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Simulated sudden increase in geomagnetic activity and its effect on heart rate variability: Experimental verification of correlation studies

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ABSTRACT

Previous research investigating the potential influence of geomagnetic factors on human cardiovascular state has tended to converge upon similar inferences although the results remain relatively controversial. Furthermore, previous findings have remained essentially correlational without accompanying experimental verification. An exception to this was noted for human brain activity in a previous study employing experimental simulation of sudden geomagnetic impulses in order to assess correlational results that had demonstrated a relationship between geomagnetic perturbations and neuroelectrical parameters. The present study employed the same equipment in a similar procedure in order to validate previous findings of a geomagnetic-cardiovascular dynamic with electrocardiography and heart rate variability measures. Results indicated that potential magnetic field effects on frequency components of heart rate variability tended to overlap with previous correlational studies where low frequency power and the ratio between low and high frequency components of heart rate variability appeared affected. In the present study, a significant increase in these particular parameters was noted during geomagnetic simulation compared to baseline recordings.

1. Introduction

The potential role of space weather, especially geomagnetic activity, in human physiological systems has been demonstrated across a range of phenomena including endocrine activity (Breus et al., 2015) and brain activity (Mulligan et al., 2010; Saroka et al., 2014). Particularly relevant to the current study, previous researchers have shown that the cardiovascular system may also be susceptible to variations resulting from geomagnetic perturbation (Dimitrova et al., 2004, 2009; Stoupel, 1999). From a pathological perspective, geomagnetic storms may actually result in an increased occurrence of myocardial infarction (Kleimenova et al., 2007; Stoupel, 1999) where the observed relationships may be associated with geophysically-mediated changes in arterial blood pressure (Dimitrova, 2006, 2009; Papailiou et al., 2011).

Although indices of mean heart rate and blood pressure have typically been employed in heliobiological research on autonomic or cardiovascular activity, there have been relatively fewer studies using heart rate variability (HRV) (Cornélissen et al., 2002; Dimitrova et al., 2013; Otsuka et al., 2001a,b). A number of earlier results presented by Otsuka and colleagues have indicated that HRV tended to decrease in response to increased geomagnetic activity for a subarctic sample of healthy males (Otsuka et al., 2001a), and that the observation of a gradation for this biological response to geomagnetic activity in a subarctic region could implicate a form of human magnetoreception (Oinuma et al., 2002). Furthermore, magnetoreception was also inferred from a light-dark-mediated response of human participants to ultra-low frequency (ULF) Pc5 geomagnetic pulsations (Otsuka et al., 2001b). Finally, the application of an artificial magnetic field simulating ULF (~0.0016 Hz) geomagnetic pulsations with a weak intensity of ~50 nT appeared to decrease participants' HRV although this particular field application was 8 h in duration (Mitsutake et al., 2004). However, additional research has also implicated higher frequency Pc1 pulsations in geomagnetic-modulated variations of HRV (Kleimenova et al., 2007) and the current study used applied magnetic fields within this range (~0.20–4 Hz). Of further interest are the results obtained by Dimitrova et al. (2013) which identified significant changes (often decreases) in total variability and various frequency components of HRV including the ratio between low frequency and high frequency power which was interpreted as the balance between

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autonomic branches (i.e., sympathetic and parasympathetic contributions to HRV). However, the authors (Dimitrova et al., 2013) also suggested that there was a degree of variation regarding how individuals accommodated geomagnetic changes with respect to autonomic-cardiovascular state.

Despite these conclusions, it should be noted that Billman (2013), after a thorough review of the relevant literature, determined that the low frequency to high frequency ratio of HRV does not reflect an evenly balanced system of influence. Rather, the low frequency component appears to be relatively ambiguous regarding specific autonomic contributions, which may be largely cholinergic in origin, while the high frequency component is more likely dominated by parasympathetic (e.g., vagal) effects. The author (Billman, 2013) derived an overall relationship of low frequency (*LF*) to high frequency (*HF*) activity with their relative autonomic contributions in arbitrary units (1 = baseline activity) following the relationship:

$$\frac{LF}{HF} = \frac{0.5\ \mathrm{PSNS} + 0.25\ \mathrm{SNS}}{0.9\ \mathrm{PSNS} + 0.1\ \mathrm{SNS}}$$

where PSNS = relative parasympathetic nervous system contribution, and SNS = relative sympathetic nervous system contribution.

Of greater importance for the field of heliobiology overall, a vast majority of relevant studies are inherently correlational in nature due to the independent measures of interest. Although related research has tended to converge upon similar conclusions regarding an effect of geomagnetic activity on human physiology, there is a persistent need for experimental verification of these effects. As an example, Mulligan et al. (2010) had earlier corroborated results revealed by Babayev and Allahverdiyeva (2007) regarding an influence of geomagnetic processes on neuroelectrical activity using correlational means. Following this, the inferences were validated through experimental simulation of sudden geomagnetic increases during electroencephalographic (EEG) recording (Mulligan and Persinger, 2012). Although cardiovascular activity has often demonstrated similar relationships throughout past investigations, there has yet to be experimental verification of this potential influence from a range of magnetic field configurations, particularly various frequency components.

