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INFLUENCIA DEL CLIMA EN VARIABLES CARDIACAS Y SU RELACIÓN CON LA ACTIVIDAD SOLAR-GEOMAGNÉTICA DURANTE EL CICLO SOLAR 24

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A mis padres,

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ÍNDICE GENERAL

ESTRUCTURA DE LA TESIS:

El trabajo de tesis que se presenta corresponde a la modalidad de artículos publicados. Está conformada por los siguientes apartados:

- Introducción. El objetivo de esta sección es contextualizar los artículos que se presentan. Se discuten las investigaciones más recientes sobre los efectos de las tormentas geomagnéticas y la presión atmosférica en el sistema cardiovascular, en particular en las componentes sistólica y diastólica de la presión arterial, así como los posibles mecanismos fisiológicos de interacción propuestos.
- Objetivos generales y particulares.
- Tres artículos publicados en revistas internacionales indizadas.
- Discusión y conclusiones generales.
- Bibliografía.

RESUMEN

El organismo humano es sensible a los cambios físicos de su entorno, la actividad fisiológica de los sistemas orgánicos es regulada entre otros factores, por los ritmos biológicos y las condiciones del medio ambiente. Numerosas investigaciones han mostrado que las variaciones significativas en las variables naturales tales como la presión atmosférica (Patm) y el campo geomagnético pueden ser factores para el desarrollo de enfermedades o incluso mortalidad, en particular en lo relacionado con el sistema cardiovascular. Los efectos se observan principalmente en las componentes sistólica (PAS) y diastólica (PAD) de la presión arterial y son distintos según el sexo y estado de salud de los individuos.

Este trabajo está conformado por tres artículos de investigación publicados en revistas internacionales indizadas, en los que estudiamos el comportamiento de las componentes PAS y PAD bajo la influencia de las variaciones de la presión atmosférica y las perturbaciones de la componente horizontal (H) del campo geomagnético asociado a tormentas geomagnéticas.

El estudio se llevó a cabo en la Ciudad de México durante los años 2008-2014 (mínimo, fase ascendente y máximo del ciclo solar 24) en tres muestras de voluntarios, con diferentes condiciones de salud (normotensos e hipertensos), divididos por grupo de edad, sexo y ciclos día-noche.

En el análisis de las series temporales usamos las pruebas estadísticas de correlaciones, ANOVA y épocas superpuestas (con ventanas temporales de dos y tres días en torno a las tormentas geomagnéticas que se presentaron). Las series temporales fueron tratadas estadísticamente y las correlaciones reforzadas con la estadística Dickey - Fuller y la Durbin - Watson.

Los resultados indican que los grupos estudiados presentan sensibilidad a las perturbaciones del campo geomagnético y a las variaciones de la presión atmosférica. La sensibilidad es distinta en hombres y mujeres, en cada grupo de edad, en los ciclos día-noche y en condiciones de salud distintas.

El poder cuantificar las variaciones de la PAS y la PAD durante los ciclos día-noche, por grupo de edad y sexo en individuos sanos e hipertensos durante un ciclo solar bajo las variaciones de las variables naturales, nos permite identificar anomalías en el comportamiento de los parámetros estudiados, lo que representa una contribución a los resultados obtenidos por otros grupos de investigadores a otras latitudes geomagnéticas.

Los estudios previos sobre actividad solar-geomagnética y presión en humanos adultos se han realizado a altas latitudes y solo algunos consideran el sexo de los participantes. Las aportaciones principales de este trabajo son:

a) Las muestras son analizadas en una latitud geomagnética media durante el ciclo solar 24 (2008-2014).

b) Se hace una distinción según el sexo, grupo de edad y ciclo día – noche.

c) Se considera el comportamiento circadiano de cada una de las componentes de la presión arterial.

ABSTRACT

The human organism is sensitive to the physical changes of its environment, the physiological activity of the organic systems is regulated among other factors, by the biological rhythms and the conditions of the environment. Numerous investigations have shown that significant variations in natural variables such as atmospheric pressure (Patm) and the geomagnetic field can be factors for the development of diseases or even mortality, particularly in relation to the cardiovascular system. The effects are mainly observed in the systolic (SBP) and diastolic (DBP) components of blood pressure and are different according to the sex and health status of the individuals.

This work is made up of three research articles published in indexed international journals, in which we study the behavior of the PAS and PAD components under the influence of the variations of the atmospheric pressure and the perturbations of the horizontal component (H) of the geomagnetic field Associated with geomagnetic storms.

The study was carried out in Mexico City during the years 2008-2014 (minimum, ascending phase and maximum of solar cycle 24) in three samples of volunteers, with different health conditions (normotensive and hypertensive), divided by group of Age, sex, and day-night cycles.

In the analysis of the time series we used the statistical tests of correlations, ANOVA and overlapping epochs (with two and three day time windows around the geomagnetic storms that were presented). The time series were treated statistically and the correlations reinforced with the Dickey - Fuller and Durbin - Watson statistics.
The results indicate that the studied groups show sensitivity to geomagnetic field disturbances and atmospheric pressure variations. Sensitivity is different in men and women, in each age group, in day-night cycles and in different health conditions.

The power to quantify the variations of SBP and DBP during day-night cycles, by age group and gender in healthy and hypertensive individuals during a solar cycle under the variations of the natural variables, allows us to identify anomalies in the behavior of the Parameters studied, which represents a contribution to the results obtained by other groups of researchers to other geomagnetic latitudes.

Previous studies on solar-geomagnetic activity and pressure in adult humans have been conducted at high latitudes and only a few consider the gender of the participants. The main contributions of this work are:

A) Samples are analyzed at an average geomagnetic latitude during the solar cycle 24 (2008-2014).

B) A distinction is made according to sex, age group and day - night cycle.

