. Persinger (1997) found that intense aggression in chronic limbic epileptic male rats was most frequently seen during large and fast fluctuations in the geomagnetic field. Other studies have indicated the geomagnetic field disturbances may affect some migratory animals' navigational ability. The hypothesis is that migratory animals such as pigeons, dolphins and whales, have internal biological compasses, which are composed of the mineral magnetite wrapped in bundles of nerve cells because these animals' geographic orientation is significantly assisted by this compass, when the compass is disabled, the animal becomes disoriented (Space Environment Center, 1998a). Pigeon handlers have observed and documented that only a small percentage of birds return home from a distant release site during disturbances of the geomagnetic field, as compared to pigeon races when the fluctuations were minimal (Space Environment Center, 1998a).

In studies using mice brains, Agadzhanyan and Vlasova (1992) found that electromagnetic fields at 5 Hz (with magnitude 100 nanoteslas) induce two types of response in surviving slices of mouse cerebellum: inhibition and excitation of the impulse activity of neurons in the brain cellular tissue. According to Aleksandrov (1995), a rise in the geomagnetic field activity is associated with an immediate increase in motor activity in fish, which is followed by states of low and extremely low activity. However, it is not known if the same pattern of effects observed in fish can be found in other species. Chibisov, Breus, Levitin, and Drogova (1995) investigated the effects of two successive geomagnetic storms, which are extraordinary fluctuations in the geomagnetic field intensity, on the cardiac activity of rabbits, and found that the initial and main phases of the geomagnetic storm were accompanied by rising and falling contractile forces of the heart as the storm developed. Moreover, Chibisov et al. also found that the storm was accompanied by degradation and destruction of mitochondria and loss of the circadian rhythmicity in the heart rate of rabbits.

The preceding studies all focused on non-humans; however, there are also some reports on the effects of the geomagnetic field activity on both human physiology and behaviors. According to Pasucal et al. (1992), some researchers found that “magnetic stimulation shortens reaction time by inducing earlier initiation of excitability increase.” Belisheva et al. (1995) stated that sudden and considerable fall in the level of the geomagnetic field intensity may cause an unstable state in the human brain. Persinger and Richards (1995) argued that both balance (vestibular experiences) and brain activity in humans have been linked to the geomagnetic field activity. Breus, Halberg, and Cornelissen (1995) saw a causal relationship between functional changes in the physiological indices of the cardiovascular and nervous systems, and strong disturbances in the geomagnetic field. According to Breus et al., "the magnetic field carried with the solar wind" (Lehtoranta, 1997), referred to as the interplanetary magnetic field, possesses rhythms corresponding to the infradian rhythms of biological systems. Ghione, Mezzasalma, Del-Seppia and Papi (1998) assessed blood pressure monitoring for diagnostic purposes over five years, and found significant, positive correlations between geomagnetic activity and systolic (daytime and 24-hour) and diastolic (daytime, nighttime, and 24-hour) blood pressures. They also found significantly higher values of blood pressure parameters for all blood pressure parameters but for systolic night-time pressure on the geomagnetically disturbed days. In the same vein, Watanabe et al. (1994) analyzed blood pressure data obtained from a 35-year-old cardiologist with a family history of high blood pressure and stroke, through around-the-clock monitoring for three years. They found statistically significant coherence at 27.7 days between systolic and diastolic blood pressure and geomagnetic disturbances, which are "rapidly varying perturbation to Earth's magnetic field" (National Academies, 2001). Silva, Moreira, Bicho, Paiva, and Clara (2000) stated that higher rates of arousal and shorter duration of the REM sleep were positively correlated with higher levels of nighttime systolic and diastolic blood pressure, and that sleep efficiency was also negatively correlated with mean levels of nighttime diastolic blood pressure. Thus, geomagnetic disturbances may be associated with elevated blood pressure, which in turn reduce sleep quality. Oraevskii et al. (1998) found that the reaction of astronauts to disturbances of the geomagnetic field involved nonspecific adaptation reaction, such as increase and stabilization of heart rate, and decrease of the heart rhythm variability and the power of respiratory waves. Halberg et al. (1998) found that the heart rate spectrum of a 28-year old, who spent a span of 267 days underground, showed a fluctuation pattern similar to that in the geomagnetic field activity. Otsuka et al. (in press) found heart rate variability was negatively correlated with geomagnetic activity, which may reflect an alteration of arterial pressure due to an alteration in geomagnetic activity. According to Burch, Reif, and Yost (1999), geomagnetic disturbances are positively correlated with incidents of epileptic seizures, myocardial infarction, stroke, sudden infant death syndrome, suicide and depression. In analyzing data of daily numbers of myocardial infarction incidence rates and number of deaths of infarction in 1989 and 1990, abstracted from registries of the 14 biggest hospitals of St. Petersburg, Villoresi, Ptitsyna, Tyasto, and Iucci (1998) also found a statistically significant increase in myocardial infarction rate during large disturbances in the geomagnetic field activity.

Becker (1972) stated that geomagnetic disturbances are significantly and positively correlated with behavioral disturbances in the human population. Chibrikin, Samovichev, and Kashinskaia (1995) did a statistical study on the link between geomagnetic field disturbances and the crime rate in Moscow, and found a significant positive correlation between the two. Fluctuations in the geomagnetic field activity have been negatively correlated with attempted suicide and self-injury rates (Ganjavi, Schell, Cachon, & Porporino, 1985). In a related vein, Sandyk, Anninos, and Tsagas (1991) suggested that the geomagnetic field activity may be positively correlated with winter depression, and that a combination of light and magnetic treatment could be the optimal therapy for winter depression. According to Persinger, Richards, and Koren (1994), the geomagnetic field activity may have a greater influence on diffuse, affective states such as the pleasantness-unpleasantness dimension of experiences, than previously suspected. Halberg, Cornelissen, Katinas, Hillman, and Schwartzkopff (2001) contend that disease risk syndromes may not be recognized unless a complex concept of time structure, "chronome", that supersedes a misconception that our body is controlled only by homeostasisis resolved. According to them, chronome consists of three components: (1) multi-frequency rhythms (i.e., 24-hour rhythm, 1-week rhythm, 1-year rhythm, etc.); (2) trends (i.e., aging, disease, and treatment); and (3) noise (other unresolved but measurable variation including 11-year sunspot cycles and other geophysical cycles such as half-year cycles in the geomagnetic field activity). Those studies use different geomagnetic indices. Thus, although different studies use different geomagnetic indices and the link is not widely accepted, this diverse set of findings suggests a possible link between the geomagnetic field activity and human behavior that merits further investigation. In the next section, I will discuss geomagnetic measure that seems to be appropriate in exploring biological effects of geomagnetic activity.

What is Appropriate Measure of Geomagnetic Activity?

One of the most common measures of geomagnetic activity is K-index (0 through 9), which is designed to provide a running record of solar activity by measuring irregular geomagnetic activity due to particle radiation from the sun (Jacobs, 1989). According to Jacobs, it indicates, at three-hour intervals (i.e., 00-03, 03-06, ..., 21-24 UT), the amplitude of irregular geomagnetic activity in the horizontal component of the geomagnetic field, taking daily geomagnetic variation due to solar radiation into account. As shown in Figure 1, each K value is assigned to a corresponding amplitude or a vertical

---

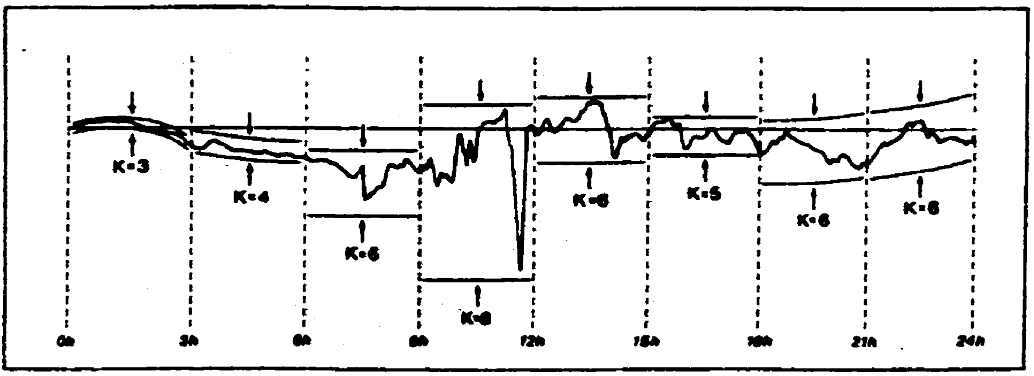


Figure 1. A time-by-amplitude plot showing a typical geomagnetic variation in the horizontal component showing the ranges corresponding to the K values assigned to each 3-hourly interval for that day (from *Introduction to Geomagnetism* (p. 284), by W. D. Parkinson, 1983, Edinburgh: Scottish Academic Press Ltd.). The horizontal axis represents universal time, while the vertical axis represents amplitude in nT.

---

range of the horizontal geomagnetic intensity for each 3-hourly interval for that day (Parkinson, 1983). According to Parkinson, each observatory has its own scale so that every observatory has about the same frequency distribution of K-indices. For decades, the K index has been used in correlational studies of biological activities and their possible link to geomagnetics.

Lakhovsky (1939) claimed that a living cell is like a wireless apparatus, having the dual power of transmitting and receiving electromagnetic waves. He argued that each species has cells that have a characteristic wavelength determined by the form and dimensions of the cells. If what matters with our physiology and behavior is the frequency, as Lakhovsky insisted, rather than the amplitude of ambient electromagnetic waves to which we are exposed, it becomes worth looking for the most bio-effective frequency band of ambient electromagnetic waves.

In examining the link between the geomagnetic activity and children's activity level and behavior, I found that children were more irritable following sudden falls in electron flux level measured at satellites in geostationary orbits (i.e., GOES-8, GOES-9, and GOES-10). According to Baker et al. (1998a) geomagnetic pulsations are strongly correlated with electron flux enhancements in the magnetosphere, which is a magnetic shield surrounding the earth. Hudson, Elkington, and Lyon (1999) analyzed the Ultra-low frequency (ULF) (0.001 - 10 Hz) oscillations, which were seen in geomagnetic disturbances in January, 1997, and found that the spectral power of the geomagnetic pulsations, measured at the ground-based Canadian Auroral Network for the Open Program Unified Study [CANOPUS] magnetometer chain, was enhanced (50-100 nT) several hours before the rise in electron fluxes measured at satellites at geostationary orbits. Moreover, Baker et al. (1998a; 1998b) infer that strong geomagnetic disturbances are associated with high-density population of magnetospheric electrons, which rapidly diffuses inward and is further accelerated by ULF waves (or geomagnetic pulsations). According to G. Rostoker of CANOPUS (personal communication, September, 1999), the fall in electron flux level measured at the GOES satellites is due to the diffusion of the magnetospheric electrons. Thus there is a link between geomagnetic disturbances, enhanced geomagnetic pulsations, which are small, sinusoidal pulsations that can often be seen in geomagnetic fluctuations in ULF range (Parkinson, 1983) and the fall in the electron flux level measured at satellites in geostationary orbits. Electron fluxes in the magnetosphere do not reach the surface of the earth (G. Rostoker, personal communication, September, 1999), but enhanced geomagnetic pulsations are observed on the ground.

Boteler et al. (1998) analyzed the spectra of ULF geomagnetic variations recorded at the Glenlea observatory (latitude 40.36° N; longitude 97.12° W), which is located about 4 km south of Winnipeg, Manitoba, Canada, and found that the mean spectral power decreases with increasing frequency. They also found that spectral power (across the whole frequency band) increases with planetary K index (Kp), which is "a 3-hourly planetary geomagnetic index of activity generated in Gottingen, Germany, based on the K-index from 12 or 13 stations distributed around the world" (Space Environment Center (1998b) (see Figure 2).

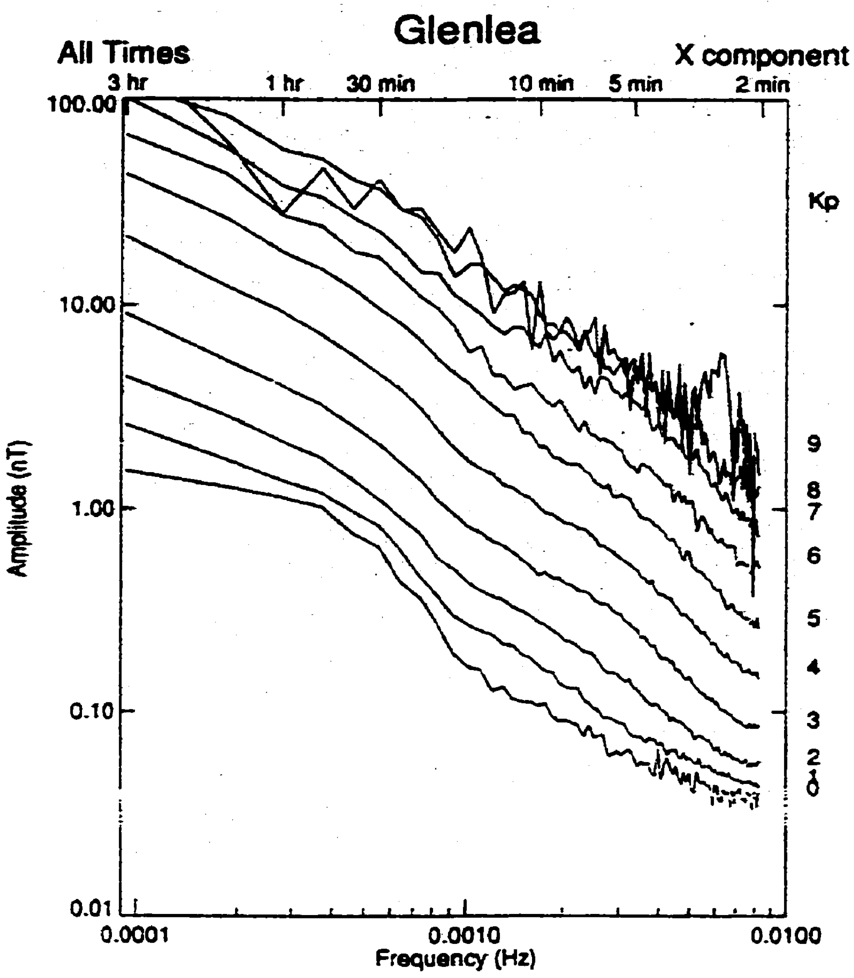


Figure 2. Mean spectra of the X component magnetic fields at Glenlea for different levels of magnetic activity, as given by Kp. The mean spectral power (as you move from left to right) decreases with increasing frequency. As geomagnetic activity, given by planetary K index (Kp), increases from 0 to 9, the spectral power (across the whole frequency band) increases (from *Geomagnetically induced currents: Geomagnetic Hazard Assessment Phase II, Final Report, 1* (p. 19), by D. H. Boteler et al., 1998, Ottawa: Geological Survey of Canada and Canadian Electrical Association).

According to Ptitsyna, Villoresi, Dorman, Iucci, and Tyasto (1998), there is a broad consensus in the international scientific community that exposure to low-frequency, low-intensity electromagnetic fields can produce biological effects despite the fact that the energy involved is quite small. Studies of some parameters of the blood system of rats exposed to magnetic fields in the frequency band of 0.01 to 100 Hz (with magnitudes 5, 50, and 5000 nT) revealed that magnetic fields at the frequencies 0.02, 0.5-0.6, 5-6, and 8-11 Hz were the most bio-effective, suggesting that ULF magnetic fields, including those of geomagnetic pulsations, are more bio-effective than "the power line" ELF (10 - 300 Hz) magnetic field (Otsuka et al., in press; Ptitsyna et al., 1998). Ptitsyna et al. also suggested that ULF magnetic fields may produce effects on nervous system and might be associated with cardiovascular disease and that living systems including humans, may have a special sensitivity to geomagnetic fields because the magnetoreception of neural structures should be evolutionarily adjusted to these fields. According to Ptitsyna et al., studies found the relation between ULF magnetic field fluctuations produced by electrified railways and cardiovascular morbidity among railway workers, especially among engine drivers, suggesting that elevated cardiovascular disease risk could be associated with an elevated occupational exposure to ULF magnetic fields. Moreover, Otsuka et al. (in press) recently examined heart rate variability of 19 clinically healthy 21- to 54-year-olds in Norway and compared group-averaged coherence between heart rate variability and the spectral power of geomagnetic pulsations with periods ranging from 10 minutes to 5 hours, under three different sunshine conditions (i.e., light/light (L/L), dark/dark (D/D), and dark/light (D/L)). They found statistically significant difference in coherence among the three sunshine conditions, the association being weaker during L/L or D/D and stronger during D/L, suggesting the presence of a light-dependent magnetoreception mechanism in humans involving geomagnetic pulsations.

The reasons that Pc 5 is preferred in the present study as a geomagnetic measure to other geomagnetic indices such as K index and geomagnetic hourly range (HRx) are that: (1) recent findings suggest possible associations of geomagnetic pulsations with heart rate variability and heart diseases; (2) Pc 5 is in the ULF range with its spectral power relatively higher than that of other geomagnetic pulsations in higher frequency bands; (3) the average spectral power of Pc 5 pulsations (5–50 nT) is large enough to stimulate neural depolarization in long-term coupling (S. Starbuck, personal communication, September 17, 1999); (4) the spectral power in Pc 5 range was moderately, positively correlated with local Ottawa K index; and (5) compared with the K index, which is based on 3-hourly data, Pc 5 can provide finer information on geomagnetic activity when shorter intervals are used for a spectral analysis. Thus, instead of the K-index, I used geomagnetic pulsations as a measure of geomagnetic activity. In the next section, I will discuss Pc 5 in more detail.

What is Pc 5?