One of the potential concerns regarding the use of magnetic fields in physiological research is the weak intensity of the applied field relative to other well-known electromagnetic sources such as magnetic resonance imaging (MRI) which employs much stronger fields in the Tesla range. However, imaging studies often required Tesla-level magnetic fields in order to discern sufficient detail from signals generated by the alterations in spin of protons. In contrast, the current experiment was involved with simulating natural conditions that disrupt essential physiological conditions (Dimitrova, 2004, 2006). There are multiple correlational studies that have shown reliable associations between the types of cardiac features we measured and natural geomagnetic activity within the 20–200 nT range (Babayev and Allahverdiyeva, 2007; Breus et al., 2015; Cornélissen et al., 2002; Dimitrova et al., 2009; Mulligan et al., 2010; Oinuma et al., 2002; Papailiou et al., 2011; Saroka et al., 2014). Furthermore, Mitsutake et al. (2004) similarly observed cardiovascular effects resulting from application of a temporally-patterned magnetic field of only 50 nT. The temporal pattern of the applied field used in the current study was constructed to optimally influence “physiological patterns”. We have found that the more proximal the temporal pattern of the applied field is to the intrinsic patterns of cellular electrical activity the less intensity that is required to produce measurable disruptions (Lagace et al., 2009; Mach and Persinger, 2009). For example, a similar phenomenon was described for the most effective simulation patterns for inducing neuronal long-term potentiation (LTP) across different layers of the entorhinal cortices (Yun et al., 2002). This is consistent with the concept of natural resonance.

There are mechanisms other than Faradic induction of potential differences by which weak, physiologically patterned (that is non-temporally symmetrical shapes such as sine waves and square waves) magnetic fields applied through the body can produce significant influence upon function. Persinger and Saroka (2013) showed that the types of experiences induced in patients whose temporal lobes were stimulated surgically by millampere electric currents were comparable to normal volunteers who were exposed transcerebrally to microtesla magnetic fields. Estimates of the current induced within cerebral tissue by the surgical currents and the energy within the cerebral volume associated with the applied magnetic field produced almost identical effective values.

The integral duration and amplitude modulations of the field configuration we employed was simulated from the amplitude displacements associated with sudden storm commencements. The construct validity of this pattern was indicated by the similarity of the effect sizes for the onset of spontaneous seizures in epileptic rats when it was applied experimentally and the background values when natural fields occurred intermittently (Michaud and Persinger, 1985). The specificity of the shape and intensity of this experimentally generated field has been shown in other settings. For example rats developing experimental forms of a demyelinating disease displayed marked attenuation of symptoms when the base frequency of the applied field was 7 Hz and the serial changes in amplitude modulations was less than 40 nT with millihertz intrinsic periodicities (Cook et al., 2000). Application of the same field at 400 nT or application of 40 nT with 40 Hz oscillations or the latter with 400 nT produced effects that did not differ from sham field exposures. The primary goal of the current study was to employ similar geomagnetic simulation hardware used in verification studies by Mulligan and Persinger (2012) and also recently applied elsewhere for geomagnetic simulation (Murugan et al., 2013) in order to verify the apparent effect of geomagnetic increases on autonomic-cardiovascular activity determined by HRV measures.

2. Methods

2.1. Participants

After receiving ethics approval from the Laurentian University Research Ethics Board (LU REB), a total of 23 individuals volunteered for the current study. Exclusion criteria included <18 years of age, history of hypertension or other known cardiovascular health issues including arrhythmia or presence of a pacemaker ($n = 2$ excluded). Short-term electrocardiograph (ECG) recordings were obtained from a sample of 21 healthy volunteers (12 males, 9 females) from 18 to 55 years of age during both control and experimental conditions in a simple counterbalanced repeated-measures design. However, a single male ECG record was rejected for further analysis given the large number of artifacts (final sample of $n = 20$). Recording was done while participants were seated comfortably and during normal spontaneous breathing within a Faraday cage.

2.2. Data recording and processing

Single-lead (two electrodes) Covidien Kendall H135SG disposable ECG electrodes were used for all recordings with a Mitsar-201 amplifier connected to a laptop computer. WinEEG v2.103.7 software was used for data collection at a sampling rate of 250 Hz. All data were exported for further processing and analysis using additional software. Automatic QRS detection and computation of *R*–*R* intervals in milliseconds was conducted with ARTiiFACT v2.05 (Kaufmann et al., 2011). All records were further verified manually for accurate identification of waveform peaks. Any artifacts were corrected using a cubic spline interpolation of *R*–*R* intervals.