C) The circadian behavior of each of the components of blood pressure is considered.

INTRODUCCIÓN

El trabajo que se presenta pertenece al área de estudio de las Relaciones Sol-Tierra. Se estudia el comportamiento cualitativo y cuantitativo de las componentes diastólica (PAD) y sistólica (PAS) de la presión arterial (PA) bajo la influencia de las variaciones de campo geomagnético (H) y presión atmosférica (Patm) en un grupo de voluntarios en la Ciudad de México durante el ciclo solar 24.

Durante las últimas décadas, numerosas investigaciones han mostrado que el organismo humano es sensible a los cambios físicos de su entorno. La rotación de la Tierra trae consigo periodos de luz-oscuridad asociados a diversos procesos conductuales y fisiológicos en los seres vivos, lo que sugiere que los organismos están en sincronía con los cambios periódicos ambientales a los cuales están sometidos. Estudios realizados en humanos muestran que esta relación se manifiesta, por ejemplo, en desórdenes de la PA debidas a las variaciones en las condiciones geofísicas (Halberg 2008).

También plantean la posibilidad de que las variaciones de los parámetros meteorológicos y de campo geomagnético son capaces de influir en la salud humana y pueden ser un factor para el desarrollo de enfermedades o incluso mortalidad, en particular en su sistema cardiovascular (Palmer et al.; Didyk et al. 2008, 2012; Breus 2010; Gurfinkel et al. 2012; Zeng et al. 2013; Zenchenko et al. 2007, 2013). Algunos estudios muestran que la Patm influye más en las variaciones de la PAS y la PAD que las perturbaciones del campo geomagnético (Ozheredov et al. 2010; Shaposhnikov et al. 2014; Azcárate et al. 2016).

Los resultados de estas investigaciones indican que en el organismo humano, las perturbaciones significativas de las variables naturales actúan como factores de estrés exógeno capaces de inducir reacciones fisiológicas específicas (Breus, 2016). Las tormentas geomagnéticas crean una reacción de estrés adaptativo en individuos sanos y en aquellos que presentan algún factor de riesgo (Breus et al. 2008).

Las personas sanas con mayor magnetosensibilidad pueden experimentar trastornos funcionales capaces de influir en su calidad de vida, por otra parte, en las que presentan algún padecimiento en su sistema cardiovascular se puede exacerbar el problema (Breus et al. 2016). Los individuos con algún grado de hipertensión o algún problema vascular son más magnetosensibles que los normotensos (Zenchenko 2007; Khabarova 2008). Estudios en individuos hipertensos muestran que existe una relación entre la presión arterial y las variables naturales (Ghione et al. 1998; Argiles et al. 1998), en particular con las variaciones del campo geomagnético (Dimitrova 2005, 2006, Gmitrov 2007; Memmedhasanov et al. 2008; Caswell et al. 2015).

Los estudios experimentales controlados llevados a cabo en humanos y animales, así como los estadísticos, que son aquellos donde se analizaron series de tiempo obtenidas en hospitales, muestran que los individuos presentan mayor magnetosensibilidad cardiovascular antes, durante y después de la ocurrencia de una tormenta geomagnética, los cambios se presentan en la frecuencia cardiaca (Mavromichalaki 2012) y en la PAS y la PAD, los efectos también dependen del grupo de edad y del sexo (Gravryuseva et al 2002; Dimitrova 2008 a,b, 2009; Azcárate et al. 2012, 2016; Martínez-Bretón et al. 2016).

Distintos grupos de investigadores multidisciplinarios buscan encontrar los mecanismos de interacción, sin embargo, las hipótesis plausibles que proponen aún no son claras y hay discrepancias en los resultados de los estudios, por lo que no son concluyentes. Los efectos observados no solo dependen de las características del campo geomagnético o de los factores físicos del medio, también están involucradas las particularidades de las variables bioquímicas y fisiológicas, lo que dificulta su estudio.

Las principales líneas de investigación que se desarrollan actualmente están enfocadas a determinar las estructuras y elementos involucrados en la magnetorecepción y como se lleva a cabo.

Una de las propuestas de mecanismo de interacción sugiere que la acción de los campos electromagnéticos estáticos y variables (campo geomagnético) afectan la microcirculación arterial y sensibilidad de los barorreceptores, las terminales nerviosas localizadas en las paredes de la aurícula cardiaca, la vena cava, el cayado aórtico y el seno carotídeo, sensibles a los cambios de presión (Okano et al. 2005; Gmitrov 2002, 2004, 2005) produciendo hiperactividad simpática paroxística (Gmitrov 2009) al provocar cambios en el tono vasomotor periférico (Okano et al. 2008). La respuesta de los barorreceptores a los estímulos dependerá de las de las condiciones iniciales o tono de los vasos sanguíneos (McKay, 2006).

Otros estudios sugieren que la respuesta de estos sistemas está en función de las reacciones de los radicales libres y especies reactivas de N, O y Ca^{2+} ante estos campos, la cual puede verse afectada. En el caso de la PA se vincula con el óxido nítrico (Muehsam et al. 1996; Okano, 2008; McKay et al, 2007). La exposición a las variaciones de campo durante una tormenta geomagnética son capaces de modificar a nivel molecular los mecanismos de magnetorrecepción en el par-radical (Ritz et al. 2010).

En otro tipo de estudios sobre la exposición de la glándula pineal a campos magnéticos externos débiles y variables se ha demostrado que la acción de dichos campos es la de inhibir la secreción de melatonina. Se reporta que la PA varía según la producción de melatonina mediante el análisis en la concentración de 6-hydroximelatonin sulfato, que es un metabolito urinario de la melatonina. Se observa que un incremento en la producción de melatonina trae consigo un descenso en la PA (Cherry 2002; Sandyk 1993; Stoilova 2008; Reiter 2009).