Geomagnetic pulsations are small, sinusoidal pulsations that can often be seen in geomagnetic fluctuations, and are classified according to their continuity and period (Parkinson, 1983) (see Figure 3). According to Parkinson, there are two types of

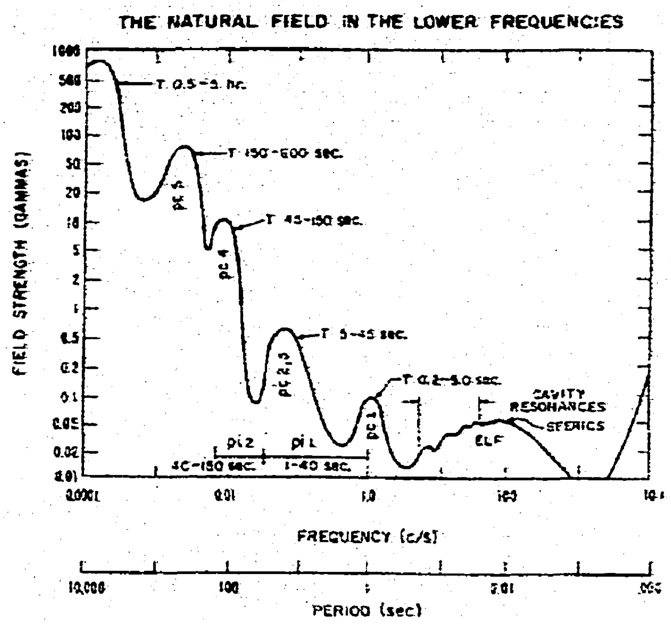


Figure 3. Nomenclature for the Natural Field Fluctuations (from *Introduction to Geomagnetic Fields* (p. 158), by W. H. Campbell, 1997, New York, NY: Cambridge University Press).

geomagnetic pulsations: one that continues with either steady or regularly fluctuating amplitude, known as "Pc" (pulsation continuous), and the other that resembles a damped oscillation, each group containing between 5 and 20 pulsation cycles, known as "Pi" (pulsation irregular). The period, amplitude, and frequency of occurrence of geomagnetic pulsations depend on sunspot number, geomagnetic latitude, degree of magnetic disturbance, time of day, and season of the year (Greenstadt, McPherron, Takahashi, & Southwood, 1979). Geomagnetic pulsations can be explained in terms of hydromagnetic oscillations in the magnetosphere resulting from energy input of the solar wind (Menk, 1993; Parkinson, 1983). According to Menk, this can be further explained by the possibilities that: (1) energetic solar wind particles penetrate the magnetosphere from the solar wind; (2) geomagnetic pulsations at the interface are generated from the viscous interaction between the streaming solar wind and plasma in the outermost boundary layer of the magnetosphere; and (3) the pulsations are generated at an inner layer of magnetosphere.

Of the geomagnetic pulsations, Pc 5's are generated by torsional oscillations of geomagnetic field lines excited by solar wind action at the magnetosphere (Parkinson, 1983). Pc 5's are broadly distributed in latitude, and they rapidly decrease in amplitude with distance form the auroral zone and increase near equator (Jacobs, 1970). Pangia, Lin, and Barfield (1990) suggested that the onset of strong geomagnetic disturbances is probably correlated with the occurrence of storm-time Pc 5 waves. Figure 4 shows

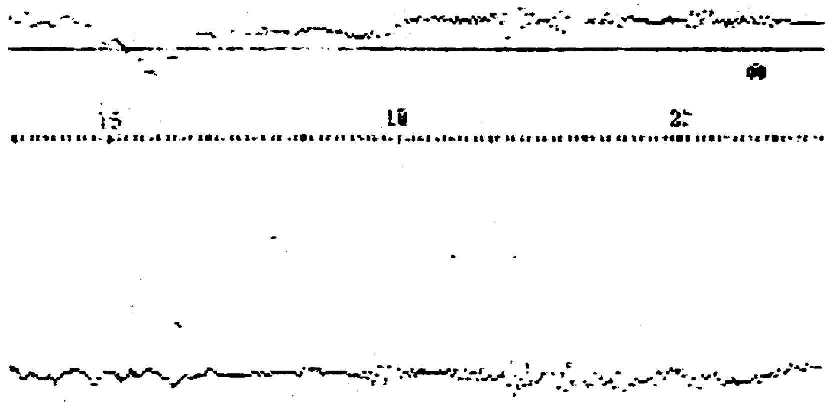


Figure 4. Several bursts of Pc 5 Pulsations recorded at Macquarie Island observatory. The upper trace is H-component and the lower D-component (from *Introduction to Geomagnetism* (p. 299), by W. D. Parkinson, 1983, Edinburgh: Scottish Academic Press Ltd.).

several bursts of Pc 5 pulsations from 1630 to 2200 UT recorded at Macquarie Island observatory (latitude 54.30° N; longitude 158.57° E;) (Parkinson, 1983). Figure 5 shows

---

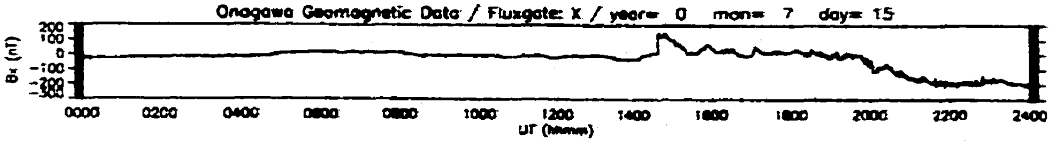


Figure 5. Geomagnetic Signals in Northward Component Observed at the Onagawa observatory on July 15, 2000. The horizontal axis stands for universal time (UT). The vertical axis stands for the amplitude (nT) of geomagnetic signals (from "Welcome to Takeshi Sakanoi Archive Files !," by Sakanoi, T., 2001, [WWW document]. http://pparc.geophys.tohoku.ac.jp/~tsakanoi/files.html).

---

a time-by-amplitude plot of geomagnetic signals in northward (X) component observed at the Onagawa observatory (latitude 38.26° N; longitude 141.29° E) on July 15, 2000 when a sudden enhancement in its amplitude was observed at the onset of an extreme geomagnetic storm at around 14:20UT. Figure 6 shows a time-by-spectral-power plot of

---

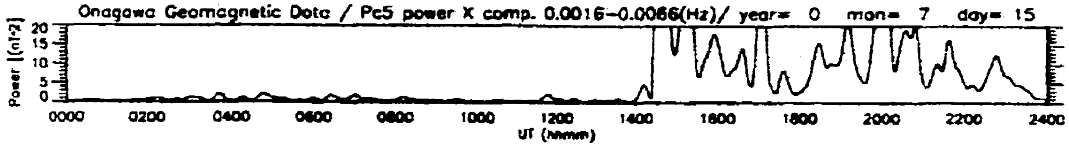


Figure 6. Geomagnetic Signals in Northward Component Observed at the Onagawa observatory on July 15, 2000. The horizontal axis stands for universal time (UT). The vertical axis stands for spectral power (nT^2) of the Pc 5 pulsations (from "Welcome to Takeshi Sakanoi Archive Files !," by Sakanoi, T., 2001, [WWW document]. http://pparc.geophys.tohoku.ac.jp/~tsakanoi/files.html).

Pc 5 pulsations in northward (X) component observed at the same observatory on the same day. The spectral power of Pc 5 pulsations also dramatically increased at the geomagnetic storm onset. What this means is that Pc 5 pulsations are closely related to solar activity and geomagnetic disturbances. Thus, Pc 5 pulsations should provide a good index for variation in geomagnetic activity.

Before the possible link between activity level and geomagnetic pulsations is discussed in more detail, a better understanding of the geomagnetic field is needed. The geomagnetic field is a product of both an internally generated magnetic field – referred to as the main field – and an externally generated magnetic field. Each will be considered in turn.

The Main Field: Internal Source of Geomagnetic Field

All magnetic objects produce a surrounding magnetic field, which is composed of invisible lines of force. These force lines extend between the poles of the object, and exert influences on the charged particles in the vicinity (Marshall Space Flight Center [MSFC], 1996). According to MSFC, it is now commonly known that due to its composition and internal processes, the planet earth is a large magnetized object, surrounded by an enormous magnetic field.

The awareness of the geomagnetic field probably began with Chinese scientists who, in about A.D. 83, were the first (on record) to notice its directional properties (Takeuchi, Uyeda, & Kanamori, 1967). According to Takeuchi et al., the early Chinese discovered that when a spoon made from lodestone is spun on a highly polished surface, it always comes to rest pointing in the same direction. However, the idea that the whole earth is one huge magnet was likely not recognized until William Gilbert who, in the 16th century, explored and charted the surface field of spherical magnetite (lodestone) using tiny magnets properties and unified earlier, sketchy findings on the directional properties of a geomagnetic field (Takeuchi et al., 1967).

Modern geophysical research indicates that the geomagnetic field is the product of the interplay of magnetic fields generated by sources within the earth, and outside its atmosphere. More than 90% of the field – the main field – is generated as a result of constant magnetohydro-dynamic processes in the earth's core (McLean, 1998). Changes in this field are normally gradual and the typical frequencies are less than one cycle per year (Parkinson, 1983). According to Parkinson, it was found that variation in the main field also has a prominent peak at 58 years and possible peaks at 450, 600, 1800, 8000 and 10,000 years. The present main field can be likened to those in the field around a bar magnet whose axis is tilted by about 11.5 degree with respect to the earth's rotational axis (Jacobs, 1989). The geomagnetic field consists of three orthogonal, magnetic vector components — northward component (X), eastward component (Y), and downward component (Z) (see Figure 7). The geomagnetic field can also be expressed as a resultant

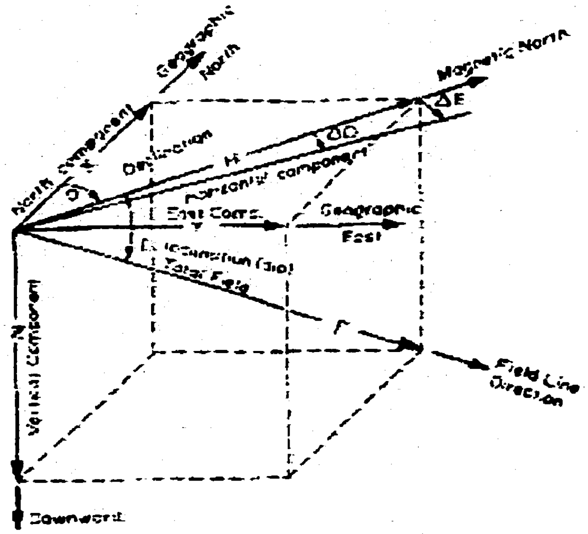


Figure 7. Components of Geomagnetic measurements for a sample Northern Hemisphere total magnetic field vector F inclined into the earth (from *Introduction to Geomagnetic Fields* (p. 4), by W. H. Campbell, 1997, New York: Cambridge University Press).

of three orthogonal magnetic vector components — the horizontal component (H), declination (D), and downward component (Z) (Campbell, 1997). The other source of the geomagnetic field is external, and is mainly influenced by particle radiation bombarding the earth from the sun in the form of solar wind.

Solar Wind: The External Source of Geomagnetic Field Activity

Like the earth, the sun also has a magnetic field. This field has areas where the magnetic field intensity is higher, and these points of concentration are identified as sunspots, because they appear as dark areas on the sun's surface (Hawkes, 1962). Associated with these sunspots are solar flares, which are our solar system's largest explosive events – equivalent to approximately 40 billion Hiroshima-size atomic bombs (Hathaway, 1998a; Space Environment Center, 1998a). Solar flares occur near sunspots, heating material to many millions of degrees in a matter of just a few minutes. In the process, massive amounts of energy are released, principally in the form of electromagnetic waves ranging from Gamma rays, X-rays, visible light and including kilometer-long radio waves, energetic particles (protons and electrons), and mass flows (Hathaway, 1998a). Solar flares can last from minutes to hours (Space Environment Center, 1998a). The continuous, high-speed outflow of ionized particles from the solar corona (continuous chain of solar flares) is also called "solar wind" (Hathaway, 1998b; Jacobs, 1989), and its speed varies from about 300 km/s (Hathaway, 1998b; Jacobs, 1989) to 1000 km/s (Rankin, 1998). Since the solar wind's dynamic pressure far exceeds the sun's magnetic field pressure, some of the solar magnetic field, which is "frozen" in solar wind, is carried away from the sun, with the consequence that the earth is exposed to both the solar particles of density of ~5/cc and an interplanetary magnetic field of ~5-10 nT (nanoteslas) (Rostoker, 1998). The solar wind stretches the earth's static dipole magnetic field into a comet-shaped magnetic cavity (likened to a windsock) called the magnetosphere. The geomagnetic field is shocked and compressed on the dayside, which is exposed to solar wind, and stretched out on the nightside past the moon's orbit (Rankin, 1998) (see Figure 8). The boundary on the dayside is at a distance of four to five

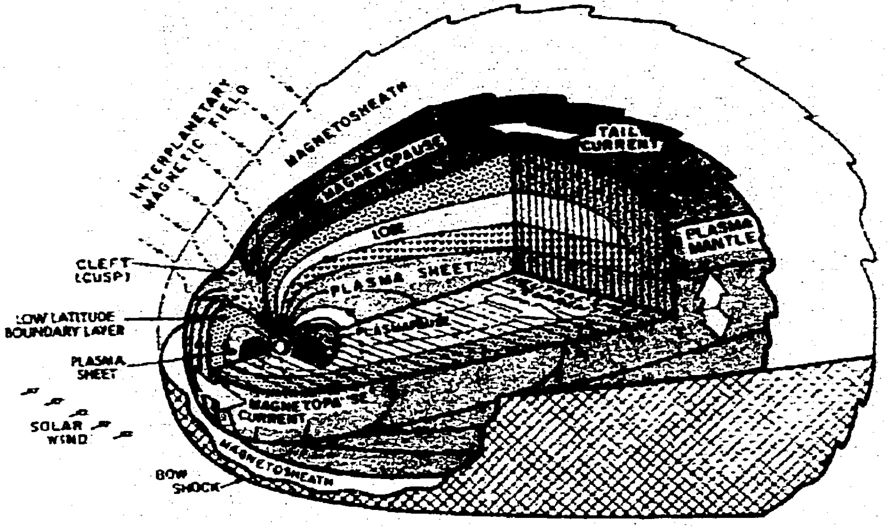


Figure 8. Three dimensional view of magnetosphere showing the various energetic particle regimes (from "Nowcasting of Space Weather Using the CANOPUS Magnetometer Array," by G. Rostoker, 1998, *Physics in Canada, 54(5)*, p. 278).

times the earth's radius — 20000–25000 km above the earth's surface; on the nightside of the earth, the magnetosphere is stretched to a greater distance, at least from 10 to 20 earth radii (Kaufman & Keller, 1981). According to Rankin (1998), the outer boundary of the magnetosphere, for the most part, prevents both the interplanetary magnetic field, and solar wind from entering the magnetosphere, and this protects biological systems from the harmful effects of ionizing radiation and high energy particles. When the solar wind reaches our planet, most of the solar wind particles are deflected by the magnetic shield around the earth (McLean, 1998). However, during periods when the geomagnetic field activity is high, some solar wind particles are guided through the geomagnetic shield by geomagnetic field lines. These external source particles can cause relatively big and fast fluctuations (geomagnetic disturbances) or, sometimes, extraordinary fluctuations (geomagnetic storms) in the geomagnetic field intensity. The amount of solar wind particles guided into the geomagnetic field depends on the orientation of the interplanetary magnetic field. Rostoker (1998) explained the mechanism of the interaction of the interplanetary magnetic field and the geomagnetic shield (see Figure 9).

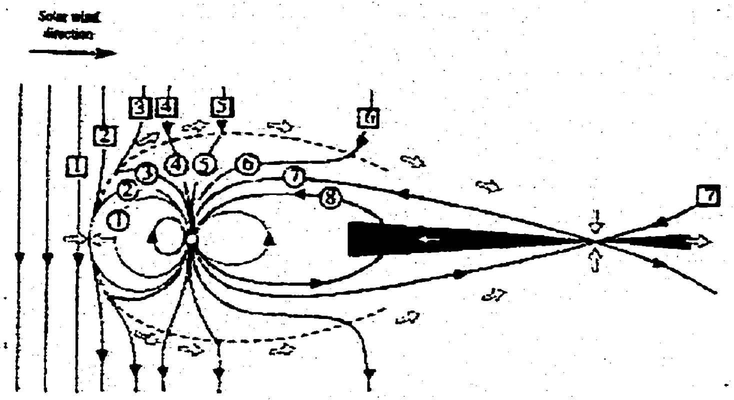


Figure 9. Flow pattern of magnetic flux tubes which merge with the solar wind magnetic field on the dayside magnetopause, and are transported over the poles into the lee of the earth (from "Nowcasting of Space Weather Using the CANOPUS Magnetometer Array," by G. Rostoker, 1998, *Physics in Canada, 54(5)*, p. 279).

It has long been known that the entry of energy from the solar wind into the magnetosphere is modulated by the interplanetary magnetic field (IMF). In particular, when the IMF has a component parallel to the frontside terrestrial magnetic field very little energy enters the magnetosphere no matter how large the solar wind kinetic energy becomes or how large is the magnitude of the IMF. However, if the IMF has a component antiparallel to the frontside terrestrial

> magnetic field, energy can enter the magnetosphere in amounts proportional to the rate at which magnetic flux is brought up to the front of the magnetosphere .... The physical process through which the entry of solar wind energy into the magnetosphere takes place is called magnetic field line merging. This leads to a flow pattern shown in Figure 9, in which it can be seen that: (1) the solar magnetic field merges with the terrestrial magnetic field on the dayside magnetopause; (2) the field lines are swept back into the lee of the earth to form the magnetotail; (3) the field lines reconnect across the neutral sheet in the midplane of the magnetotail and are transported through the action of magnetic tension back into the near-earth dipole field configuration. (Rostoker, 1998, p. 279)

As shown in Figure 10, magnetic field line reconnection occurs when oppositely directed magnetic lines are brought together (Parkinson, 1983). According to Haaland et al.

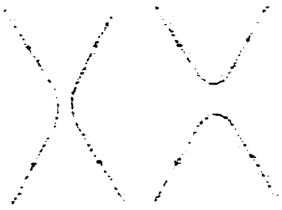


Figure 10. Magnetic merging of lines of force. The configuration on the left can change to that on the right, and vice versa (from *Introduction to Geomagnetism* (p. 258), by W. D. Parkinson, 1983, Edinburgh: Scottish Academic Press Ltd.).

(1999), the magnetic field line reconnection leads to backward pressure and redirection of ionized particles in the tail of the magnetosphere, causing enhanced geomagnetic pulsations at the ionosphere, which is a layer of "Earth's upper atmosphere that is partially ionized by solar x-rays and ultraviolet radiation and energetic particles from space" (National Academies, 2001).

Solar wind creates magnetic fields changing the main field by as much as 9% (Hawkes, 1962, McLean, 1998; Space Environment Center, 1998a). The aurora glows of molecules and atoms in the upper atmosphere that collide with the solar wind particles are a visual manifestation of geomagnetic disturbances due to the solar wind (Space Environment Center, 1998a). In the next section, I will discuss the intensity of the geomagnetic field.

Intensity of Geomagnetic Field

The intensity of the magnetic field at the earth's surface is approximately 32000 nT (320 milligauss) at the equator, and 62000 nT (620 milligauss) at the North Pole (Space Environment Center, 1998b). The geomagnetic field is comparable to the peak magnetic fields between the wire and rails of an electric railroad during bursts of acceleration. As shown in Table 1, the geomagnetic field intensity is negligible compared to some man-made fields that are used for medical purposes. For example, magnetic

Table 1

Typical Magnetic Fields from Various Sources

(nT)

Source	Maximum	Typical
During MRI		2,000,000,000
At the surface of the earth (in the United States)	70000	45000
Between wire and rails of an electric railroad	65000	3500 to 12500
Alongside a transformer substation		1500 to 2500
Under urban power distribution lines	2000	100 to 300
Under pole-to-home lines	400	100
In household wiring	500 to 1000	50 to 100

Note. Table adapted from "Electromagnetic Fields and Power Lines," by W. B. Bennett, 1995, *Scientific American-Science & Medicine, 2(4)*, p. 71.

resonance imaging (MRI) creates a magnetic field about 50,000 times as large as the geomagnetic field (Bennett, 1995). Even though we are not constantly exposed to such extremely strong man-made electromagnetic fields, we are continuously immersed in the geomagnetic field even during our sleep. Geomagnetic activity can be measured in various way, and in the next section, I will discuss what the most appropriate measure of geomagnetic activity would be.

Effects of Solar Activity on Human Behavior

The sun has an overwhelming influence on us. The total output of the sun for one second could provide the U.S. with enough energy for the next 9 million years (Space Environment Center, 1998a). Thus, ionizing radiation, such as solar disturbances and galactic cosmic radiation, might be a great danger and hindrance for humans living and working in space (Schimmerling, 1995).

There is some evidence of a link between solar activity and human behavior. Solar activity has an 11-year cycle (solar cycle or sunspot cycle). It takes about 4.6 years for the radiowaves emitted from the sun, which is a measure of solar activity, to reach their maximum amplitude, and about 6.7 years for them to return to their minimum amplitude (Hawkes, 1962). According to Persinger (1997), about 70 years ago A. L. Chizevskii had found that most wars and human group conflicts occurred slightly after the maximum of solar cycle. Putilov (1992) looked at 17,600 historical events (13,000 historical events between 1961 and 1976; 4,600 historical events between 1956 and 1977), and found that the frequency and polarity of the events (e.g., intrapolitical events, revolutions, counter-revolutions, uprisings, internecine wars, disorders, clashes, and radical reforms) were highest in the year of the solar maximum and the year following. This may be related to the fact that the intensity and number of geomagnetic storms usually come to the peak about one year after the year of the solar maximum (Campbell, 1997).

From the perspective of a psychological impact of this cycle, Raps, Stoupel, and Shimshoni (1992) found a significant positive correlation ($r = .20$) between monthly numbers of first admissions for a single psychiatric unit and solar activity level in the corresponding month, over the period 1977 to 1987. According to Halberg et al. (1991, November), Breus and her colleagues found a significant and positive correlation between solar flux and monthly and daily means of sudden death in Moscow ($r = .38, p < .05$). Becker (1990) did a statistical study of putative relationships between solar activity and violent crime. He focused on monthly variation over an 11-year solar cycle, and yearly variation over a 30-year period encompassing three solar cycles. Becker reported that sunspot numbers were significantly correlated with violent crime at the yearly level. Aggressive and violent behaviors are relatively rare and do not lend themselves to prospective study. The present study will focus on the fluctuations in a class of ongoing behavior that might relate to variation in solar and geomagnetic activity.

Activity Level and Geomagnetic Pulsations

During my work as a bus driver for Shirahata Preschool in Yokohama, Japan, a particular incident piqued my interest regarding the importance of the effect of solar and geomagnetic activity on children's motor activity. One day in May, 1995, most of the children on the bus became remarkably irritable. Later I found that it was the very day the geomagnetic activity in Japan increased noticeably because of a sudden and strong solar flux. Of course, this could have been a coincidence; therefore I conducted an informal study of the preschool children on the bus by rating their general activity level and by comparing this activity with solar and geomagnetic activity levels. Through the informal study, I found that the children were irritable and inactive predominantly during the days when geomagnetic activity was high, although my observation could have been biased toward my expectation. This led to the basic hypothesis of this thesis that children may be susceptible to the influence of geomagnetic activity.

Much of the formal research linking geomagnetic fluctuations to human behavior has been done retrospectively. A more convincing demonstration would involve a study in which a specific measure of geomagnetic fluctuations is predicted in relation to specific behavioral measures, specifically motor activity level (AL) in children. The choice of AL as a measure of behavior in this context is not based on any previous research. However, as a measure of human behavior, AL has the advantage of being continuously variable over time. Thus, it is possible to see if ongoing variation in geomagnetic levels have a non-chance relation with ongoing variation in AL.

Activity level is a core dimension of individual differences in infant and child temperament (Eaton & Enns, 1986). It is related to age and gender differences, and is influenced by both genetic and environmental factors (McKeen, 1988). Activity level has been defined in various ways. According to Eaton (1994), activity level is the individual's customary level of energy expenditure through movement. Rothbart (1986) defined activity level as "the level of children's gross motor activity, including movement of arms and legs, squirming and locomotor activity". Buss and Plomin (1975) considered motor activity level as an important component of an individual's behavioral style or temperament. According to Thayer (1989), gross motor activity is associated with physiological arousal. Thayer also found that the high arousal state was associated with heightened energy and optimism, and that low arousal state was associated with reduced energy, less optimism and increased tension. Thus, motor activity level and mood would reflect individual's physiological arousal level. Following Thayer's line of argument, I suspect that arousal level is related to the sleep-wake cycle and that a geomagnetic-behavior link is related to sleep regulation.

Possible Mechanism for Geomagnetic-Behavior Link

Although the possible dynamics of geomagnetic activity affecting human behavior is still unknown, some researchers suspect melatonin, a hormone produced mainly during nighttime darkness by the pineal gland, may play a key role. Melatonin is said to help regulate circadian rhythms, to slow the growth of some cancer cells (e.g., breast cancer cells), and to influence mood and behavior (National Institute of Environmental Health Sciences and U. S. Department of Energy, 1995). Pineal and plasma melatonin levels, which are usually highest at night and extremely low during the day, are modified by environmental light (Betrus & Elmore, 1991). According to Betrus and Elmore, the reduced amount of daylight during winter in higher latitudes leads to a circadian rhythm pattern of melatonin secretion that is longer in duration compared with melatonin secretion in the summer. According to Lavie, Haimov, and Shochat (1997), melatonin is involved in sleep regulation by shutting off the wakefulness system. Dolberg, Hirschmann, and Grunhaus (1998) suggested that melatonin has a role in sleep disturbances that are related to major depressive disorders. Some studies on animals have suggested that melatonin might play an important role in modulation of motor activity level (Hatta, Wolterink, & Van Ree, 1995).

The role of melatonin may be pivotal because, according to Cornelissen et al. (1999), the pineal gland may receive and mediate the effects of an electromagnetic field. Moreover, Rapport et al. (1998) found: (1) suppression in melatonin secretion; and (2) increased secretion of cortisone, a stress hormone, both in healthy humans and in patients with cardiovascular diseases as well as in astronauts working in the space in the SOYUZ space craft and MIR station, during geomagnetic storms. Using portable heart rate monitors, Breus et al. (1998) investigated the effects of two successive geomagnetic storms on two cosmonauts in the MIR station and found a nonspecific adaptive stress reaction in the cardiac activity of the astronauts. Kay (1994) has also suggested that disturbances in the geomagnetic field could suppress the nighttime peak in serum melatonin concentration in humans. Partonen (1998) hypothesized a group of photoreceptors that modulate the response of the photoreceptive system to light, and the pineal response to a magnetic stimulus, in patients with winter seasonal affective disorder. If their arguments are right, geomagnetic disturbances during the night may have some influence on the sleep-wake cycle, physiological arousal, and motor activity level in humans. However, there are inconsistencies among published findings relating the effects of the electromagnetic field to nighttime melatonin secretion in animals (Stevens & Davis, 1996), so Kay's argument is still very controversial.

Another possible component of the mechanism of the effects of geomagnetic activity on human behavior is the long-term depression (LTD) of intercellular excitatory postsynaptic potentials caused by ULF geomagnetic pulsations. According to Breus et al. (1995), ULF electromagnetic fields of the same order of amplitude as that of geomagnetic pulsations have a profound influence both on biological systems and at the cellular level. According to George (1998), electrical stimulation at low frequencies in the single Hz range results in long-term associative depression (LTD) of transmission in synapses in the hippocampus and motor cortex, while high-frequency electrical stimulation of neurons can result in long-term increases in the efficiency of transmission in their synapses on other neurons (called long-term potentiation — LTP). George also suggests that mood change can also be caused by electromagnetic stimulation at low frequencies and amplitudes. Although this finding is open to discussion, I suspect that exposure to geomagnetic pulsations could lead to neuronal long-term depression and decreased motor activity level. S. Starbuck of the University of Minnesota BIOsphere and the COSmos [BIOCOS] team (personal communication, September 17, 1999) discussed the putative effects of geomagnetic pulsations on mood and sleep as follows:

> First, the energy levels of two types of magnetic pulsations (Pc 5 and Pi 2) are high enough (10-50 nT) to stimulate neural depolarization in long-term coupling. This process is likely known to you as LTP (long-term potentiation). Having some electronics and physics background, I created two types of artificial geomagnetic pulsation generators. The first was a hydromagnetic wave generator built with a large amount of mercury metal and powerful electromagnets, which produced ULFR at amplitudes comparable with the normal background level of geomagnetic pulsations. There were two basic effects of exposing myself to the radiation from this device, the first was headaches that would last for several days and the second was a slight buzzing sound that seemed to be coming from my forehead. Mostly, this just made me irritable and I looked for another way of controlling the power level, frequency and polarity of the produced radiation. I eventually created a high power electronic ULFR machine, that could produce amplitudes about six times higher than background levels. The effects of my first exposure to this were quite different, even pleasant. At a week at the lowest power settings (approximating normal exposure) my sleep time was dramatically reduced to only a few hours per night (I typically need 8 hours of sleep) and I had none of the hangover effect that normally comes with losing sleep. I was also highly motivated, although this could

> be partly due to the placebo effect in that I expected to be motivated. At higher power levels, I tested my reaction time, and it had decreased considerably ..... and I began to see colorful phosphenes. It also created a euphoric feeling that lasted for hours afterwards. When I changed the polarity, in the next set of tests, I began to feel a similar buzzing sound that had come from being exposed to the previous ULFR generator. I soon developed a headache that took me three days to get rid of. Considering the fact that I could very well be endangering my life with this machine, I dismantled it and decided to work instead on the more practical and safer epidemiological approach to discovery.

Starbuck's finding might suggest the existence of effects of magnetic pulsations on mood and sleep. However, his finding has not been peer-reviewed, and there are inconsistencies among published findings of the effects of electromagnetic field at ULF on mood. Starbuck's experience is suggestive, not definitive. Thus, existing literature suggests a link between geomagnetic pulsations and human physiology and behavior, which leads to the present focus on natural variation in geomagnetic pulsations and its possible effects. For various practical reasons, I addressed this general hypothesis by focusing specifically on children and their level of motor activity.

Why Preschool-aged Children were Chosen As Participants?

In the study, preschool-aged children were chosen as participants because they were generally active, and because preschools (or day care centers) allowed activity recording in relatively unstructured settings, which would contribute to a high level of AL variability, making it easier to see if there are AL differences related to variation in geomagnetic activity. In the next section, I am going to discuss when children would be most affected by geomagnetic fluctuations.

When Would Geomagnetic Fluctuations Affect Children Most?

There seem to be two important factors that might affect children's motor activity level. One factor is diurnal variation. According to Shafii et al. (1996), most melatonin is secreted during the night, from 11 p.m. to 3 a.m., with a peak at 2 a.m. Sadeh (1997) examined sleep-wake patterns of 20 healthy infants, and found that a delayed peak of urinary melatonin was associated with more fragmented sleep during the night. Moreover, Burch et al. (1999) found that the mean overnight urinary excretion of a melatonin metabolite, 6-hydroxymelatonin sulfate, was lower on geomagnetically active days. Therefore, if geomagnetic pulsations suppress the secretion of melatonin, nighttime geomagnetic pulsations would most suppress the melatonin secretion. The suppressed endogenous melatonin level might cause a phase-shift or disturbance in the children's sleep-wake cycle, and subsequently reduce the next day's children's motor activity level. Therefore, I think that geomagnetic pulsations during the night, especially between 11 p.m. and 3 a.m., would affect children's AL the next day. The other factor of possible importance is the season of year. Figure 11 illustrates the seasonal distribution of geomagnetic disturbances where the daily planetary Ap index, a 3-hourly planetary index of geomagnetic activity, is greater than a value of 25 (a disturbance which might occur on average 5 times per month) (Thompson, 1995b). As shown in Figure 11, geomagnetic disturbances occur most frequently near the vernal and autumnal equinox (March/April;

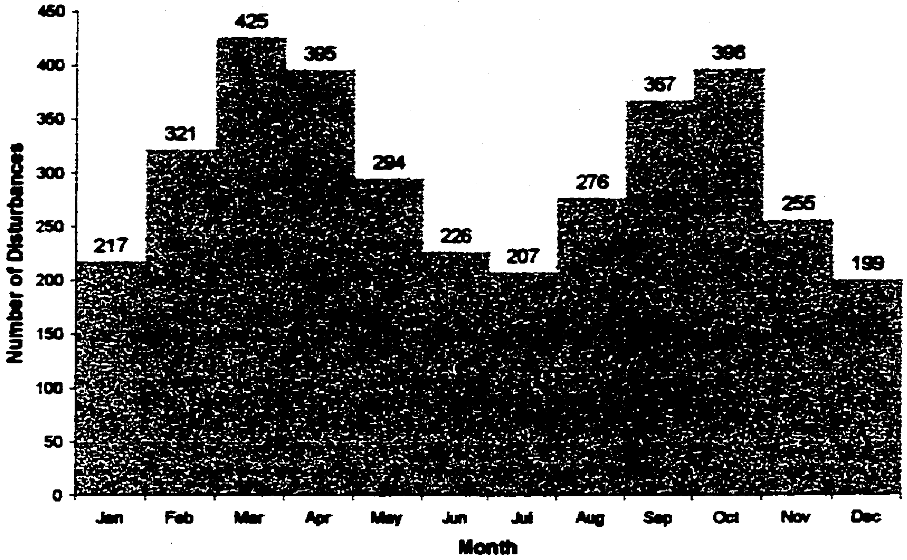


Figure 11. The Seasonal Distribution of Geomagnetic Disturbances (from "The Seasonal Distribution of Geomagnetic Disturbances," by Thompson, R., 1995a, [WWW document]. http://www.ips.oz.au/background/richard/season_distrib.html).

September/October), and occur least near the summer and winter solstice (June/July; December/January) (Thompson, 1995b). Bergiannaki, Paparrigopoulos, and Stefanis (1996) found that the lowest values of nighttime urinary melatonin excretion were observed in April and August-October when the fluctuations in the geomagnetic field was high. Kay (1994) found that geomagnetic disturbances are associated with subsequent increase in the incidence of psychotic depressive illness in males, although neither length-of-day effects nor other climate effects were controlled in his study. He argued that the onset of depressive illness, admission to hospital, prescriptions of antidepressant medication, and incidence of suicide have a bimodal annual distribution, which may be associated with the equinoctial increase in geomagnetic storms, by acting as a precipitant in susceptible individuals thorough desynchronisation of pineal circadian rhythms or via an effect on serotonin and adrenergic systems leading to depressed mood and secondary disruption of pineal melatonin synthesis. He also suggested that geomagnetic storms in spring may enhance the suppressing effect of increasing daylight on melatonin systhesis, leading to a phase advance in the circadian rhythm, while the effect of geomagnetic storms in autumn would tend to be partially compensated for by the pineal response to decreasing light intensity.

Thus, data collection in spring and autumn was preferred. However, due to practical restrictions, the data collection for the current study was done in summer (i.e. from May 30th to August 2nd, 2001) during which there were some geomagnetically active days. In the next section, I will discuss the hypotheses of the study.

Hypotheses

I believe that preschool children's motor activity level is influenced by nighttime pulsations in geomagnetic field intensity. The nighttime peak in their serum melatonin secretion might be suppressed by the ultra-low frequency geomagnetic pulsations. Consequently, their overall activity level on the following day would decrease because of the sleep disturbance (or phase-shift in sleep cycle) the night before. In other words, it is hypothesized that children's motor activity level after enhanced nighttime geomagnetic pulsations is significantly lower than on days of normal geomagnetic pulsations. More specifically, enhanced geomagnetic pulsations would most effectively affect sleep and consequently children's next-day AL, by effecting their nighttime melatonin secretion. Because it was not practically possible to measure nighttime melatonin, I collected parent reports of their child's sleep disturbance instead. An implication of the preceding hypothesis is that children's sleep behavior would be more disturbed on nights with enhanced geomagnetic pulsations.

In short, I believe that preschool children's motor activity level and sleep should be influenced by the suppression of nocturnal melatonin secretion due to pulsations in geomagnetic field intensity, between 11 p.m. and 7 a.m. Children's sleep behavior should be more disturbed and subsequent motor activity level should be lower on days of enhanced geomagnetic pulsations than on days of normal geomagnetic pulsations.

Method

A sample of 32 preschoolers wore two different types of activity monitors on their right ankles for five hours once a week for ten weeks. A measure of child's sleep was completed by each child's parent on the morning of each activity assessment. Geomagnetic data for the study measurement days were obtained, and the spectral analysis was performed on them to define a period of geomagnetic pulsations. Sleep disturbance and AL measured following nighttime geomagnetic pulsations were contrasted with the same measures following a non-pulsation night.

Recruitment

Five day care centers in Winnipeg were sent a letter that included a general description of this study, the nature of participant involvement, and a request for participation (Appendix A). Approximately one week after the letter had been mailed, the day care center directors were contacted by telephone by the investigator, who answered any questions regarding the study and ascertained their willingness to participate (see Appendix B for the telephone protocol). Four of the five directors agreed to cooperate with the study.

After getting permission from the directors of the center, the parents of attending children were sent a letter that included a general description of this study, the nature of the child's involvement, a request for participation (Appendix C), and a consent form (Appendix D). If the parents were willing to participate in the study, they were asked to:

complete and return the consent form to the center, for forwarding to the investigator and to assess their child's sleep with a sleep disturbance scale in the mornings of the days of behavioral measurement.