Nuestra investigación se llevó a cabo durante el ciclo solar 24, durante los años de 2008 a 2014. Elaboramos tres artículos de investigación en los que se presentan los resultados obtenidos.

Los estudios anteriores a este trabajo de investigación doctoral, se realizaron principalmente en altas latitudes geomagnéticas. La revisión mostró que tienen deficiencias en la homogeneidad de los grupos de edad en las muestras empleadas, no consideran el comportamiento fisiológico de las componentes de la presión arterial y en la mayor parte, no hay reporte de control de los factores endógenos y exógenos que puedan originar variaciones importantes de la presión arterial en los participantes, que son variables muy sensibles. En nuestra investigación consideramos el comportamiento de las componentes sistólica y diastólica de la presión arterial y separamos los datos por sexo, grupo de edad y ciclo día-noche.

Se trata de un estudio de series de casos, los datos de las series de tiempo se obtuvieron mediante el monitoreo ambulatorio de la presión arterial con el Monitor Ambulatorio de la Presión Arterial modelo TM-2421. Cada uno de los voluntarios participantes en periodos quietos y perturbados de actividad geomagnética, durante 7 días en promedio para cada serie. Con el fin de garantizar la calidad de los datos, los participantes fueron entrenados en el uso correcto del monitor y llevaron un control estricto en su estilo de vida. Es importante mencionar que el seguimiento y coordinación de los voluntarios por parte de médicos del Instituto Politécnico Nacional, investigadores expertos en el tema del sistema cardiovascular y los ritmos biológicos, favoreció la obtención y calidad de las series temporales.

Pocas investigaciones muestran resultados cuantitativos de las variaciones de la PAS y la PAD durante la ocurrencia de una tormenta geomagnética. El trabajo de selección y análisis realizado con las series de tiempo de la PA de cada uno de los individuos que participaron en la investigación, así como las consideraciones y subgrupos que tomamos para el estudio, nos permitió conocer con más detalle el comportamiento de estas componentes respecto a lo reportado previamente en la literatura.

Los artículos elaborados se presentan a continuación.

1) Azcárate T., Mendoza B., Sánchez de la Peña S., Martínez, J.L. Temporal variation of the arterial pressure in healthy young people and its relation to geomagnetic activity in Mexico. Adv. Space Res. 50, 1310-1315, 2012. (doi:10.1016/j.ars.2012.06.015).
2) Azcárate T., Mendoza B., Levi J.R. Influence of geomagnetic activity and atmospheric pressure on human arterial pressure during the solar cycle 24. Adv. Space Res. 58, 2116-2125, 2016.(doi:10.1016/j.asr.2016.05.048).
3) Azcárate T., Mendoza B. Influence of geomagnetic activity and atmospheric pressure in hypertensive adults. Int J Biometeorol. 2017. (doi:10.1007/s00484-017-1337-x).

OBJETIVOS

Objetivo General

Estudiar la influencia de las variables naturales: meteorológica (presión atmosférica) y de actividad solar (tormenta geomagnética) en las componentes sistólica y diastólica de la presión arterial en humanos a latitudes medias durante el ciclo solar 24.

Objetivos específicos

a) Estudiar el comportamiento de las componentes sistólica y diastólica de la presión arterial bajo la influencia de las variables naturales en una muestra de individuos en el ciclo día-noche, divididos por sexo y grupo de edad durante el ciclo solar 24.
b) Determinar la variación cuantitativa de los valores de las componentes sistólica y diastólica de la presión arterial durante la ocurrencia de una tormenta geomagnética.

En los tres artículos que se presentan se reportan los resultados que dan cumplimiento a los objetivos planteados.

PRESENTACIÓN DEL ARTÍCULO: *“Temporal variation of the arterial pressure in healthy young people and its relation to geomagnetic activity in Mexico.”*

Las deficiencias encontradas en las muestras usadas en estudios estadísticos previos, nos dieron la pauta para establecer condiciones controladas para la obtención de datos. Con el fin de dar mayor peso al análisis estadístico. Se planteó el objetivo de estudiar el comportamiento temporal de las componentes de la presión arterial bajo la influencia de las variaciones de las variables naturales (campo geomagnético y presión atmosférica) en grupos con características de salud, edad y sexo similares y bajo las mismas condiciones ambientales.

Este primer estudio se realizó en la Ciudad de México, se investigó el comportamiento temporal de la PAS y la PAD de un grupo de 51 adolescentes normotensos bajo la influencia de las variaciones del campo geomagnético durante los meses de abril y mayo de 2008, en particular durante la tormenta geomagnética moderada del 24 de abril (Dst = -43 nT). Los datos de la componente H del campo geomagnético se obtuvieron del observatorio de Teoloyucan, Estado de México (TEO 19.74ºN, -99.18 W).
Para obtener mayor sensibilidad en los resultados y poder comparar la respuesta de la PAS y la PAD entre grupos, dividimos las series temporales por sexo y ciclo día-noche. Para el análisis estadístico se aplicaron el test ANOVA y el análisis de épocas superpuestas a los grupos de hombres, mujeres y a toda la muestra.
El test ANOVA aplicado a la PAS, la PAD y la componente H durante la tormenta geomagnética estudiada, muestra que hay respuesta estadísticamente significativa de la presión arterial. Con el análisis de épocas superpuestas (en una ventana temporal de tres días alrededor de la tormenta geomagnética) encontramos que los mayores cambios ocurren en la PAS en los grupos de hombres y mujeres. En términos cuantitativos, los mayores cambios en la PAS ocurrieron dos días antes y

un día después de la tormenta en los grupos estudiados. El grupo de mujeres presentó mayor sensibilidad a las variaciones de campo geomagnético que el de los hombres. Los resultados obtenidos en este artículo son acordes a lo encontrado por Dimitrova (2008 a, b), sin embargo, no se pueden generalizar debido a que la muestra estudiada es pequeña.