Participants

Initially, 36 children (35 parents) from five day care centers in Winnipeg agreed to participate in the study. Of those children, three withdrew from the study. Two of them were from the same day care center. Consequently 33 children (32 parents) from four day care centers in Winnipeg participated in the study (see Table 2) between May 29 and August 3, 2000. These thirty-three children (55% female) between the ages of 3 and 5 years comprised the sample. Their mean age, which was calculated from the first day of observation, was 4.5 years. Their average height and weight were 105 cm and 18.1 kg respectively (see Table 2).

Table 2

Descriptive Statistics for Participants by Center and Overall

Day care		Age in years		Height in cm		Weight in kg		
center	*N*[a]	*M*	*SD*	*M*	*SD*	*M*	*SD*	% ♀
A	3	5.1	0.4	108	3	17.0	1.6	67
B	15	4.5	0.6	107	6	19.7	2.5	40
C	7	4.2	0.8	100	7	16.6	2.8	86
D	8	4.9	0.6	103	5	17.0	1.3	50
Overall	33	4.5	0.8	105	6	18.1	2.6	55

[a]Number of children who participated.

Sleep Disturbance Measurement

Because there is no sleep scale that measures the quality of preschool-aged children's sleep based on their sleep behaviors observed during the previous night, the

Child Sleep Disturbance Scale (CSDS) was developed for the study (see Table 3). The scale consists of ten items which are based on items from Children's Sleep Behavior Scale (Fisher, Paulet, & McGuire, 1989), which are arranged in a five-choice Likert-scale format. Although the items in Children's Sleep Behavior Scale ask about child's sleep behavior over the past six months, eight out of ten items in the CSDS ask about his/her sleep behavior during the previous night. Because some parents did not answer Items 1, 2, or 8, these three items were excluded from the score calculation. Hence, each weekly CSDS score was calculated as a deviation from the grand mean of the number of items answered "Yes" for Item 3, 4, 5, 6, and 7 for all weeks for that child. This procedure

Table 3

Child Sleep Disturbance Scale

Item	
1. Did he/she wake up during last night?	(Yes / No)
2. If so, approximately how many hours in total?	________________ hrs
3. Did your child complain about difficulties going to sleep?	(Yes / No)
4. Did he/she get up to go to the bathroom during last night?	(Yes / No)
5. Did you hear your child talking in his/her sleep last night?	(Yes / No)
6. Was he/she restless during sleep last night?	(Yes / No)
7. Did he/she wake up during last night?	(Yes / No)
8. If so, how many times?	________________ times
9. At what time did he/she go to bed?	________________
10. At what time did he/she get up?	________________

removed child-to-child differences while leaving week-to-week variability. The mean CSDS score was -0.07 (*SD* = 0.64). Cronbach's alpha for the five items was .55, which represents marginal level of internal consistency for the five items. Thus, the sleep disturbance scale is probably not reliable.

Motor Activity Level Measurement

Two types of instruments were used to measure AL in the sample of children, an electronic accelerometer and a mechanical motion recorder.

Accelerometer

Computer Science and Applications (CSA) Model 7164 monitors (accelerometer) were used to get continuous data on children's motor activity level. They measure the acceleration, frequency, intensity, and duration of movements of the instrument in real time, and store the continuous real-time record. Average acceleration is calculated for a specified epoch, which was set at one second, for the present study. The instrument measures 5.1 × 4.1 × 1.5 cm, and weighs 42.6 g (Computer Science and Applications Inc. [CSA], 1998). It can be worn at the waist, on the wrist, or around the ankle (Janz, 1994). The accelerometer sensor consists of a piezoceramic cantilever beam and 1.5-g seismic mass (CSA, 1998; Tryon & Williams, 1996), and generates a charge that is proportional to the strain acting on the 1.5-g mass attached to the free end of the cantilevered beam (Tryon & Williams, 1996). The charge produced is filtered by an analog bandpass filter and digitized at 10 times per second (CSA, 1998), and the digital value is summed over a user-defined epoch (CSA, 1998). All programming operations, such as setting the initial epoch, intervals, instructing the monitor to turn on and off at a specific date and time, and downloading collected data, were done with a personal computer.

Accelerometer Validity

To evaluate the validity of CSA accelerometer, Janz (1994) did a study using thirty-one 7- to 15-year-old children observed in their homes. She had them wear a CSA accelerometer and a heart rate telemetry monitor for a total of 36 hours, 12 hours a day, and found that the mean movement counts correlated with the average heart rate, *r* = .57. For vigorous physical activity, the correlation coefficient between the mean number of minutes spent at high level of movement correlated .69 with heart rate (Janz, 1994).

To assess the validity of CSA accelerometer, Melanson and Freedson (1995) compared CSA accelerometer data with data collected using a different type of accelerometer in a laboratory setting. They had 28 young adults (mean age of 21 years) perform slow walking, fast walking, and jogging on a treadmill at three different gradients (0%, 3% and 6%); energy expenditure (kcal/min) was used as the criterion measure (Melanson & Freedson, 1995). The results showed that both accelerometers discriminated changes in speed, but not changes in grade, and that both movement counts data collected by two types of accelerometers had significant, positive correlation with energy expenditure (*r* = .66 - .82), heart rate (*r* = .66 - .80), treadmill speed (*r* = .82 - .92), and with each other (*r* = .77 - .82) (Melanson & Freedson, 1995).

Accelerometer Reliability

To measure the within-device reliability of the CSA accelerometer, Tryon and Williams (1996) used a pendulum test. In the test on a CSA accelerometer, they performed three pendulum tests with fifty 10-second epochs for each. They then compared the results of the three tests by calculating the mean for the three sets of the accelerometer movement count difference between tests; they found that the mean difference in movement counts was very small, only 6.4 (*SD* = 6.1) over 150 different counts. To evaluate the within-device reliability more precisely, they also used a spinner, which gave them better control of decay rate than with a pendulum. From the results of five repeated spinner tests, they found that the within-device reliability was high under frequencies between 0.25 and 2.50 Hz, *M* = 1.025, *SD* = 0.007. To evaluate the between-device reliability, they submitted 40 CSA accelerometers to the spinner test, one by one, and found that the between-device reliability among the devices was excellent under the frequencies between near-zero and 5 Hz, with its maximal sensitivity at 0.75 Hz.

Actometer

The actometer, an older type of motion recorder, was used in the present study. The instrument was commercially available from Alan Willis, 282 Watertown Road, Middlebury, CT, 06762, USA. It is a modified woman's wrist watch with a watchcase diameter of 25 mm and a weight of 10 g excluding the wrist band (Eaton, McKeen, & Saudino, 1996). In these modified watches the apparent passage of watch hands is proportional to the number of times the recorder is tilted or oscillated. The actometer is not responsive to intensity of movement. Instead, it provides a frequency measure of arm or leg movement (Eaton et al., 1996).

Eaton et al. (1996) have validated the actometer readings against a mechanical criterion. A chemical shaker was used to expose 19 actometers simultaneously to differing amounts of oscillatory movement. The results revealed that the actometers did indeed differentiate among the different movement conditions (Eaton et al., 1996).

Eaton et al. (1996) estimated the reliability of the actometers from the chemical shaker data, by calculating an intraclass correlation coefficient, which estimated the degree of concordance among the readings of the 19 actometers. The results revealed a coefficient of .98 for the shaker bath study, sharing a very high level of agreement among the instruments in assessing a common movement criterion (Eaton et al., 1996).

Procedure

Study Design: A Schedule of Day Care Center Visit

Once a week, on the same day of the week for ten consecutive weeks, I visited each of four day care centers in Winnipeg, Manitoba, Canada (see Table 4). A center was visited on the same day of the week. This procedural step was taken to avoid possible day-of-week effects.

Table 4

Schedule of Day Care Center Visit

Day of Week	Tuesday	Wednesday	Thursday	Friday
Day Care Center	A	B	C	D

Absences and Missing Data

Missing data was not uncommon because children could be absent on one or more of the ten assessment days for each center. Averaging the number of the attendance across all ten weeks provided a mean attendance rate of 72.8%. As shown in Table 5,

Table 5

Attendance by Participant and Week

Child ID	Week 1	2	3	4	5	6	7	8	9	10	Day Present Out of 10
001	0	1	1	1	1	1	1	1	0	0	7
002	1	1	1	1	1	1	1	1	1	0	9
003	1	1	1	0	0	1	0	1	1	0	6
004	1	1	1	1	1	1	1	1	1	0	9
005	1	1	1	1	1	1	1	1	1	1	10
006	1	1	1	1	0	0	0	0	0	0	4
007	1	1	1	1	1	0	1	1	1	1	9
008	1	1	1	1	1	1	1	1	1	1	10
009	1	1	0	1	1	0	0	1	1	1	7
010	1	1	1	1	1	1	0	0	0	0	6
011	0	1	1	1	0	0	0	0	0	0	3
012	1	1	0	1	1	1	1	1	1	0	8
013	0	1	1	1	1	0	1	1	1	1	8
014	1	1	1	1	1	0	1	0	1	0	7
015	1	1	1	1	1	0	1	1	1	0	8
016	1	1	1	1	1	1	0	1	1	1	9
017	1	1	1	1	1	1	1	1	1	1	10
018	1	1	1	0	1	1	0	1	0	1	7
019	1	1	1	1	0	0	0	0	0	0	4
020	1	1	1	1	1	1	0	0	1	1	8
021	1	1	1	1	1	1	0	1	1	1	9
022	1	1	1	1	1	1	0	1	1	1	9
023	0	1	1	0	1	1	0	0	1	1	6
wd[a]	0	1	0	0	0	0	0	0	0	0	1
025	0	1	1	1	1	0	0	1	1	1	7
026	0	0	1	1	1	1	0	1	1	1	7
027	1	0	0	0	1	0	0	0	0	0	2
028	0	1	0	0	1	0	0	0	0	0	2
029	1	1	1	0	1	0	0	1	0	0	5
030	1	1	1	1	1	1	0	0	0	0	6
031	1	1	1	1	1	1	0	1	1	1	9
032	0	1	1	1	0	1	0	0	1	0	5
033	1	1	1	1	1	0	0	0	0	0	5
034	1	1	1	1	1	1	0	1	1	1	9
wd[a]	1	1	0	0	0	0	0	0	0	0	2
wd[a]	1	1	1	0	0	0	0	0	0	0	3
Total *n*	25	31	29	27	28	20	11	21	22	16	230
% Children Present	76	94	88	82	85	91	33	64	67	48	—

Note. Number "1" in a cell stands for a participation of the child on the week, whereas number "0" stands for an absence of the child on the week. [a]Child who withdrew from the study.

children's weekly attendance rates for the first six weeks were higher (76% - 94%) than those for the last four weeks (33% - 67%). This might be because the last five weeks were during summer holidays when some of the children's families were out of town.

Sleep Disturbance Measurement with Child Sleep Disturbance Scale

Approximately one week before the first visit to the day care centers, the Child Sleep Disturbance Scale (CSDS) was distributed to the parents of all the participants through their day care center. Then every night before the day of visit, the parent got a call from either the investigator or a day care center staff member. The parent was asked to complete the CSDS on the morning of the day of the visit and reminded to send the form with the child to the day care center. On the morning (10:00 a.m.) of the day of visit, the investigator collected the completed CSDS. If the CSDS did not reach the day care center, either the investigator or a day care staff member called the child's parent later the day of visit and asked the same scale item questions about the child's sleep during the previous night.

Sleep Disturbance Scale Completion Rate

Averaging the number of the submissions across all ten weeks provided a mean completion rate of 71.9%. As shown in Table 6, weekly submission rates of completed

Table 6

Submission of the Sleep Disturbance Scale (CSDS) by Parents and Week

Child ID	Week										n of CSDS Submitted Out of 10
	1	2	3	4	5	6	7	8	9	10	
001	0	1	1	1	0	1	1	0	1	0	6
002	1	1	1	1	0	1	1	1	1	0	8
003	1	1	1	1	0	1	0	1	1	0	7
004	1	1	1	1	0	1	1	1	0	0	7
005	1	1	1	1	1	0	1	1	1	1	9
006	1	1	1	0	0	1	0	0	0	0	4
007	1	1	1	1	1	0	1	1	1	1	9
008	1	1	1	1	1	1	1	1	1	1	10
009	1	0	0	1	1	0	0	1	1	1	6
010	1	0	1	1	1	1	1	1	0	0	7
011	1	1	1	0	0	0	0	0	0	0	3
012	0	1	0	1	1	1	1	1	1	0	7
013	1	1	1	1	1	0	1	1	1	1	9
014	1	1	1	1	1	1	1	1	0	0	8
015	1	1	1	1	1	0	1	1	1	0	8
016	1	1	1	1	1	1	1	1	1	0	9
017	1	1	1	1	1	1	1	1	1	1	10
018	1	1	1	0	1	1	1	1	0	1	8
019	0	1	0	1	0	0	0	0	0	0	2
020	0	1	1	1	1	0	0	1	1	1	7
021	0	1	1	1	1	1	0	1	1	1	8
022	0	1	1	1	1	1	0	1	1	1	8
023	0	1	1	0	1	1	0	0	1	1	6
wd[a]	0	0	0	0	0	0	0	0	0	0	0
025	0	1	1	1	0	1	0	0	1	1	6
026	0	1	1	1	1	1	0	1	1	1	8
027	1	0	0	0	1	0	0	0	0	0	2
028	0	1	0	0	1	0	0	0	0	0	2
029	1	1	1	1	1	0	0	1	1	0	7
030	1	1	1	1	1	1	0	0	0	0	6
031	1	1	0	1	1	1	0	1	1	0	7
032	0	1	1	1	0	1	0	0	1	0	5
033	1	1	1	1	1	0	0	0	0	0	5
034	1	1	1	1	1	1	0	1	1	1	9
wd[a]	0	0	0	0	0	0	0	0	0	0	0
wd[a]	0	0	0	0	0	0	0	0	0	0	0
Total *n*	22	30	27	27	24	21	14	22	22	14	223
% Children Present	71	97	87	87	77	68	45	71	71	45	—

Note. Number "1" in a cell stands for the submission of the CSDS for the night before an observation, whereas "0" a missing CSDS for that observation.

[a] Child who withdrew from the study.

CSDS by the parents for the first six weeks were higher (68% - 97%) than those for the last four weeks (45% - 71%).

Activity Measurement with Two Instruments

On the morning of each visit, I strapped a packet containing a counterbalanced pair of instruments (an actometer strapped on an accelerometer or vice versa) to each participating child's ankle by means of an elastic band. Teachers were given instrument-care instruction sheets regarding the care and use of the two instruments (Appendix E) and record sheets for the logging of any time that the actometers were off (Appendix F). Fifteen accelerometers and twenty-one actometers were used in the present study. The discrepancy in the number of the two instruments is simply due to the attempt to obtain the results from as many instruments as possible, and more actometers than accelerometers were available for use. Teachers were encouraged to maintain normal daily routines after I left the day care center in the morning. Later that day, I returned to remove the instruments and took the necessary readings. I then completed the Instruments Record Sheet (Appendix G) for each child.

Accelerometers were randomly selected from a total of 15 after being scattered and shuffled on a table. Likewise actometers were randomly selected from a pool of 21 after being gently shaken and shuffled in a plastic cup. The selected accelerometers and actometers were then scattered on a table, on which they were shuffled, paired, and taped each other, with an actometer on top of an accelerometer. One of the reasons that randomization, instead of counterbalancing, was used in the selection of the instruments was that the there was difference in the number of the two instruments. Another reason was that it was hard to design a counterbalancing plan because the number of participants was unknown at the beginning of the study. The 15 accelerometers were programmed, in advance, to record acceleration from 10:00 a.m. to 3:00 p.m. On the morning (10:00 a.m.) of the day of visit, after demonstrating the accelerometers and actometers to the teachers, I recorded the start time of each actometer on the Instrument Record Sheet. Then the measurement bundle was fit snugly around each participant's right ankle with an elastic band. In the afternoon (3:00 p.m.), approximately five hours later, the instruments were removed, and the final readings were recorded by the investigator. On subsequent visits, each child wore the instruments around the same ankle.

Although the two instruments were to remain on the child for five hours, teachers could remove them at anytime if necessary. Through the instructions, the teachers were encouraged to maintain daily routines with their students during the 5-hour data collection period.

Score Calculations and Data Reduction for Geomagnetic Data

Geomagnetic Pulsations (Pc 5x). According to Rostoker, Samson, Olson, and Southwood (1979), recovery from active geomagnetic substorm is coupled with the appearance of low frequency Pc 5's, and the onset of the substorm leads to a suppression of it. Noting the link between geomagnetic activity and pulsations, in the present study, I used geomagnetic pulsations as a geomagnetic measure. In an informal study, I compared geomagnetic pulsation data obtained at Parkfield station (latitude 35.889° N; longitude 120.42° W) with my diary data and found that my neighbors were more irritable when the spectral amplitude of geomagnetic pulsations in lower frequency range of 0.0017 to 0.0033 Hz in the Pc 5 band was high. Thus, I used geomagnetic pulsations in that frequency range, which were defined as Pc 5x pulsations. They are part of the period range of Pc 5 pulsations. According to Kaufman and Keller (1981), the area of excitation of Pc 5 is such that the spectral amplitude of the pulsations decreases by an order of magnitude over a distance of 30° in longitude and 5° in latitude from the Pc 5 center (the area with maximum amplitude for the pulsations). Such a relatively large area would include the locations of Winnipeg and Pinawa, Manitoba, Canada. Thus, I used five-second-sampled geomagnetic data recorded at a ground station of the Canadian Auroral

Network for the Open Program Unified Study [CANOPUS] in Pinawa at latitude 50.20° N and longitude 96.04° W because its geographical location is within a distance of 0.7° in longitude and 1.1° in latitude from Winnipeg. The data were obtained from CANOPUS of the Canadian Space Agency, Edmonton and accessed using FTP transfer from the UNIX server of CANOPUS.

If our brains were sensitive to three directional changes (changes in each of the three orthogonal geomagnetic components — northward, eastward, and downward), rather than to the total magnetic field intensity, we would have to expect changes in the level of geomagnetic influences depending on our position relative to the field (i.e., standing vertically; lying horizontally). Moreover, in a location in the high-latitude northern hemisphere, such as Winnipeg, Canada, the orientation of the total magnetic field is almost vertically downward, whereas in a city in the high-latitude southern hemisphere, such as Macquarie Island, Australia, the orientation is almost vertically upward due to the earth's characteristics as a huge magnet. If our brains were sensitive to three directional changes rather than to changes in the total magnetic field, a person who travels from Winnipeg to Macquarie Island or vice versa by plane would have hard time getting adjusted to a geomagnetic field in the opposite direction. That seemed to be unreasonable. Thus, in the current study I used the total magnetic field (F), which is given as

$$F = \mathrm{SQRT}\ (X^2+Y^2+Z^2) \qquad (1.1)$$

The power spectra of the total magnetic field of the geomagnetic data was determined with power spectral analysis. To increase the accuracy of spectral estimates, the results for each interval were then "smoothed". In the next two sections, I will discuss spectral analysis and smoothing and how they were applied to the analysis of the Pc 5x pulsations for the study.