Como parte de la investigación que se presenta en este artículo, se estudiaron las características del clima espacial durante la tormenta del 24 de abril de 2008, la cual se asocia a las perturbaciones originadas en el borde de un hoyo coronal. Es posible que los efectos de estas perturbaciones influyan en las variables fisiológicas estudiadas.

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Temporal variation of the arterial pressure in healthy young people and its relation to geomagnetic activity in Mexico

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Abstract

We present a study of the temporal behavior of the systolic (SBP) and diastolic (DBP) blood pressure for a sample of 51 normotensive, healthy volunteers, 18 men and 33 women with an average age of 19 years old in Mexico City, Mexico, during April and May, 2008. We divided the data by sex along the circadian rhythm. Three geomagnetic storms occurred during the studied time-span. The strongest one, a moderate storm, is attributed to a coronal hole border that reached the Earth. The ANOVA test applied to the strongest storm showed that even though we are dealing with a moderate geomagnetic storm, there are statistically significant responses of the blood pressure. The superposed epoch analysis during a three-day window around the strongest storm shows that on average the largest changes occurred for the SBP. Moreover, the SBP largest increases occurred two days before and one day after this storm, and women are the most sensitive group as they present larger SBP and DBP average changes than men. Finally, given the small size of the sample, we cannot generalize our results.

Keywords: Geomagnetic activity; Geomagnetic storms; Blood pressure; Solar activity

1. Introduction

Among the mortality causes, those of cardiac origin have great interest for medical research. High blood pressure is one of the known risk factors implicated in cardiac death.

Recent works have presented evidences that solar/geomagnetic activity alters the arterial pressure in humans (see for instance reviews by Zhadin (2001), Breus et al. (2002), Palmer et al. (2006), Mendoza and Sánchez de la Peña (2009)). Gmitrov (2006) found an association between geomagnetic field variations and cardiovascular accidents related with blood pressure circulation. Stoilova and Dimitrova (2008) examined blood pressure, heart rate and electrocardiograms during perturbed and quiet days according to the Ap index; in particular there was a clear tendency for changes in blood pressure during increased geomagnetic activity. Dimitrova et al. (2008) found an increase in systolic and diastolic pressures some days before major and severe storms, particularly for the case of a moderate storm they found an increase during the day of the storm. Also, Dimitrova (2008) found that average values of systolic, diastolic and pulse pressures and subjective complaints were significantly increased with geomagnetic activity increments during the maximum of solar activity. Zenchenko et al. (2009) found that half of the group they studied experienced arterial pressure elevation with increased geomagnetic activity, independent of age and gender; the authors point out that in this subset the participants had mild cardiovascular pathologies. Papailiou et al. (2011) found statistically significance levels of the effects of the geomagnetic storms few days before and after on SBP

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and DBP in a group of few thousands of Slovak aviators. However in a review, Okano (2005, 2008) mentions studies indicating that blood pressure is affected in animals but not in humans as a response to static magnetic field intensity, being the geomagnetic field a type of such fields.

The largest geomagnetic field disturbances are the magnetic storms. They involve changes of up to 500 nT, ~1%, compared with the intensity of the background geomagnetic field at the magnetic poles (~60 000 nT). In middle and low latitudes the changes are normally up to ~150 nT, ~0.33%, of the background geomagnetic field intensity at the magnetic equator (~30 000 nT) (Campbell, 1997). If the solar/geomagnetic activity can affect human health, the populations living at higher geomagnetic latitudes would be more vulnerable as they are exposed to larger geomagnetic variations. So it is natural that research on this topic has been firstly and mainly carried out at high latitudes, while at middle and low latitudes such studies are scarce.

In the present paper, we worked with a group of young healthy volunteers in Mexico City, located at middle geomagnetic latitudes, dividing our data by gender and considering the circadian (day/night) rhythm. Our purpose was to assess the effect of a moderate geomagnetic storm that occurred during the time span of the study on the SBP and DBP components.

2. Data

We have 51 normotensive, healthy volunteers, 18 men and 33 woman with an average age of 19 years old (ages between 18 and 23 years old), all of them are medical students. They were monitored in the Centre of Chronomic Research of the National School of Medicine and Homeopathic of the National Politechnique Institute in Mexico City. The volunteers were committed to keep a healthy life style during the test: no smoking, no alcohol or coffee drinking, no intake of medicines or any other substances that altered their blood pressure, have a sufficient number of sleep hours, adequate food intake and avoid stressful situations. Besides, they kept a diary to annotate any situation that produced emotional or physical stress.

The volunteers self-monitored their arterial tension during April 4 to May 16, 2008, for each of the two blood pressure components: the SBP and the DBP. These values were obtained using the oscillatory method, with the TM-2421 Ambulatory Blood Pressure instrument from de AND Japan Co. The minimum scale of the instruments is 1 mmHg, then we associate to these measurements an uncertainty of ±0.5 mmHg. We divided the data by gender, because hor-

Table 1
Average systolic and diastolic pressures for the women group.

	AV		SD
Day time			
SBP	105.8	–	6.6
DBP	65.2	–	5.7
Night time		%	
SBP	99.0	6.9	7.5
DBP	59.3	9.9	7.2

The *first* column presents the variables of the study: SBP = Systolic pressure in mmHg; DBP = diastolic pressure in mmHg. DAY TIME: The *second*, column is the average value of each time series. The *third* column is blank. The *fourth* column is the standard deviation of the pressure components for each time series. For NIGHT TIME: The *second*, column is the average value of each time series. The *third* column is the difference in percentage between the average values of the pressure components in the day/night as follows: [(*average day value – average night value*)/*average night value*] × *100*. The *fourth* column is the standard deviation of the pressure components time series.