Introduction to Spectral Analysis. By means of power spectral analysis (or Fourier analysis), any periodic waveform can be decomposed into a series of sine (or cosine) waves whose frequencies are integer multiples of the basic repetition frequency 1/T, known as the fundamental frequency (Kearey & Brooks, 1993). A waveform can be expressed in two different domains: (1) the time domain, in which wave amplitude is expressed as a function of time; (2) and the frequency domain, in which the wave amplitude is expressed as a function of frequency (see Figure 12).

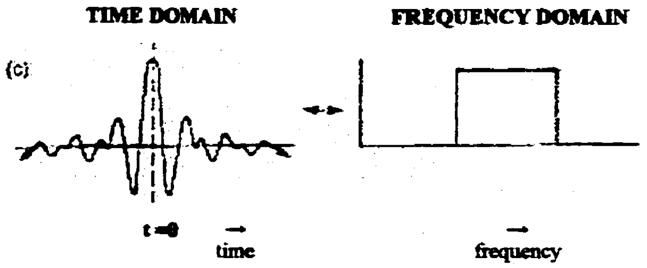


Figure 12. A Fourier transform pair for transient waveforms approximating seismic pulses (figure adapted from *An Introduction to Geophysical Exploration* (p. 13), by P. Kearey, & M. Brooks, 1993, Oxford: Blackwell Scientific Publications). The figure on the left represents shows a waveform expressed in the time domain, while the figure on the right shows the same waveform expressed in the frequency domain.

According to, I. J. Ferguson of University of Manitoba (personal communication, July 22, 2001), in the case of a periodic signal, the longer the time series analyzed, the higher the value of the power spectral density estimate. For a sinusoidal signal with amplitude A and an integral number cycles present in the time series of length L, the power spectral estimate S is given by:

$$S = \frac{A^2 L}{2} \qquad (2.2)$$

where the dimensions of the power spectrum are $nT^2.s$ or nT^2/Hz.

Periodogram Method: A Method Used for Calculating power Spectra. There are two basic methods for calculating power spectra, the periodogram method and the autocovariance function method. The first one involves estimating the spectrum by calculating the Fourier Transform of the time series and smoothing the spectral estimates, while the second one involves determination of the autocovariance function and calculation of the power spectrum from this quantity using a Fourier Transform (Bendat & Piersol, 1971). In the present study, the periodogram method was used because it utilizes the Fast Fourier Transform algorithm, and is the more efficient algorithm on modern computers (I. -J. Ferguson, personal communication, July 22, 2001).

The periodogram shows the power spectrum, an estimate of the power spectrum, involves calculating the power at each frequency from the corresponding Fourier Transform value. The variance of the estimates is large, but the accuracy of the estimates may be increased by *smoothing*. This procedure involves averaging independent estimates obtained from different segments of the time series or from a narrow band of frequencies (Ferguson, 1988). According to Ferguson, there is a tradeoff between the density of spectral estimates (i.e., resolution) and the accuracy of each estimate.

Application of the Theory to the Spectral Analysis of Pc 5x. The power spectra of the total magnetic field were determined using a power spectral program developed by I. J. Ferguson of the University of Manitoba. The power spectral program was based on a relative simple Fast Fourier Transform algorithm that required the number of points to be an even power of 2. To obtain the spectral estimates, the time series data were divided into 3-hourly intervals, and the power spectrum for each interval was calculated using smoothing. The smoothing involved averaging of results from multiple sets of segments with each interval.

For easier comparison with Ottawa K index, each day of five-second-sampled Pinawa data was divided into eight three-hourly segments. In dividing the original time series data into windows (or intervals), window size was determined so that the number of data points for each window is an even power of 2 and is the closest to 2160 data points (i.e., three hours or 180 minutes). Accordingly, data points of 2048 (i.e., 170.67 minutes x 12 = 2048.04), the 10th power of 2, were chosen for a window size.

To increase the accuracy of each spectral estimate, while minimizing decrease in resolution, subsegments length of 64 data points (i.e., 5.33 minutes) was chosen such that there was a total of 16 segments for each window for the FFT analysis in the current study (i.e., 2048/64 = 16). The size of error in the spectral analysis is proportional to 1/square root of the number of segments in each window. Thus, the use of 16 segments resulted in a factor of 4 reduction in the uncertainty of the spectral estimates (i.e., 1/SQRT (16) = 1/4) (I. -J. Ferguson, personal communication, July 22, 2001).

The preiodograms were next plotted to determine whether the enhanced signals were associated with Pc 5x pulsations. For example, Figure 13 shows a periodogram for a

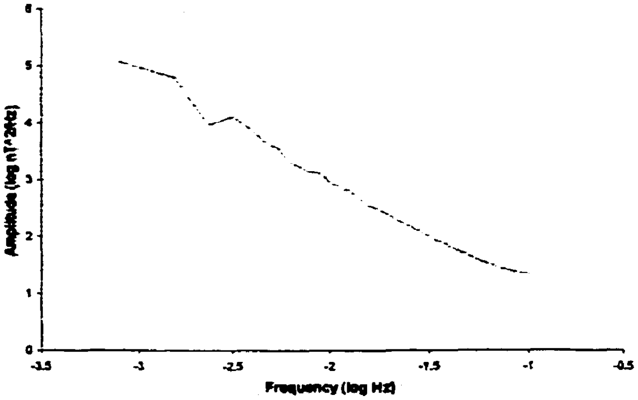


Figure 13. Periodogram of Pinawa Pc 5x pulsations recorded between 2:07 CDT and 8:31 CDT on May 30th, 2000. The amplitude of Pinawa Pc 5x is in nT^2/Hz.

period with enhanced Pc 5x pulsations recorded at the Pinawa observatory between 2:07 CDT and 8:31 CDT on May 30th, 2000. If pulsations were seen in the periodograms, time-by- amplitude plots of the signals were then created and checked by visual examination to qualify and classify the geomagnetic pulsations based on the duration and strength. Figure 14 shows a time-by-amplitude plot of five-second sampled raw

geomagnetic data for 2:07 to 8:31 CDT on May 30 th, 2000. If the duration of the elevated geomagnetic pulsations (Pc 5x) was more than 4 hours, the pulsation data were further considered for matching with AL data.

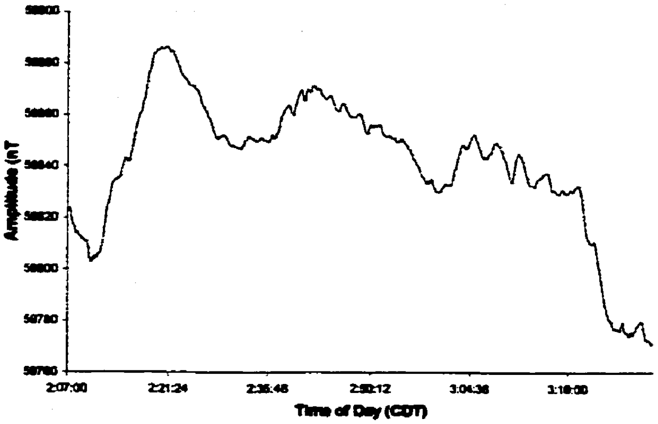
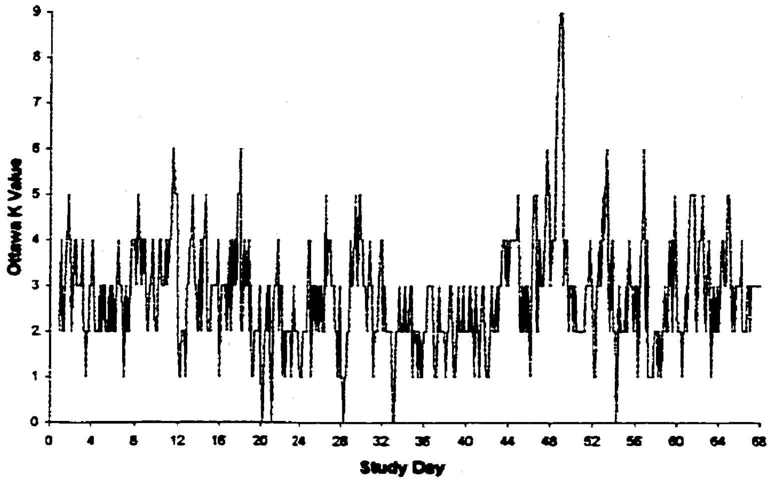


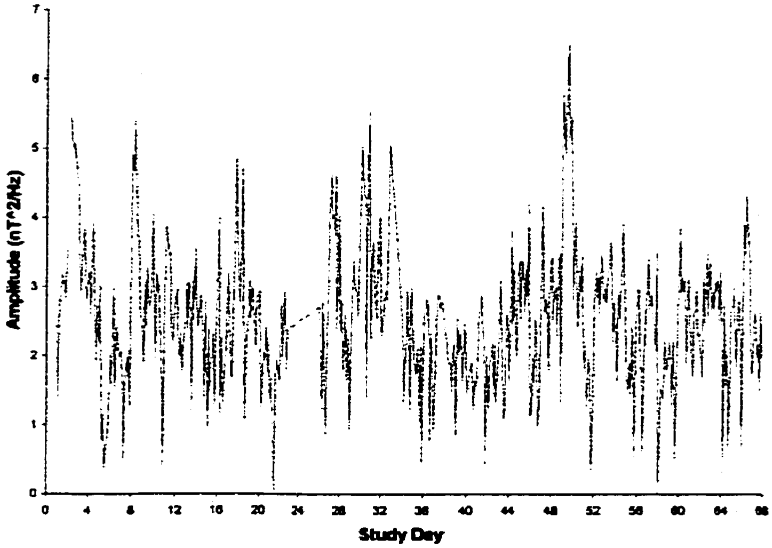
Figure 14. Time-by-amplitude plot of Pinawa Pc 5x pulsations recorded between 2:07 CDT and 8:31 CDT on May 30 th, 2000. The amplitude of Pinawa Pc 5x is in nT^2/Hz.

Overall Geomagnetic Activity throughout the Study

Figure 15 shows overall geomagnetic activity, as given by local Ottawa K values



(a) Ottawa K Values



(b) Pinawa Pc 5x

Figure 15. Ottawa K values (a) and spectral power of Pinawa Pc 5x (b) throughout the study (May 29 *th* to August 3*th*, 2000). The amplitude of Pinawa Pc 5x is in nT^2/Hz.

and Pinawa Pc 5x, throughout the study. There was an extreme geomagnetic storm (see Appendix H for the definition) on July 16, 2000 (Day 48), and both Ottawa K and Pinawa

Pc 5x peaked on the day, but there was no study measurement on either July 16 or 17, 2000 (Day 50). There were also five days with moderate geomagnetic storms (i.e., daily maximum Ottawa $K = 6$), 14 days with minor geomagnetic storms (i.e., daily maximum Ottawa $K = 5$), 24 geomagnetically active days (i.e., daily maximum Ottawa $K = 4$), and 22 geomagnetically quiet days (i.e., daily maximum Ottawa $K = 2$ or 3) during the study. According to Boteler et al. (1998), the spectral power (across frequency band) of geomagnetic pulsations increases with the level of Kp. There was a weak, positive correlation ($r = .32, p < .01$) between the daily sum of Ottawa K values and daily sum of log-transformed spectral power of Pinawa Pc 5x pulsations throughout the current study. The results is in agreement with the results from an informal study in which I found statistically significant, positive correlation between daily sum of Ottawa K values and the daily sum of spectral power of Pinawa Pc 5x pulsations ($r = .56, p < .001$).

Classification of Day

According to Ptitsyna et al. (1998), health effects of magnetic field exposure might be proportional to the time spent above a threshold. For the current study, geomagnetic pulsations were classified into two levels, enhanced geomagnetic pulsations and background level geomagnetic pulsations. To enable comparison with motor activity level data, the classification was done on a day by day basis.

We do not know whether there is a threshold for the possible effects of Pc 5x pulsations on human behavior. If it exists, however, there would be a difference in the results of a comparative analysis in which days of enhanced Pc 5x pulsations are compared with those of normal Pc 5x pulsations using a different cut-off point each time. To select statistical levels, I used the observed probability distribution function of geomagnetic storms, which will be discussed in the next section.

Occurrence Rates of Geomagnetic Storms. According to a space weather disturbance scale (see Appendix H) developed by National Oceanic and Atmospheric

Administration [NOAA] (2001), the average frequencies of geomagnetic storms (i.e., extreme, severe, strong, moderate, or minor geomagnetic storms) are 4, 60, 130, 360, and 900 days per 11-year solar cycle respectively. In other words, geomagnetic storms are observed for 1454 days out of 4015 days on average, and the occurrence rate is about 36 percent (the 64th percentile). According to the scale, extreme, severe, or strong geomagnetic storms are observed for 194 days out of 4015 days, and the average occurrence rate is about five percent (the 95th percentile) (NOAA, 2001).

Distribution of the Amplitude of Pinawa Pc 5x Pulsations and Three Cut-off Points. The distribution of the amplitude of spectral power estmates corresponding to Pc 5x pulsations recorded at the Pinawa observatory between May 3 and September 28, 2000 was extremely, positively skewed (skewness = 16.663). Its mean and standard deviation were 2.56×10^4 nT^2/Hz and 2.40×10^5 nT^2/Hz respectively.

Based on the average occurrence rate of overall or geomagnetic storms (64%) and that of extreme, severe, and strong geomagnetic storms (95%) reported by NOAA, I set two tentative cut-off points between enhanced geomagnetic pulsations and normal geomagnetic pulsations at the 64 and 95th percentiles of the distribution at which the amplitude of Pc 5x was mathematically equivalent to about 0.9 nT and 8.2 nT respectively. I arbitrarily set another tentative cut-off point at the 90th percentile of the distribution at which the amplitude of Pc 5x was mathematically equivalent to about 3.6 nT to determine whether there is any difference in the results of the analysis of the main hypothesis depending on the three cut-off points. By using each of the three cut-off points, the behavioral measurement periods were classified into two groups: days of enhanced geomagnetic pulsations (High), and days of normal geomagnetic pulsations (Normal). High days were defined as days with elevated geomagnetic pulsations (Pc 5x) with a total duration of more than 4 hours during the 8 hours between 11:00 p.m. CDT

(4:00 UT) the night before and 7:00 a.m. CDT (12:00 UT). The rest of the days were classified as Normal days.

When the Cut-off Point was Set at the 95th Percentile. When the cut-off point was set at the 95th percentile (8.2 nT) of the distribution of the amplitude of Pc 5x, there was one High day with the duration of the Pc5x pulsations more than four hours) — May 30th, 2000, which was then yoked to a Normal day with lowest K values for the same day care center — July 4th, 2000. (see Figure 16) for day care center A.

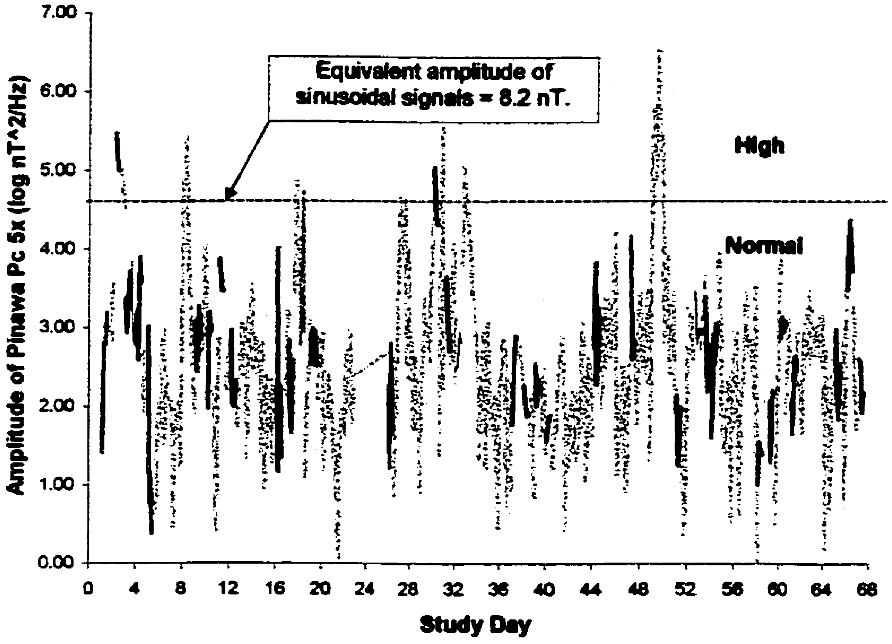


Figure 16. Pinawa Pc 5x for May 29th to August 3th, 2000. The bold lines represent changes in Pc 5x during study measurement of the participants. The amplitude of Pinawa Pc 5x is in nT^2/Hz.

When the Cut-off Point was Set at the 90th Percentile. When the cut-off point was lowered to the 90th percentile (3.6 nT) of the distribution of the amplitude of Pc 5x, there were two High days, May 30th and June 27th, 2000, which were then yoked to two Normal days from the same day care center. The two Normal days were those with the shortest period of enhanced geomagnetic pulsations and the lowest K values for the same day care center — July 4th and July 25th, 2000 for day care center A.

When the Cut-off Point was Set at the 64th Percentile. When the cut-off point was further lowered to the 64th percentile (0.9 nT) of the distribution of the amplitude of Pc 5x, there were four High days, May 30th, June 6th, June 27th, and July 11th, 2000, which were then yoked to four Normal days from the same preschool. The four Normal days were those with the shortest period of enhanced geomagnetic pulsations and the lowest K values for the same day care center — June 13th, July 4th, July 18th, and July 25th, 2000 for day care center A.