Table 2
Average systolic and diastolic pressure for the men group.

	AV		%	SD
Day time				
SBP	113.0	–	6.8	6.1
DBP	69.3	–	6.3	6.4
Night time		%	%	
SBP	105.3	7.3	6.4	8.1
DBP	59.7	16.1	0.7	7.1

The *first* column presents the variables of the study: SBP = Systolic pressure in mmHg; DBP = diastolic pressure in mmHg. For DAY TIME: The *second*, column is the average value of each time series. The *third* column is blank. The *fourth* column is the day-time percentage difference between men and women (from Table 1) of the average pressure components as follows: [(*average men day value-average women day value*)/*average women day value*] × 100. The *fifth* column is standard deviation of the pressure components time series. For NIGHT TIME: The *second* column is the average of each time series. The *third* colum is the difference in percentage between the average values of the pressure components in the day/night as follows: [(*average day value – average night value*)/*average night value*] × *100*. The *fourth* column is the night-time percentage difference between men and women (from Table 1) of the pressure components as follows:
[(average men night value-average women night value)/average women night value] × 100. The *fifth* column is the standard deviation of the pressure components time series.

Table 3
Average systolic and diastolic pressure for all the sample.

	AV		SD
Day time			
SBP	107.6	–	6.3
DBP	66.0	–	5.6
Night time		%	
SBP	100.5	7.1	7.1
DBP	59.3	11.3	6.5

The *first* column presents the variables of the study: SBP = Systolic pressure in mmHg; DBP = diastolic pressure in mmHg. For DAY TIME: The *second*, column is the average value of each time series. The *third* column is blank. The *fourth* column is the standard deviation of the pressure components time series. For NIGHT TIME: The *second*, column is the average value of each time series. The *third* colum is the difference in percentage between the average values of the pressure components in the day/night as follows: [(*average day value – average night value*)/*average night value*] × *100*. The *fourth* column is the standard deviation of the series.

monal activity produces different responses in blood pressure (e.g., Oelkers, 1996; Pechere-Bertschi et al., 2004), and according to a circadian rhythm (day-night), as it has been shown that blood pressure exhibits a spectrum of rhythms including a circadian behavior (e.g., Halberg et al., 2009).

We discarded those data with extreme values. The final database has 22712 measurements corresponding to the SBP and DBP.

Not all subjects provided data between 4 April and May 16. As the individual blood pressure time series have gaps of hours, the data is not sufficient to carry out analysis on an individual basis: For the 7.8% of the cases we have data for all the time-span considered (4th April–16th May). For the 37.3% of the cases we have data from the 4th to the 12th of April. For the 37.3% of the cases we have data from the 12th to the 24th of April. For the 17.6% of the cases we have data from the 24th of April to the 16th of May. Then we constructed an average time series for women, men, all the sample and for day and night, taking advantage of the fact that the individuals are an homogeneous group concerning age and health conditions. To construct the average time series and to reduce inter-individual differences we normalized the data using the algorithm: (*data-media*)/*standard deviation*. Tables 1–3 present the parameters of central tendency of the groups.

During the time-span of the study, three geomagnetic perturbations occurred on the days 7th of April (Dst = −29 nT), 24th of April (Dst = −43 nT) and 3rd of May (Dst = −22 nT) of 2008 (http://wdc.kugi.kyoto-u.ac.jp/kp/index.html). Only the second one reached the category of moderate storm.

3. Results

As mentioned above, the sample is divided by gender and in a circadian time-span. The day time-span was between 7:00 and 22:00 h, while the night time-span was between 22:01 and 6:59 h. The pressure values were obtained every 30 min during the day and every 60 min during the night. The Fig. 1 shows an example of the type of time series that we used. In Tables 1–3 we summarize the behavior of the data.

To study the relation between the geomagnetic field and the blood pressure components, we use the superposed epoch method around the geomagnetic storm day, together with the ANOVA test to check its statistical significance. As we mentioned before, the storm of the 24th of April is the strongest storm out of the three occurred during the time-span of the study. Moreover, for this particular storm we have the maximum number of data compared to the other storms, allowing us to use the data of 32 subjects (62.8% of the sample). Therefore, we concentrate our analysis on this geomagnetic event.

3.1. Superposed epoch analysis

We considered a temporal window of three days around the geomagnetic storm day (day 0) and, as indicated above, a sample of 32 individuals. Fig. 2 shows the behavior of the average SBP and DBP. Additionally we apply the ANOVA test to evaluate the statistical significance of the peaks appearing in this analysis. Table 4 presents the significance levels (p-values) obtained.