Score Calculations and Data Reduction for Activity Data

Accelerometers. Each child's motor activity level was calculated as the median of one-minute averages of one-second sampled accelerometer data for each day of observation, 10:00-15:00 Central Daylight Time (CDT) after excluding data for periods in which the instruments were off. Because the one-second sampled CSA scores showed strongly and positively skewed distribution, which remained after log-transformation of the data, the median, instead of the mean, of the one-second sampled data was used as a summary measure for the right ankle. The accelerometer was initialized to record the average acceleration on the ankle for every one-second epoch. One CSA score for a participant, who withdrew from the study after the first week of the measurement, was excluded from the analysis. Of a total of 15 CSA accelerometers, three of them were later excluded from the analysis due to their extremely low sensitivity to acceleration. Since there was greater-than-expected inter-instrument variability in the accelerometers, activity data from actometers were used for the test of the main hypothesis.

Actometers. Eaton et al. (1996) estimated that an actometer registers 1 activity unit (AU) for every five changes in direction. Using this information, one can estimate the number of arm movements from the number of elapsed actometer seconds by multiplying the seconds by 5. This product is divided by the number of hours the actometer has been worn to obtain a measure of total movements per hour. For example, a participant whose actometer showed an elapsed time of 16 min (960 sec) over 6.0 recording hours would generate a total movements per hour estimate of 200 (200 = 5 * 960 / 6). In the present study, the actometer movement counts were calculated in the same way for the behavioral measurement period, 10:00-15:00 CDT for each day of observation after subtracting time that the instruments were off. Of a total of 21 actometers, one actometer was excluded because it broke during the study.

Overall Activity Level. Because it was found that the sensitivity of the CSA accelerometers to acceleration varies from one accelerometer to another, each child's overall AL was based on the actometer measure. Each child's activity score for each day was expressed as the deviation from his/her grand mean over all days of assessment. The expression of individual scores as deviations around the mean score for the child removes overall child-to-child differences from consideration. That these individual differences were substantial was revealed in a variance components analysis. The variance components of the actometer movement counts per hour and the accelerometer movement scores were analyzed by using the VARCOMP procedure of SAS (SAS Institute, 1988). The results of the analysis revealed that more than half of the overall variance of actometer movement counts/hr score (60.2%) and accelerometer score (57%) was systematically related to person-to-person differences. The week-to-week differences were much smaller than the person-to-person differences for both actometer movement counts/hr score (7.7%) and accelerometer score (3.1%). The use of residual scores removes the substantial child-to-child differences from the analysis and allows for more focused attention on day-to-day differences.

Results

Accelerometer Score Results

As noted earlier, the distribution of the CSA scores for 1-minute average of all the 1-second epochs across all the children was extremely, positively skewed. This might be because the 1-second epoch chosen for the CSA activity measurement was so short that many of the 1-second epochs had scores of zero. Typical activities during the behavioral measurement at a day care center were indoor free play, out-door free play, lunch, nap, staff directed activity (art, science, etc.), snack, gym, quiet activities, and a field trip. The other possible reason would be that the children spent more time on sedentary activities than on physical activities. Accordingly, the median, instead of the mean, of one-minute averages of one-second sampled CSA score was calculated for each child's AL for each day. The CSA median for the full sample was also clearly skewed (skewness = 1.3) but not as much as the mean CSA score was (see Figure 17). The mean and standard deviation of the median CSA for the full sample were 11.4 units and 11.0 units respectively.

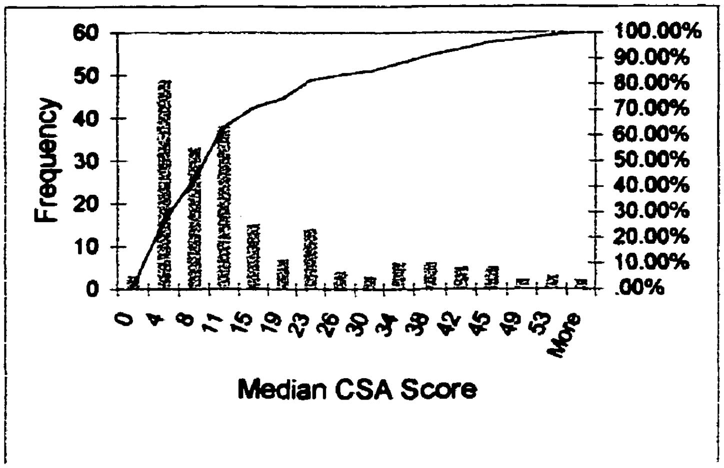


Figure 17. Distribution of the Median CSA Scores for Each Child for Each Week.

Actometer Score Results

In the present study, the hourly mean and standard deviation of actometer movement counts averaged for each child were 864.6 units and 355.2 units respectively. The distribution of the actometer score was positively skewed (skewness = 0.9).

Convergence of Accelerometers and Actometers

It was hypothesized that the two types of motion recorders, accelerometer and actometer, would be correlated. To see the correlation between accelerometer data and actometer data, McKeen (1998) did two studies. In her first study, she had 21 students (10 males and 11 females) in an introductory psychology course wear the two instruments on their wrists for 24 hours. She then correlated each participant's daily accelerometer data with its daily actometer data, and found that the correlation between the daily accelerometer counts and the daily actometer counts was significant, $r = .52$, $p < .05$. In her second study, in which 80 students (38-39 males and 40-45 females) wore the instruments on their wrists for 24 hours, the correlation between the two movement counts was higher ($r = .70$, $p < .0001$) than that in the first study, suggesting an effect from a bigger sample size. These results of her studies also suggest that there are additional or complementary aspects of movement measured by the two instruments that are not redundant. One measures average acceleration, and the other provides an estimate of movement frequency.

To test the assumption that the accelerometer and actometer measures are strongly and positively related, the concordance of these two scores was then assessed with a correlation after performing tests of normality on the distributions of both variables and removing outliers by using the UNIVARIATE procedure of SAS (SAS Institute, 1988).

As mentioned above, the distributions for the CSA accelerometer score and the actometer score were both skewed (skewness = 1.1 and 0.9 units respectively). As shown in Figure 18, a strong, positive correlation was seen between the actometer data (movements per hour) and CSA accelerometer data (the median of one-minute average of one-second sampled acceleration data) for each child for each week ($r = .70, p < .0001$)[1].

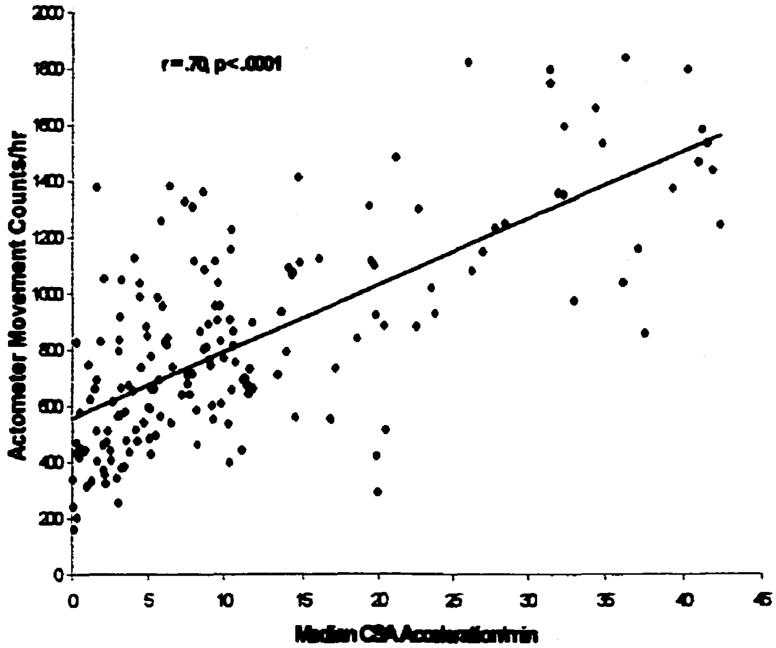


Figure 18. Actometer And CSA Movement Counts for Each Child for Each Week (*N* = 173).

To obtain a summary score for each child, the two types of data were then averaged across all the weeks attended. There was a statistically significant positive

---

[1] The two types of data were then log-transformed to the base 10 and then were correlated each other because the distributions of both CSA accelerometer data and actometer data were positively skewed (skewness = 1.35 and 0.70 units respectively). The correlation between the two types of log-transformed data also showed a correlation ($r = .69, p < .0001$) similar to that obtained with untransformed data.

correlation between the summary scores for accelerometers and actometers ($r = .89, p < .0001$) (see Figure 19).

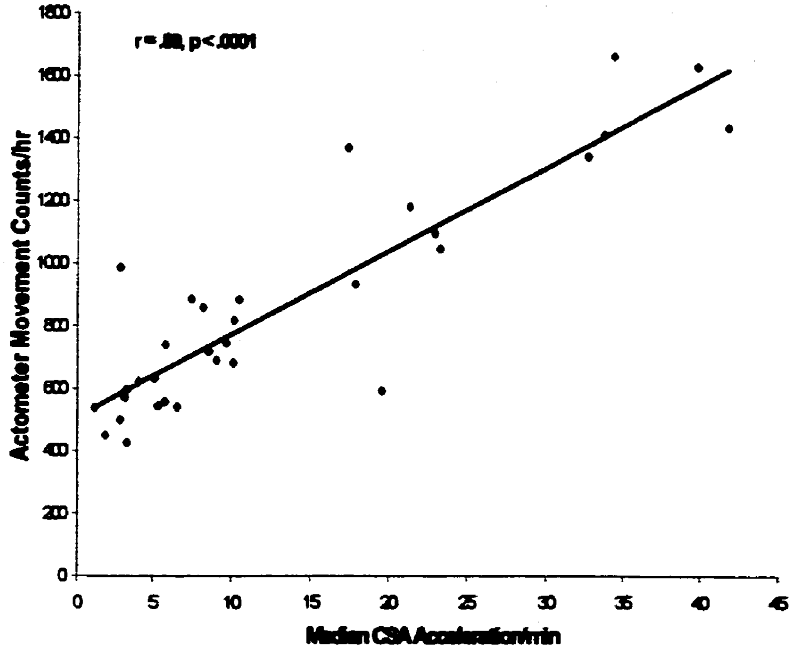


Figure 19. Actometer and CSA Movement Counts for Each Child ($N = 32$).

One outlier was excluded from the analysis because the outlier probability was over .05.

Gender Differences in AL

There was a statistically significant gender difference in median acceleration ($t = 2.23, p < .03$), whereas there was no statistically significant difference in the frequency of movement ($t = 1.57, p < .13$) (see Figure 20). The gender pattern was similar, however, and suggests that the movements of boys could be sharper and quicker than those of girls. The size of the gender difference in standard deviation units was .73 for the CSA accelerometers and .54 for the actometers.

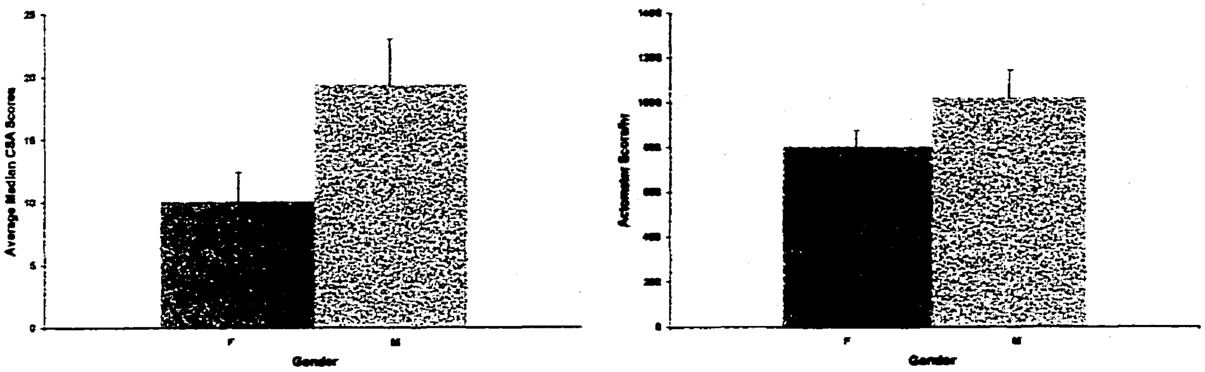


Figure 20. Gender Differences in the Median CSA Scores and Actometer Scores.

Why Actometers, Not CSA Accelerometers?

Calibration of 15 CSA accelerometers showed larger-than-expected differences in the sensitivity to acceleration among them. Although it would have been interesting to use the one-second sampled data otherwise, I decided to use activity data from actometers, which were better calibrated and had less inter-instrument variability than those from CSA accelerometers.

Sleep Disturbance and Activity Level Measured by Actometers

There was no statistically significant correlation between the weekly CSDS score and the overall AL for each child for each week.

Pc 5x Pulsations and Sleep Disturbance

For the analysis of Pc 5x pulsations and parent-reported sleep disturbance, only the data from day care center A were used because the day care center did not have a field trip throughout the study measurement days maintained generally the same daily activities.

When the 95th Percentile (8.2 nT) was Used as a Cut-off Point. When the 95th Percentile (8.2 nT) of the distribution of Pinawa Pc 5x pulsations for a span of the current study was used as a cut-off point, there were four participants whose sleep behavior was reported by their parents both on a High and a Normal day at day care center A (see Table 7).

Table 7

Number of Children Whose Sleep was Reported on both High and Normal Days at Day Care Center A

Pc 5x Cut-off Point[a]	Total *n* of Children[b]	*n* of Children[c]	High Day(s)	Normal Day(s)
95th %ile	4	4	May 30, 2000	July 4, 2000
90th %ile	11	4	May 30, 2000	July 4, 2000
		7	June 27, 2000	July 25, 2000
64th %ile	27	5	May 30, 2000	July 4, 2000
		5	June 6, 2000	June 13, 2000
		7	June 27, 2000	July 25, 2000
		10	July 11, 2000	July 18, 2000

Note. [a]The cut-off point in the distribution of the amplitude of Pc 5x between High and Normal days. [b]Total number of children whose sleep behavior was reported by their parents on both High and Normal days for each cut-off point. [c]Numbers of children whose sleep behavior was reported by their parents on both High and Normal days.

For these two contrasting days, the mean CSDS scores for the two groups were compared by using a paired t-test. The results of the paired t-test on the mean sleep disturbance scores from the four children were non-significant ($t = -0.47, p < .66$).

When the 90th Percentile (3.6 nT) was Used as a Cut-off Point. When the 90th percentile (3.6 nT) was used as a cut-off point, there were eleven participants whose sleep behavior was reported by their parents both on a High day and a Normal day. For these two contrasting days, the mean sleep disturbance socres for the two groups were compared by using a paired t-test. The results were non-significant ($t = -0.88, p < .39$).

When the 64th Percentile (0.9 nT) was Used as a Cut-off Point. When the 64th percentile (0.9 nT) was used as a cut-off point, there were 27 participants whose sleep behavior was reported by their parents both on a High day and a Normal day. To compare the High and Normal days, a paired t-test was applied to the sleep disturbance for the two groups. The results were again non-significant ($t = 0.2, p < .85$). Thus, for all comparisons, there was no evidence that sleep disturbance was varied with geomagnetic disturbances.

Pc 5x and Activity Level Measured by Actometers

Table 8 displays the number of children at day care center "A" who provided an activity measure on a high and normal day. For each of the cut-off points, a paired t-test was applied. When the 95th percentile was used, there was statistically significant difference between the high and normal day, with overall daily mean actometer leg movements per hour on the High day being slightly lower than that on the Normal day (*t*

Table 8

Number of Children Who Wore an Actometer on both High and Normal Days at Day Care Center A

Pc 5x Cut-off Point[a]	Total *n* of Children[b]	*n* of Children[c]	High Day(s)	Normal Day(s)
95th %ile	8	8	May 30, 2000	July 4, 2000
90th %ile	18	8	May 30, 2000	July 4, 2000
		10	June 27, 2000	July 25, 2000
64th %ile	37	8	May 30, 2000	July 4, 2000
		12	June 6, 2000	June 13, 2000
		10	June 27, 2000	July 25, 2000
		7	July 11, 2000	July 18, 2000

Note. [a]The cut-off point in the distribution of the amplitude of Pc 5x between High and Normal days. [b]Total number of children who wore an actometer on both High and Normal days for each cut-off point. [c]Numbers of children who wore an actometer on both High and Normal days.

= -2.75, $p < .02$). The means and standard deviations for the High and Normal days were -99.21 units and 201.48 units (High days) and 207.78 units and 243.81 units (Normal days) respectively. The overall effect size, *d* (Cohen, 1969) for differences in activity level was -1.15, which suggests that children's overall AL on days with enhanced geomagnetic pulsations was reduced during and immediately after a High pulsations day. When the 90th percentile (3.6 nT) was used as a cut-off point, there was a non-significant, though with borderline significance, result ($t = -1.81$, $p < .08$). The means were in the expected direction, and were 12.66 units and 254.92 units (High days) and 154.44 units and 224.38 units (Normal days) respectively, and the mean effect size was -1.15 units. When the 64th percentile (0.9 nT) was used as a cut-off point, the results of the paired t-test on actometer movement counts per hour from the 37 children showed no significant difference between type of day ($t = -0.64$, $p < .52$). The means and standard deviations for the High and Normal days were -0.04 units and 1.31 units (High days) and -0.12 units and 1.66 units (Normal days) respectively.

Discussion

This study evaluated the possibility that fluctuations in preschool-aged children's motor activity level are associated with variations in geomagnetic pulsations. This association was thought to be mediated by sleep disturbance. More specifically, it was hypothesized that high-amplitude pulsations in the intensity of the earth's magnetic field would, by disturbing their sleep the night before, decrease children's activity level. Sleep disturbance and activity level measured on days of enhanced geomagnetic pulsations were contrasted with the same measures on days of normal geomagnetic pulsations in a sample of 32 preschoolers. Three different thresholds for defining days of enhanced geomagnetic pulsations were evaluated. Before discussing the study's results for this main hypothesis, I will address two subsidiary issues, the convergence of different activity measures and the presence of gender differences. The convergence of actometer and accelerometer measures was also performed.

Activity Data from Actometers and Accelerometers

As hypothesized, a strong, positive correlation was found between the summary scores for the two types of motion recorders, accelerometer and actometer. The correlation between these two measures indicates that the results are not limited to one type of activity monitor. However, because there was greater-than-expected inter-instrument variability for the accelerometers, activity data from the actometers were used to address the hypotheses of the study.

Gender Differences in Activity Level

To address the unresolved question of gender differences in activity level, Eaton and Enns (1986) did meta-analysis on results from 90 citations encompassing 127 independent gender difference contrasts, and found that males are generally more active than females. In the current study, statistically significant gender differences were seen in median acceleration, which indicated that boys' median acceleration was larger than that of girls. On the other hand, gender differences in the frequency of movement were non-significant although its effect size for this measure ($d = .54$) was very close to those found by Eaton and Enns. Thus, the present data are consistent with a large body of evidence regarding the existence of gender differences in motor activity level in children.