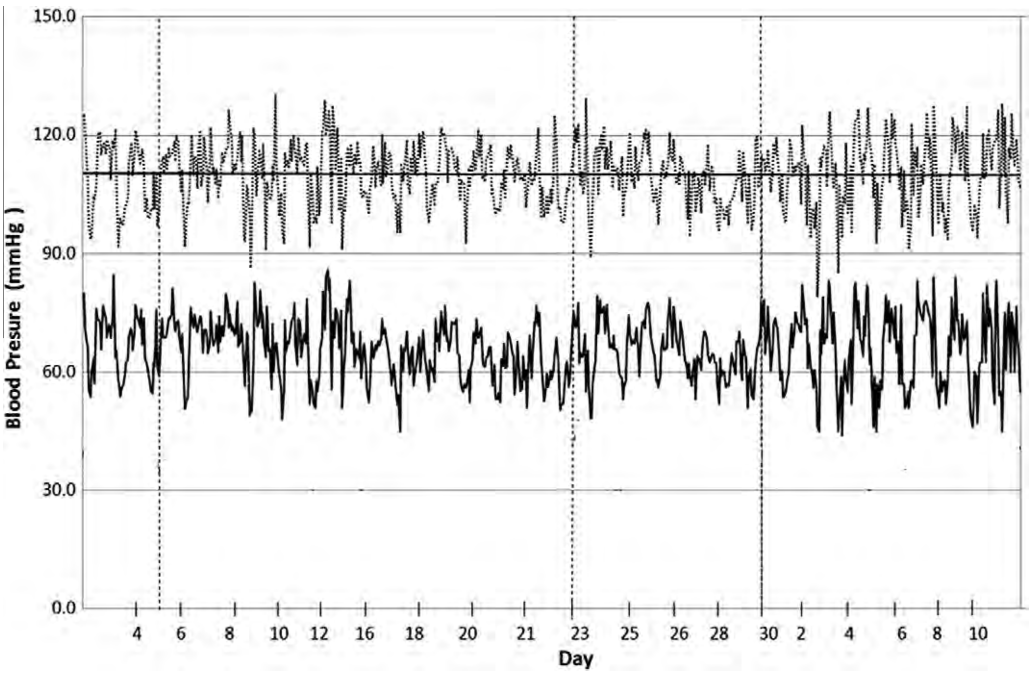

Fig. 1. Night-time behavior of the SBP (pointed line) and DBP (solid line) components for the men group.

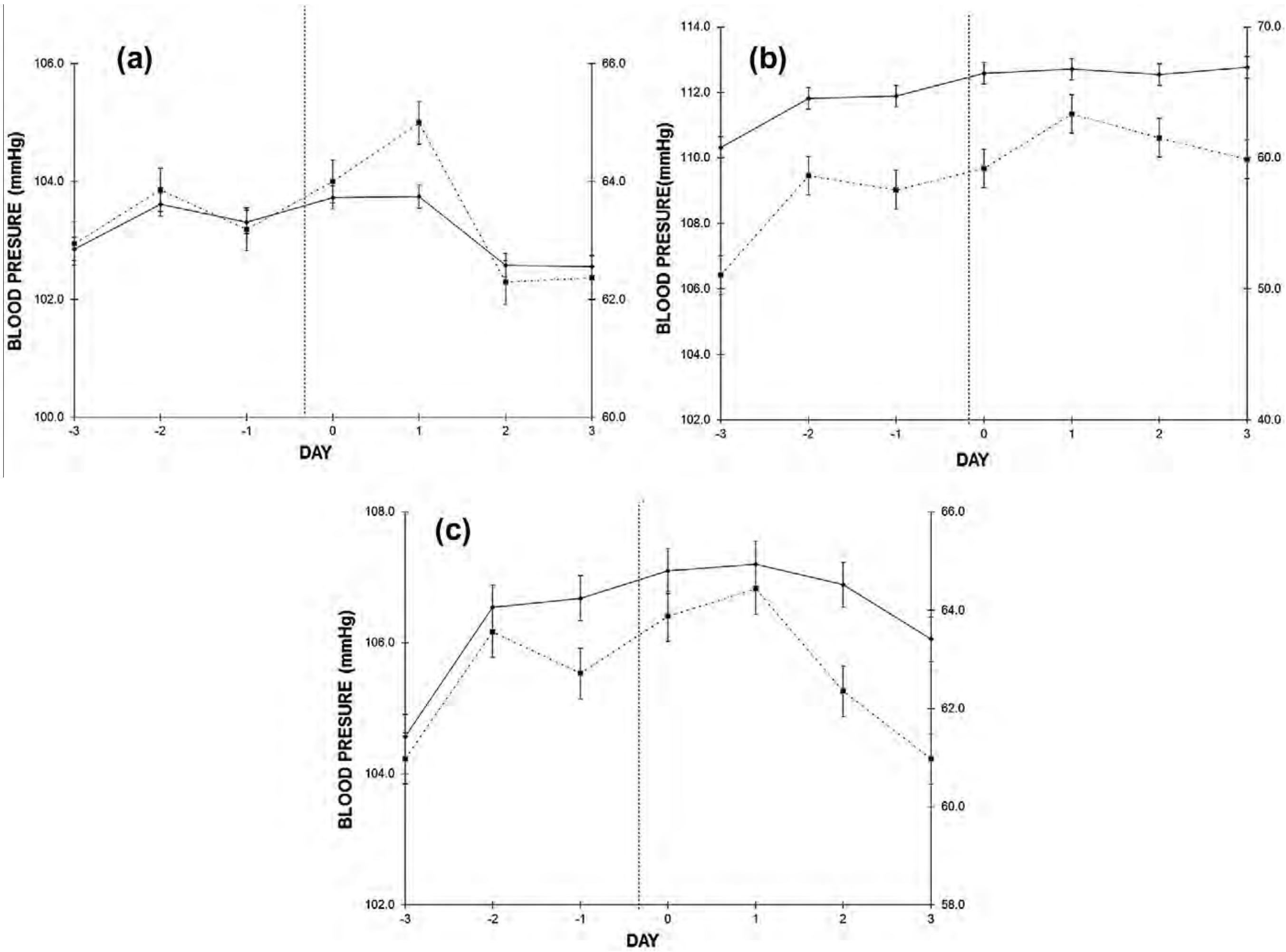

Fig. 2. Behavior of the SBP (pointed line, left-hand scale) and DBP (solid line, right-hand scale) during a three-days window around the geomagnetic storm day of the 24th April, 2008, for (a) women; (b) men; and (c) all the sample. The vertical error bars correspond to one standard deviation.