Tests of the Main Hypothesis

To test the main hypothesis that high-amplitude pulsations in the intensity of the geomagnetic field decrease children's motor activity level, by disturbing their sleep the night before, I asked the following three questions: (1) Is children's overall activity level associated with parent-reported sleep the night before?; (2) Is children's sleep more disturbed during nighttime periods of enhanced geomagnetic pulsations?; and (3) Is children's overall activity level lower following nighttime periods of enhanced geomagnetic pulsations? In the next three sections, I will discuss the three questions in more detail.

Activity Level and Sleep. Before correlating activity data with sleep disturbance data obtained with sleep disturbance scales, the internal consistency for five items, which were selected from items in the sleep disturbance scales, was examined. Cronbach's alpha for the five items was .55, suggesting a marginal level of internal consistency for the items. Thus, the sleep disturbance scales are probably not reliable, suggesting that children's sleep was not rated accurately. For this reason, absence of a correlation between children's activity level and parent-reported sleep disturbance may be attributable to the use of the underdeveloped sleep disturbance scales. An answer to the question about sleep disturbance and activity level will require a better measure of sleep.

Geomagnetic Pulsations and Sleep. To address the question of the putative effect of geomagnetic pulsations on children's sleep, I compared the mean score of parent-reported children's sleep disturbance data for a night of enhanced and normal geomagnetic pulsations in Pc 5x range (i.e., 0.0017 - 0.0033 Hz). A paired t-test was applied to the sleep disturbance for a night of enhanced Pc 5x pulsations and that of normal Pc 5x pulsations using three cut-off points. For all comparisons, there was no evidence that sleep disturbance was varied with the spectral power of Pc 5x pulsations. As with the issue of sleep and activity level, the absence of an effect may be due to an unreliable sleep measure.

Geomagnetic Pulsations and Activity Level. Although functional relationships between magnetic field exposure and health effects are not known, some research suggests that the health effects might be proportional to the time spent above a threshold (Ptitsyna et al., 1998). The same suggestion can be applied to the putative effects of Pc 5x pulsations on activity level. When the highest threshold (8.2 nT) was used to define enhanced Pc 5x pulsations, activity level was significantly lower on the day of enhanced geomagnetic pulsations although the results are based on one day only with a small sample size. When the lower two thresholds (3.6 nT and 0.9 nT) were used to define the pulsations, no significant difference was found in activity level. Thus, although the results in the current study are mixed, they suggest a threshold effect for Pc 5x pulsations on children's activity level. The duration of exposure to Pc 5x pulsations above the threshold may also be the critical issue. The value of the present findings requires interpretation in the context of the strengths and weaknesses of the present study.

The Strengths of the Current Study

Behavioral Measurement Settings. According to Eaton and Enns (1986), larger magnitudes in gender differences in activity level were found when behavior was measured with automatic recording devices in familiar, non-stressful, unrestricted surroundings in the presence of peers. These conditions apply to the circumstances of the present study, so there is a reason to believe that satisfactory activity measurement was used. Moreover, another strength of the current study would be that the results are based on large samples of activity level obtained from a total of 38 days of study measurement.

Choice of Pc 5x Pulsations as a Geomagnetic Measure. Much of the formal research linking geomagnetic fluctuations to human behavior has been done retrospectively, using K index as a geomagnetic measure. For a more convincing demonstration, the current study used more specific measures of geomagnetic fluctuations (i.e., spectral power of Pc 5x pulsations) to predict children's motor activity level, which has the advantage of being continuously variable over time.

Weaknesses of the Current Study and Some Possible Solutions to Them

How to Increase the Sample Size. In the current study, the number of participants was small ($N = 33$), which limited statistical power. More children need to be measured over more days; more accelerometers would be needed to increase the maximum number of children who can be measured on the same day and the design of a future study should emphasize data collection over more days. Days with enhanced Pc 5x pulsations above the highest threshold are relatively infrequent, so it would be important to maximize the number of days of assessment to capture the high threshold days. Several steps could be taken to enlarge the sample of children and days. For example, now that the convergence of the two instruments has been established, only one of them should be needed. In the present study, activity data from the accelerometer were not used for the tests of main hypotheses because of the greater-than-expected inter-instrument variability. To increase the sample size in the future studies, however, it would be better to use only accelerometers after thorough factory calibration. Because a packet of two different types of activity monitors looks somewhat bulky on a preschool-aged child's ankle, and that would have made some directors of day care centers feel reluctant to give permission for participant recruitment. It would also be possible to recruit more children if each of them gets paid or rewarded for their participation. More investigators would be useful so that activity measurement could occur simultaneously at more than one day care center. Finally, data collection should be scheduled between March and June to avoid a summer holiday season and to increase the chance of sampling high threshold days.

How to Increase the chance of Doing Activity Measurement on Days of Enhanced Geomagnetic Pulsations. There was only one day with enhanced Pc 5x pulsations during the study measurement. To increase the chance of doing activity measurement on days of enhanced Pc 5x pulsations, it would be better for us to do the activity measurement when extreme, severe, or strong geomagnetic storms are predicted by the space weather forecast issued from the NOAA Space Environment Center. The space weather warnings are usually released two to three days in advance of the onset of geomagnetic storms. Thus, it is possible to visit day care centers and put the activity monitors on children's leg a day before the onset of the expected geomagnetic storms. In that way, the total number of visits to day care centers can be reduced from ten weeks to, say, six weeks. That would make participant recruitment easier, too.

What would be Better Measurement of Sleep Disturbance? The use of the sleep disturbance scales in the current study was not reliable, probably because parents did not have enough opportunity to directly observe their children's sleep behavior. Research has found that sleep duration can be measured with an accelerometer. For example, Reid and Dawson (1999) found a high correlation between EEG and sleep duration recorded by an accelerometer. In the current study, behavioral measurement was limited to five hours (between 10:00 a.m. and 3:00 p.m.) per week at the day care center only. The use of 24-hour activity measurement with accelerometers could provide objective data of child's sleep and of daytime activity. That will also help the investigator(s) obtain more detailed information of the child's nap and sleep from the teacher and the parent.

How to Get More Detailed Information on Daily Activity. In the present study, the Activity Recording Sheet was not used so that the teachers would not be discouraged from participating by the work involved. Instead, I collected monthly schedules from each day care center, and kept track of their outdoor activity such as field trips. Thus, little information on actual day care activities was available. In the future studies, a time-structured diary of day care activities could be developed and filled out by the investigator(s) based on the information obtained in a brief interview with teachers and day care staffs on each study measurement day.

How to Control Other Weather Variables that might Affect Children's Behavior. Provided that Pc 5x pulsations have biological effects, there are many problems to be solved. In particular, the analytic separation of geomagnetic variation from other variables, such as air temperature, humidity, air pressure, sunshine hours, solar flux, cosmic ray intensities, and solar radio bursts, will be very difficult unless the effects are tested under controlled experimental settings. Thus, more experimental work is needed to isolate geomagnetic effects.

How to Determine the Thresholds. There is no study that clearly establishes a given threshold for ULF waves and an affect on human behavior, physiology, or psychology. In the present study, I explored three thresholds for the spectral power of Pc 5x pulsations. The thresholds calculated were based on the distribution of spectral power of geomagnetic pulsations recorded at the Pinawa Observatory between May 29 and August 3, 2000. More geomagnetic pulsations data would be needed to get more accurate estimates of the three thresholds. Even so, many uncertainties remain. We do not know how long it takes for Pc 5x pulsations to affect sleep and it would be hard to determine the minimum required duration of exposure to Pc 5x pulsations. It would also be necessary to see whether long-time exposure to Pc 5x pulsations reduces nighttime secretion of melatonin, thus disturbing sleep in both humans and animals. Perhaps the best approach for now would be to do some intensive sleep study in which participants will be exposed to Pc 5x pulsations for several hours while their behavioral, physiological, and psychological endpoints are continuously monitored or intermittently rated under controlled settings.

How to Find Day Care Centers with a Desirable Daily Schedule. Of the four day care centers I visited in the current study, two often went out for field trips, while the other two had their children play in the back yard on fine days. Thus, some activity data do not seem to represent the children's typical activity level. In future studies, the role of activity constraints, such as field trips, needs more attention.

Review of Possible Mechanisms

In hindsight, it is clear that the study could have been better done. Nevertheless, some findings are suggestive, so a discussion of the possible mechanisms that mediate geomagnetic pulsations and activity level is in order. There are two possible mechanisms that could explain the possible link between geomagnetic disturbances and human physiology and behavior.

Long Term Potentiation and Long Term Depression. Startbuck (personal communication, September 17, 1999) hypothesized that the average spectral power of Pc 5 (5–50 nT) is large enough to depolarize the neuronal membranes in long term potentiation. On the other hand, Chen et al. (1996) examined the induction of synaptic efficacy in surgically resected human temporal cortex and found that long term depression was elicited by prolonged low frequency stimulation (1 Hz, 15 min), while long term potentiation was elicited by high frequency stimulation (100 or 40 Hz). Likewise, George (1998) found that electrical stimulation at low frequencies in the single Hz range results in long-term associative depression (LTD) of transmission in synapses in the hippocampus and motor cortex. Otani and Connor (1996) found that 0.033 Hz stimulation stabilizes long term depression induced by 2 Hz stimulation to the synaptic pathway of adult rat hippocampus. Thus, Starbuck's hypothesis does not fit recent findings on long term potentiation and long term depression. Although Pc 5x pulsations may elicit long term depression and reduce activity level, it is controversial and open to discussion.

Nighttime Melatonin Secretion and Geomagnetic Disturbances. Kay (1994) has suggested that disturbances in the geomagnetic field could suppress the nighttime peak in serum melatonin concentration in humans. If his argument is right, geomagnetic disturbances during the night may have some influence on the sleep-wake cycle and motor activity level in humans. However, there are inconsistencies among published findings relating the effects of the electromagnetic field to nighttime melatonin secretion in animals (Stevens & Davis, 1996), so Kay's argument is still very controversial.

Conclusion

The results of the present study does not directly address the question of mechanism, but it reveals a possible association between geomagnetic pulsations and activity level. With better measurement and sampling, future study could better test my conviction that geomagnetic pulsations influence sleep and activity level.

References

Agadzhanyan, N. A., & Vlasova, I. G. (1992). Influence of a very low frequency magnetic field on the rhythmics of nerve cells and their resistance to hypoxia. *Biophysics, 37*, 581-589.

Aleksandrov, V. V. (1995). Electrokinetic fields of hydrobionts. Biorhythms of locomotor activity. Connection with geomagnetism. *Biophysics, 40*, 753-759.

Baker, D. N., Pulkkinen, T. I., Li, X., Kanekal, S. G., Blake, J. B., Selesnick, R. S., Henderson, M. G., Reeves, G. D., Spence, H. E., & Rostoker, G. (1998a). Coronal mass ejections, magnetic clouds, and relativistic magnetosphere electron events: ISTP. *Journal of Geophysical Research, 103* (A8), 17279-17291.

Baker, D. N., Pulkkinen, T. I., Li, X., Kanekal, S. G., Ogilvie, K. W., Lepping, R. P., Blake, J. B., Callis, L. B., Rostoker, G., Singer, H. J., & Reeves, G. D. (1998b). A strong CME-related magnetic cloud interaction with the Earth's magnetosphere: ISTP observations of rapid relativistic electron acceleration on May 15, 1997. *Geophysical Research Letter, 25*, 2975-2978.

Becker, A. J. (1990). Geomagnetic Activity and Violent Behavior. *Subtle Energies and Energy Medicine Journal, Vol. 1, No. 2: 1990.* [WWW document]. URL http://linus.nekesc.k12.ks.us/~issseem/vol1no2.html

Becker, R. O. (1972). Electromagnetic forces and life processes. *Technology Review, December*, 32-38.

Belisheva, N. K., Popov, A. N., Petukhova, N. V., Pavlova, L. P., Osipov, K. S., Tkachenko, S. E., & Baranova, T. I. (1995). Qualitative and quantitative evaluation of the effect of geomagnetic field variations on the functional state of the human brain. *Biophysics, 40*, 1017-1014.

Bendat, J. S., & Piersol, A. G. (1971). *Random data: Analysis and measurement procedures*. New York: Wiley-Interscience.

Bennett, W. R. (1995). Electromagnetic Fields and Power Lines. *Scientific American-Science & Medicine, 2* (4), 68-77.

Bergiannaki, J., Paparrigopoulos, T. J., Stefanis, C. N. (1996). Seasonal pattern of melatonin secretion in humans: Relationship to daylength variation rate and geomagnetic field fluctuations. *Experientia, 52* (3), 253-258.

Betrus, P. A., & Elmore, S. K. (1991). Seasonal affective disorder, Part I: A review of the neural mechanisms for psychosocial nurses. *Archives of Psychiatric Nursing, 5* (6), 357-364.

Boteler, D. H., Boutilier, S., Swatek, D., Bui- Van, Q., Leonard, R., Hughes, B., Hajagos, L., Ferguson, I. J., & Odwar, H. D. (1998). Geomagnetically induced currents: Geomagnetic Hazard Assessment Phase II, Final Report, 1 (Publication No. 357T 848A). Ottawa: Geological Survey of Canada and Canadian Electrical Association.

Breus, T. K., Baevsky, R. M., Nikulina, G. A., Chernikova, A. D., Chibisov, S. M., Oraevskii, V. N., Halberg, F., Cornelissen, G., & Petrov, V. M. (1998). Geomagnetic activity effects on humans in nonstationary extreme conditions and comparison with laboratory observations. *Biophysics, 43*, 767-775.

Breus, T. K., Halberg, F., & Cornelissen, G. (1995). Influence of solar activity on the physiological rhythms of biological systems. *Biophysics, 40*, 719-730.

Burch, J. B., Reif, J. S., Yost, M. G. (1999). Geomagnetic disturbances are associated with reduced nocturnal secretion of a melatonin metabolite in humans. *Neuroscience Letters, 266* (3), 209-212.

Buss, A. M., & Plomin, R. (1975). *A temperament theory of personality development.* New York: John Wiley & Sons.

Campbell, W. (1997). *Introduction to geomagnetic fields.* New York, NY: Cambridge University Press.

Chen, W. R., Lee, S., Kato, K., Spencer, D. D., Shepherd, G. M., & Williamson, A. (1996). Long-term modifications of synaptic efficacy in the human inferior and middle temporal cortex. *Proceedings for National Academy of Science U. S. A., 93,* 8011-8015.

Chibisov, S. M., Breus, T. S., Levitin, A. Y., & Drogova, G. M. (1995). Biological effects of a planetary magnetic storm. *Biophysics, 40,* 957-966.

Chibrikin, V. M., Samovichev, E. G., & Kashinskaia, I. V. (1995). Dynamics f social processes and geomagnetic activity. 1: Periodic components of variations in the number of recorded crimes in Moscow. *Biofizika, 40,*(5), 1050-1053.

Cornelissen, G., Halberg, F., Engebretson, M., Simpson, H., Perfetto, F., Tarquini, R., Breus, T. K., Grafe, A., Wetterberg, L., & Schröder, W. (1999, December). *Geomagnetic disturbance spectra, latitude and the biosphere.* Paper presented at the meeting of the American Geophysical Union, San Francisco, CA.

Cohen, J. (1969). *Statistical power analyses for the behavioral sciences.* New York: Academic Press.

Dolberg, O. T., Hirschmann, S., & Grunhaus, L. (1998). Melatonin for the treatment of sleep disturbances in major depressive disorder. *American Journal of Psychiatry, 155,* 1119-1121.

Eaton, W. O. (1994). Temperament, development, and the five factor model: lessons from activity level. In C. P. Halverson, G. A. Kohnstamm, & R. P. Martin (Eds.), *The developing structure of temperament and personality from infancy to adulthood* (pp.173-187). Hillsdale, NJ: Erlbaum.

Eaton, W. O., & Enns, L. R. (1986). Sex differences in human motor activity level. *Psychological Bulletin, 100*, 19-28.

Eaton, W. O., McKeen, N. A., & Saudino, K. J. (1996). Measuring human individual differences in general motor activity with actometers. In K. P. Ossenkopp, M. Kavaliers, & P. R. Sanberg (Eds.), *Measuring Movement and Locomotion: From Invertebrates to Humans* (pp.79-92). New York: Springer.

Ferguson, I. J. (1988). *The Tasman Project of Seafloor Magnetotelluric Exploration.* Unpublished master's thesis, Australian National University, Canberra, Australia.

Fisher, B. E., Pauley, C., & McGuire, K. (1989). Children's Sleep Behavior Scale: Normative data on 870 children in grades 1 to 6. *Perceptual and Motor Skills, 68*, 227-236.

Ganjavi, O., Schell, B., Cachon, J. C., Porporino, F. (1985). Geophysical variables and behavior: XXIX. Impact of atmospheric conditions on occurrences of individual violence among Canadian penitentiary populations. *Perceptual and Motor Skills, 61*, 259-275.

Geological Survey of Canada National Geomagnetism Program (1998). Short-term forecasts. *Geological Survey of Canada Geomagnetic Forecasts.* [WWW document]. URL http://www.geolab.nrcan.gc.ca/geomag/e_forcast_levels.html

George, M. S. (1998). Why would you ever want to?: Toward understanding the antidepressant effect of prefrontal rTMS. *Human Psychopharmacology in Clinical Experiment, 13*, 307-313.

Ghione, S., Mezzasalma, L., Del-Seppia, C., & Papi, F. (1998). Do geomagnetic disturbances of solar origin affect arterial blood pressure?. *Journal of Human Hypertension, 12,* 749-754.

Greenstadt, E. W., McPherron, R. L., & Takahashi, K. (1979). Solar wind control of daytime midperiod geomagnetic pulsations. In D. J. Southwood (Ed.), *ULF Pulsations in the Magnetosphere* (pp.89-110). Tokyo: Center for Academic Publications Japan.

Haaland, S., Stadsnes, J., Søraas, F., Ullaland, S., Doke, T., Reeves, G. D., Wilken, B., Zong, Q., & Kokubun, S. (1999). GEOTAIL HEP-LD Results: 2 : Timing differences in substorm onset signatures. *Reprints of Publications.* [WWW document]. URL http://www.fi.uib.no/~haaland/timing/Timing.html

Halberg, F., Breus, T. K., Cornelissen, G., Bingham, C., Hilman, D. C., Rigatuso, J., Delmore, P., & Bakken, E. (1991, November). *Chronobiology in Space.* Paper presented at the meeting of the 37th Annual Meeting of the Japan Society of Aerospace and Environmental Medicine, Nagoya, Japan.