4. Space weather

We also want to explore the space weather during the geomagnetic storm of the 24th of April. In Fig. 3 we show the temporal behavior of the Dst index and the Bz interplanetary magnetic field component during the 24th of April, 2008 (DOY 114), the day of the geomagnetic storm. We notice that the deepest Dst phase is associated to a strong negative Bz component present since few hours before. Moreover, one day before the storm there is a plasma ß » 1, as the magnetic field intensity is small (0.7 nT) while the ß = 77.7 (http://omniweb.gsfc.nasa.gov/), indicating a high plasma density. Furthermore, in Fig. 4 we notice that during the 24th of April (DOY 114) the plasma velocity increases, the azimuthal flux presents a sharp decrease and an increase and the temperature sharply increase, also the density increases during DOY 113 and 114. All these are signatures of a Heliospheric Current Sheet (HCS) crossing. Finally, the Kp time series show a similar structure roughly every 27 days along four months (http://wdc.kugi.kyoto-u. ac.jp/kp/index.html), indicating that these Kp perturbations arise from a coronal hole border. We conclude that the increment in the Kp index is due to the presence of a coronal hole border whose perturbations travel through the HCS, then when the Earth crosses the HCR it feels the hole border influence.

5. Discussion

Tables 1–3 show the parameters of the central tendency of the SBP and DBP for women, men and the entire sample, along all the studied period. During the time-span of the study three geomagnetic storms were reported, the strongest one was a moderate storm occurring the 24th of April, 2008, also around the days of this storm we were able to use the data of the 32 subjects of our study. The ANOVA test were applied to this event.

The ANOVA test showed that the SBP and DBP were statistically significant affected by the geomagnetic activity from day −2 to day 0 of this activity, this indicates that even though we are dealing with a moderate geomagnetic storm, there are significant responses of the blood pressure.

Table 4
Levels (*p*-values) of the ANOVA test concerning the effect of geomagnetic storms on SBP and DBP for the days before (−), during (0) and after (+) the storm of the 24th of April, 2008.

Day	*p*-Value	
	SBP	DBP
Women		
−3 to −2	0.341	0.348
−2 to −1	0.252	0.320
−1 to 0	0.076*	0.013*
0 to 1	0.000*	0.000*
1 to 2	0.190	0.028*
2 to 3	0.220	0.200
3 to 4	0.132	0.107
Men		
−3 to −2	0.266	0.310
−2 to −1	0.230	0.270
−1 to 0	0.079*	0.014*
0 to 1	0.008*	0.192
1 to 2	0.042*	0.025*
2 to 3	0.912	0.675
3 to 4	0.567	0.968
All the sample		
−3 to −2	0.171	0.002*
−2 to −1	0.000*	0.573
−1 to 0	0.098	0.027*
0 to 1	0.000*	0.001*
1 to 2	0.051	0.001*
2 to 3	0.169	0.003*
3 to 4	0.003*	0.024*

The values with (*) indicate statistical significance.

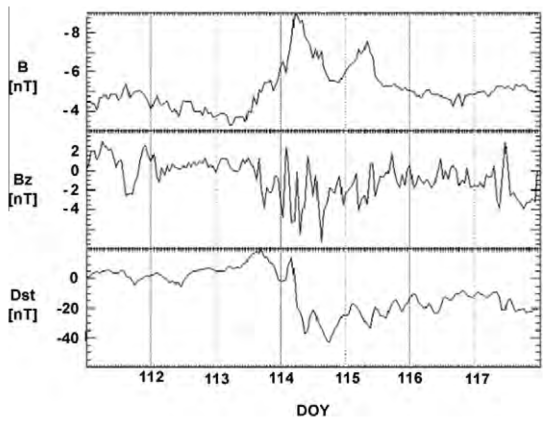

Fig. 3. Behavior of the Dst index and the Bz interplanetary magnetic field component during the 24th of April, 2008 (DOY 114), the day of the geomagnetic storm (http://omniweb.gsfc.nasa.gov/).

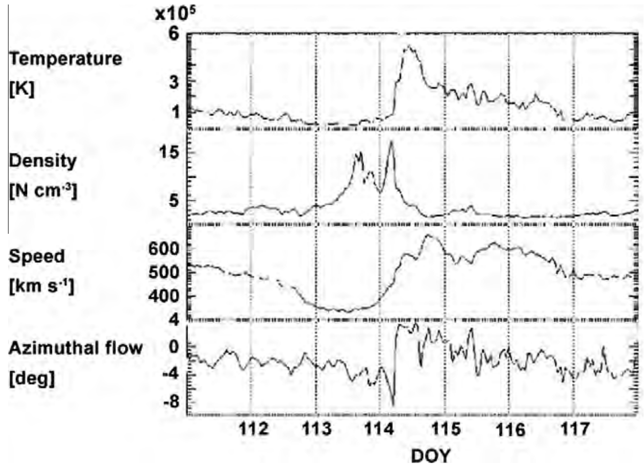

Fig. 4. Hourly plasma IMP/WIND/ACE/Geotail data. Strong changes in temperature, density speed and azimuthal flux are evident during the 23th and 24th of April, 2008 (DOY 113 and 114) (http://omniweb.gsfc.nasa.gov/).

Table 5
Average percentage changes in the SBP and DBP components during a 3-days window around the geomagnetic storm of the 24th of April, 2008.

Days	Women		Men		All the sample	
	SBP	DBP	SBP	DBP	SBP	DBP
Average changes in absolute value	1.18	0.64	1.1	0.52	1.16	0.73

We applied also the superposed epoch analysis to this geomagnetic storm, the results appear in Fig. 2 and Table 5. On average for women, men and the entire sample, the largest changes occurred for the SBP. The figure also shows sharp increases in SBP two days before the storm and one day after the storm. The DBP shows this behavior in a lesser degree for women and a smooth increase around the day of the storm for men and the entire sample. The largest percentage change considering the three groups was in SBP for women, this change, ∼1.2%, is small in comparison with the σ of the corresponding SBP average pressure which is ∼8% (see Table 1). We can speculate that these small changes are due to the fact that the geomagnetic storms occurring during this study were moderate, therefore they did not produced an important variation in the pressure components and do not compromise the health of the individuals of this study.