Halberg, F., Cornelissen, G., Katinas, G., Hillman, D., & Schwartzkopff, O. (2001). Season's Appreciations 2000. Neuroendocrinology Letters, 22, 53-73.

Halberg, F., Cornelissen, G., Sonkowsky, R. P., Lonzoni, C., Galvagno, A., Montalbini, M., & Schwartzkopff, O. (1998). Chrononursing (chronutrics), psychiatry and language. *New Trends in Experimental and Clinical Psychiatry, 14,* 15-26.

Hathaway, D. H. (1998a). Solar Flares. *Marshall Space Flight Center Space.* [WWW document]. URL http://science.msfc.nasa.gov/ssl/pad/solar/flares.htm

Hathaway, D. H. (1998b). The Solar Wind. *Marshall Space Flight Center Space.* [WWW document]. URL http://science.msfc.nasa.gov/ssl/pad/solar/sun_wind.htm

Hatta, K., Wolterink, G., & Van Ree, J. M. (1995). Prolyl-leucyl-glycinamide, thyrotropin-releasing hormone and b-endorphin-(10-16), like antidepressants, antagonize melatonin-induced behavioral changes in rats. *European Journal of Pharmacology, 284,* 327-330.

Hawkes, J. (1962). *Man and the Sun.* London: The Cresset Press.

Hudson, M. K., Elkington, S. R., & Lyon, J. G. (1999). Increase in relativistic electron flux in the inner magnetosphere: ULF wave mode structure. *Do We Understand the Inner Magnetotail Dynamics During Substorms?* [WWW document]. URL http://www.dartmouth.edu/~spacephy/papers/98H_cospar_neps-single.html

Jacobs, J. A. (1970). *Geomagnetic Micropulsations.* New York, NY: Springer-Verlag.

Jacobs, J. A. (1989). *Geomagnetism, 3.* San Diego, CA: Academic Press.

Jacob, R. G., Thayer, J. F., Manuck, S. B., Muldoon, M. F., Tamres, L. K., Williams, D. M., Ding, Y., & Gatsonis, C. (1999). Ambulatory blood pressure responses and the circumplex model of mood: A 4-day study. *Psychosomatic Medicine, 61,* 319-333.

Janz, K. F. (1994). Validation of the CSA accelerometer for assessing children's physical activity. *Medicine and Science in Sports and Exercise,* 369-375.

Kaufman, A. A., & Keller, G. V. (1981). *The Magnetotelluric Sounding Method.* New York: Elsevier Scientific Publishing Company.

Kay, R. W. (1994). Geomagnetic Storms: Association with Incidence of Depression As Measured by Hospital Admission. *British Journal of Psychology, 164,* 403-409.

Kearey, P., & Brooks, M. (1993). *An Introduction to Geophysical Exploration.* Oxford: Blackwell Scientific Publications.

Lakhovsky, G. (1939). *The Secret of Life.* London: William Heinemann Ltd.

Lavie, P., Haimov, I., Shochat, T. (1997). Melatonin - shutting off the wakefulness system. In G. J. M. Maestroni, & R. J. Reiter (Eds.), *Therapeutic Potential of Melatonin* (pp.149-160). Basel, Karger: Front Home Res.

Lehtoranta, V. K. (1997). Interplanetary magnetic field. *Glossary of Solar Terrestrial Terms.* [WWW document]. URL http://www.sci.fi/~fmbb/astro/glossar1.htm

Marshall Space Flight Center (1996). Education. *Marshall Space Flight Center Space Plasma Physics Branch.* [WWW document]. URL http://wwwssl.msfc.nasa.gov/ssl/pad/sppb/edu/magnetosphere/bullets.html

McKeen, N. A. (1988). *Infant Motor Activity: Temperament and Wake-Sleep Behaviour.* Unpublished master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

McLean, S. (1998). Geomagnetic Data at NGDC. *National Geophysical Data Center.* [WWW document]. URL http://www.ngdc.noaa.gov/seg/potfld/geomag.shtml

Menk, F. W. (1993). Low latitude geomagnetic pulsations: A user's guide. *Exploration Geophysics, 24,* 111-114.

National Academies (2001). Glossary. *Space Weather Research Perspective* [WWW document]. URL http://www.nas.edu/ssb/swglossary.html

National Institute of Environmental Health Sciences and U. S. Department of Energy (1995). *Questions and Answers About Electric and Magnetic Fields Associated with the Use of Electric Power.* Washington DC: U. S. Government Printing Office.

National Oceanic and Atmospheric Agency (2001). Categories. *NOAA Space Weather Scale.* [WWW document]. URL http://www.spaceweather.noaa.gov/stories/solarscales.html

Oraevskii, V. N., Breus, T. K., Baevskii, R. M., Rapoport, S. I., Petrov, V. M., Barsukova, G. V., Gurfinkel, Yu. I., & Rogoza, A. T. (1998). Geomagnetic Activity Effects on the Functional Characteristics of the Human Organism. *Biophysics, 43*, 776-782.

Otani, S., & Connor, J. A. (1996). A novel synaptic interaction underlying induction of long-term depression in the area CA1 of adult rat hippocampus. *Journal of Physiology, 492*, 225-230.

Otsuka, K., Ichimaru, Y., Cornelissen, G., Weydahl, A., Ichimaru, Y., Kobayashi, M., Holmeslet, B., Hansen, T. L., Mitsutake, G., Engebretson, M. J., Schwartzkopff, O., & Halberg, F. on behalf of the "ICEHRV" Working Group (2001). Possible light-dependent magnetoreception mechanism and potential human health hazard of geomagnetic ULF pulsations. Manuscript submitted for publication.

Partonen, T. (1998). Magnetoreception attributed to the efficacy of light therapy. *Medical Hypotheses, 51*, 447-448.

Pangia, M. J., Lin, C. S., & Barfield, J. N. (1990). A correlation study of Pc 5 magnetic pulsations with substorm onsets. *Journal of Geophysical Research, 95* (A7), 10699-10702.

Parkinson, W. D. (1983). *Introduction to Geomagnetism.* Edinburgh: Scottish Academic Press Ltd.

Pasucal, L. A., Vals, S. J., Wassermann, E. M., Brasil, N. J., Cohen, L. G., & Hallett, M. (1992). Effects of focal transcranial magnetic stimulation on simple reaction time to acoustic, visual and somatosensory stimuli. *Brain, 115*, 1045-1059.

Persinger, M. A. (1997). Geophysical variables and behavior: LXXXIII. Increased geomagnetic activity and group aggression in chronic limbic epileptic male rats. *Perceptual and Motor Skills, 85*, 1376-1378.

Persinger, M. A., Richards, P. M., Koren, S. A. (1994). Differential ratings of pleasantness following right and left hemispheric application f low energy magnetic fields that stimulate long-term potentiation. *International Journal of Neuroscience, 79*, 191-197.

Persinger, M. A., & Richards, P. M. (1995). Vestibular experiences of humans during brief period of partial sensory deprivation are enhanced when daily geomagnetic activity exceeds 15-20 nT. *Neuroscience Letters, 194*, 69-72.

Ptitsyna, N. G., Villoresi, G., Dorman, L. I., Iucci, N., & Tyasto, M. (1998). Natural and man-made low-frequency magnetic fields as a potential health hazard. *Physics – Uspekhi, 41*, 687-709.

Putilov, A. A. (1992). Non-uniform distribution of historical events within the eleven-year solar cycle. *Biophysics, 37*, 527-533.

Rankin, R. (1998). ULF magnetohydrodynamic waves and the auroral substorm. *Physics in Canada, 54*, 316-326.

Rapport, S. I., Boldypakova, T. D., Malinova, N. K., Oraevskii, V. N., Meshcheriakova, S. A., Breus, T. K., & Sosnovskii, A. M. (1998). Magnetic storms as a stress factor. *Biophysics, 43*, 587-595.

Raps, A., Stoupel, E., & Shimshoni, M. (1992). Geophysical variables and behavior: LXIX. Solar activity and admission of psychiatric inpatients. *Perceptual and Motor Skills, 74*, 449-450.

Reid, K.; & Dawson, D. (1999). Correlation between wrist activity monitor and electrophysiological measures of sleep in a simulated shiftwork environment for younger and older subjects. *Sleep, 22*, 378-385.

Rothbart, M. (1986). Longitudinal observation of infant temperament. *Developmental Psychology, 22*, 356-365.

Rostoker, G. (1998). Nowcasting of space weather using the CANOPUS magnetometer array. *Physics in Canada, 54*, 277-284.

Rostoker, G., Samson, J. C., & Olson, J. V. (1979). Latitudinal and longitudinal variation of Pc 4, 5 pulsations and implications regarding source mechanisms. In D. J. Southwood (Ed.), *ULF Pulsations in the Magnetosphere* (pp.1-15). Tokyo: Center for Academic Publications Japan.

Sandyk, R., Anninos, P. A., & Tsagas, N. (1991). Magnetic fields and seasonality of affective illness: Implications for therapy. *International Journal of Neuroscience, 58*, 261-267.

SAS Institute. SAS Language Guide for Personal Computers . (1988). *SAS Language Guide for Personal Computers (Release 6.03 ed.)*. Cary NC: Author.

Savage, C. (1994). *Aurora The Mysterious Northern Lights*. Toronto: Grey Stone Books.

Schimmerling, W. (1995). Space and radiation protection: scientific requirements for space research. *Radiation and Environmental Biophysics, 34*, 133-137.

Sadeh, A. (1997). Sleep and melatonin in infants: a preliminary study. *Sleep; 20,* 185-191.

Shafii, M., MacMillan, D. R., Key, M. P., Derrick, A. M., Kaufman, N., & Nahinsky, I. D. (1996). Nocturnal serum melatonin profile in major depression in children and adolescents. *Archive of General Psychiatry, 53*, 1009-1013.

Silva, A. P., Moreira, C., Bicho, M., Paiva, T., Clara, J. G. (2000). Nocturnal sleep quality and circadian blood pressure variation. *Review of Portuguese Cardiology, 19*, 991-1005.

Space Environment Center (1998a). A Primer on the Space Environment. *Planetary Changes.* [WWW document]. URL http://sec.noaa.gov/primer/primer.html

Space Environment Center (1998b). Geomagnetic field. *Glossary of Solar Terrestrial Terms.* [WWW document]. URL http://www.sec.noaa.gov/info/glossary.html

Stevens, R. G.; & Davis, S. (1996). The melatonin hypothesis: electric power and breast cancer. *Environmental Health Perspectives, 104* (Suppl. 1), 135-140.

Takeuchi, H., Uyeda, S., & Kanamori, H. (1967). *Debate about the Earth.* San Francisco: Freeman, Cooper & Co.

Thayer, R. E. (1989). *The Biopsychology of Mood and Arousal.* New York: Oxford University Press.

Thompson, R. (1995a). Meaning of X-Ray Fluxes From the Sun. *IPS Radio & Space Services.* [WWW document]. URL http://www.ips.oz.au/background/richard/xray_background.html

Thompson, R. (1995b). The Seasonal Distribution of Geomagnetic Disturbances. *IPS Radio & Space Services.* [WWW document]. URL http://www.ips.oz.au/background/richard/season_distrib.html

Tryon, W. W., & Williams, R. (1996). Fully proportional actigraphy: A new instrument. *Behavior Research Methods, Instruments, & Computers, 28*, 392-403.

Villoresi, G., Ptitsyna, N. G., Tyasto, M. I., & Iucci, N. (1998). Myocardial infarction and geomagnetic disturbances: An analysis of morbidity and mortality data. *Biofizika, 43*, 623-631.

Watanabe, Y., Hillman, D. C., Otsuka, K., Bingham, C., Breus, T. K., Cornelissen, G., & Halberg, F. (1994). Cross-spectral coherence between geomagnetic disturbance and human cardiovascular variables at non-societal frequencies. *Chronobiologia, 21*, 265-272.

Appendix A - Participant Recruitment Letter for Directors

March 1, 2000

director~
day care address~
day care postal~

Dear Director director~:

Mr. Gen Mitsutake, a graduate student in developmental psychology, and I are conducting a research project on the stability of children's level of motor activity over time. We are also interested in whether or not fluctuations in activity are related to features of the weather. This research requires the participation of children aged four to six, and we are writing to request your center's cooperation. We would be most appreciative if you would distribute to the parents a consent form and a letter that describes the study. We have appended a summary of the project and a copy of the parent letter.

Mr. Mitsutake will call you in the near future to see if your center might participate. In the meantime, either Mr. Mitsutake or I can be reached at 474-6955, and we would be happy to answer any questions you might have. If it would be helpful, either or both of us would be willing to attend a meeting concerning this request.

Yours truly,

Warren O. Eaton, Ph.D.

Professor

Appendix B - Telephone Protocol for Director

director~ **Center ID** ______________________________

phone~ **Date/Time** ______________________________

Hello ... Gen Mitsutake U of M. Calling about research project?
letter sent .. received? This research is for my master's thesis in developmental psychology.
What it would involve for you?

Distribute letters to the parents

Provide a small place in your center where I could set up a small child's table, a few materials and a recorder.

Describe study:
There would be 10 visits (2 visits in 1 day):

First day:

Put the watches on he children's ankle in the morning (10 am)

Remove the watches in the afternoon (3 am)

Cyclic visits (once a week)
As well, I would gladly visit the center before any testing begins to make myself known to the children so they would not be nervous with me.

Y **N**

Thank you very much for your time.
Do you have any questions?
How many 4, 5, & 6-year-olds do you have? and How many letters would you need?
Directions: Is your center easy to find (e.g. is it in a school or other non-obvious location?).

If you need to contact me, my phone number at laboratory: 474-6955 or home: 261-5186. There is an answering machine at both numbers if you wish to leave a message.

Appendix C - Participant Recruitment Letter for Parents

March 1, 2000

Dear Parent:

We are conducting research on children's motor activity levels over a period of 5 weeks. Your child's day care center has kindly agreed to cooperate, and I am writing to request your permission to allow your daughter or son to participate.

If you agree that your child can participate, please complete the enclosed form and return it to the day care center. Each participating child would wear two different types of small motion recorders that measure movement for total of 25 hours (once a week for 5 hours). We have successfully used the two motion recorders on many adults and children before without problems.

If you are willing to have your child participate, please complete the attached form and return it to the center as soon as possible. All obtained information will be used only for research purposes and will remain confidential. As well, one group data will be used in any publications resulting from this data. A summary of the results of the study will be sent to the center.

If you have any questions or want more details, please feel free to call me or my graduate student, Gen Mitsutake, at 474-6955.

Yours truly,

Warren O. Eaton, Ph.D.
Professor

Gen Mitsutake, B.A.
Graduate Student

Appendix D - Consent Form

Dear Parents/Guardians: **Please complete the following and return it to the center.**

Child's name: ________________________________

(first name) **(Surname)**

_____ **I do** consent to let my child participate in Dr. Eaton's study.

_____ **I do not** consent to let my child participate in Dr. Eaton's study.

Parent or guardian signature:_____________________ Date:_________________

Appendix E - Instrument Instructions

A. Please leave the recorder on the children as much as possible. Although we want the children to wear the instrument as long as possible, it may be necessary to remove it. The recorders aren't waterproof, so be sure to remove them if they are apt to be immersed. It is also very important for us to know of times when a recorder is off the child's ankles. So if you find it necessary to remove the recorder:

1) On the attached sheet note the time of day (not the tome on the recorder itself) when the recorder is removed and reattached.

2) Be sure to re-attach the recorder on the leg from which it was removed.

3) Be sure the recorder is snugly fastened on the <u>outside</u> of the ankle just above the ankle bone.

B. The recorders aren't fragile so you can treat the children as you normally do.

If you are uncertain about what to do, please call:

Gen Mitsutake
261-5186
or
leave a message at:
474-6955

Appendix F - Instruments Removal Sheet (for Teachers)

Center ID ____________ Date ____________________

Instruments Removal Sheet

Child's Name	Actual Time of Day **Instruments Removed (hh:mm)**	Actual Time of Day **Instruments Re-attached (hh:mm)**	**Reason of Removal**
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	
	:	:	

Appendix G - Instrument Record Sheet

Instrument Record Sheet

Child's ID#: ______________________________

Child's Name: ____

Centre ID#: __________________________

Date	**Actual Initial Reading Time**	Acto Initial Reading	Best Time to Remove the Recorders	**Actual Time of Removal**	Acto Final Reading
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :
	:	: :	:	:	: :

Appendix H - NOAA Space Weather Scale: Geomagnetic Storms

Category		Effect[a]	Physical Measure[b]	Frequency
Scale	Descriptor			
G5	Extreme	Power systems: grid systems can collapse and transformers experience damage. Spacecraft operations: extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents reach hundreds of amps, HF (high frequency) radio propagation impossible in many areas for one to two days, satellite navigation degraded for days, low-frequency radio navigation out for hours, and the aurora seen as low as the equator.	Kp=9	about 1 day /3 years
G4	Severe	Power systems: possible voltage stability problems, portions of grids collapse and protective devices trip. Spacecraft operations: experience surface charging and tracking problems, orientation problems need corrections. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and the aurora seen as low as the tropics.	Kp=8, including a 9-	about 11 days /2 years
G3	Strong	Power systems: voltage corrections required, false alarms triggered on protection devices, and high "gas-in-oil" transformer readings likely. Spacecraft operations: surface charging on satellite components, increased drag on satellite, and orientation problems need corrections. Other systems: intermittent satellite navigation and low-frequency radio navigation problems, HF radio intermittent, and the aurora seen as low as mid-latitudes.	Kp=7	about 12 days /year
G2	Moderate	Power systems: high-latitude power systems affected. Spacecraft operations: corrective actions required by ground control; changes in drag affect orbit predictions. Other systems: HF radio propagation fades at higher latitudes, and the aurora seen as low as 50 degrees.	Kp=6	about 33 days /year
G1	Minor	Power systems: weak power grid fluctuations. Spacecraft operations: minor impact on satellite operations. Other systems: the aurora seen at high latitudes (60 degrees); migratory animals begin to be affected.	Kp=5	about 82 days /year

Note. Table adapted from "Categories"," by National Oceanic and Atmospheric Agency, 2001, *NOAA Space Weather Scale.* [WWW document]. URL http://www.spaceweather.noaa.gov/stories/solarscales.html
[a]Some or all of these effects are possible. [b]Kp values (may change to use other measures, such as DST, as basis) determined every 3 hours. [c]number of storm events when Kp level was met (number of storm days).

Index