Dimitrova et al. (2008) found for the case of a moderate storm, increases in SBP and DBP during the day of the storm; in our study the largest increases occurred one day after the storm (See Fig. 2). In another study Dimitrova (2008) found that SBP and DBP increased still at moderate geomagnetic storms, also coinciding with our results. Furthermore, the Dimitrova (2008) study found that women were more sensitive than men during geomagnetic field increases, also in agreement with our results.

The Fig. 2 shows that sharp changes in the pressure components started three days before the storm. One possibility is that they are caused by the ultra-low frequency geomagnetic fluctuations. These fluctuations can appear few days before the storm main phase, and are related to the substorm process that starts when the reconnection between the interplanetary and the geomagnetic fields occurs (e.g., McPherron, 2005). Some of these fluctuations have frequencies that coincide with the cardiac rhythm. In our sample, we found average cardiac frequencies between 60 and 80 pulsations/minute corresponding to frequencies of ∼0.7–1 Hz, that coincide with the Pc1 geomagnetic pulsations. Also it has been pointed out that an increase in solar wind density near the magnetosphere one day before the beginning of the increase in the *Kp* index is a quite typical situation, particularly in years of sunspot minimum with the main contribution of gradually developing storms formed by solar wind high-speed streams fromcoronal holes. An increase in solar wind density results in an increase in the dynamic pressure on the magnetosphere, its restructuring, and a change in the geometry and quality factor of an ionospheric duct. As a consequence, the parameters of Schumann resonances change, *Pc*1 pulsations are generated, and infrasound generation is intensified. All these processes are discussed in the literature as affecting the biological systems. Thus, it is reasonable to consider just the moment of solar wind density increase as the beginning of magnetosphere changes with biotropic effect (Zenchenko, 2011).

6. Conclusions

The performed study presents the following results:

- Given the small size of the sample, we cannot generalize our results.
- The ANOVA test showed that even though we are dealing with a moderate geomagnetic storm (the event of the 24th of April), there are statistically significant responses of the blood pressure from day −2 to day 0 of the storm.
- The superposed epoch analysis during a three-days window around the geomagnetic storm of the 24th of April, shows that on average the largest changes occurred for the SBP. Moreover, the SBP largest increases occur two days before and one day after the storm. Women showed the largest changes in both SBP and DBP, indicating that they are the most sensitive group.
- The geomagnetic storm considered in the superposed epoch analysis is attributed to a coronal hole border that reaches the Earth. As the hole border perturbations travel through the HCS, when the Earth crosses the HCR it feels the hole border influence.

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PRESENTACIÓN DEL ARTÍCULO*: "Influence of geomagnetic activity and atmospheric pressure on human arterial pressure during the solar cycle 24."*

La realización del primer artículo nos permitió identificar áreas de oportunidad en el manejo de las series de tiempo y en el seguimiento a los voluntarios que podían optimizarse para obtener mejores resultados.

En este segundo trabajo de investigación doctoral, además de la componente H del campo geomagnético, se incluye la Patm como variable meteorológica. El estudio se realizó durante el ciclo solar 24, por lo que el número de series de tiempo y datos es considerablemente mayor. Para alcanzar los objetivos propuestos se llevó a cabo una revisión exhaustiva de cada una de las series con el fin de integrar una base de datos consistente para el análisis. El número inicial de series de datos era mayor, algunas series no estaban completas, por este motivo se descartaron del estudio, esta situación no comprometió la calidad de las series ni la validez de los resultados.

En este artículo investigamos el comportamiento de la PAS y la PAD de una muestra de 304 voluntarios normotensos, 152 hombres y 152 mujeres, con edades entre 18 y 84 años en la Ciudad de México durante el periodo 2008-2014 correspondiente a las fases mínima, ascendente y máxima de actividad del ciclo solar 24. Los datos se dividieron por sexo y grupo de edad y por ciclo día-noche. El análisis se realizó entre la PAS, la PAD y las variables naturales usando tres métodos: correlaciones, análisis bivariado y épocas superpuestas (con una ventana temporal de tres días alrededor del día en que ocurre la tormenta geomagnética).

Los resultados muestran que existe una correlación entre la PAS, la PAD y la Patm y H, misma que es mayor durante la noche. El análisis bivariado mostró que las correlaciones mayores ocurren entre la PAS, la PAD y la Patm. El análisis de épocas superpuestas mostró que el mayor número de cambios significativos ocurre en la PAS y la PAD en el grupo de mujeres. Finalmente, los cambios más grandes de la PAS y la PAD ocurren durante el mínimo y la fase ascendente del ciclo solar

24, probablemente porque las tormentas geomagnéticas fueron más intensas en este periodo que durante el resto del ciclo.

Durante el periodo de estudio dimos seguimiento a las condiciones del clima espacial y la actividad geomagnética, con el fin de identificar las perturbaciones significativas y convocar a los participantes a realizar el monitoreo ambulatorio de la presión arterial. La coordinación de actividades, obtención de datos y seguimiento a los voluntarios para monitorear su condición de salud general y asesoría de dudas, se llevó a cabo en el Centro de Investigación Cronómica de la Escuela Nacional de Medicina y Homeopatía del Instituto Politécnico Nacional, bajo la guía y supervisión del entonces estudiante de medicina Jonathan Levi.

Las series de tiempo se obtuvieron durante periodos con perturbaciones y sin perturbaciones geomagnéticas, para tener valores basales de referencia y poder cuantificar los efectos.

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Influence of geomagnetic activity and atmospheric pressure on human arterial pressure during the solar cycle 24

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Abstract

We performed a study of the systolic (SBP) and diastolic (DBP) arterial blood pressure behavior under natural variables such as the atmospheric pressure (AtmP) and the horizontal geomagnetic field component (H). We worked with a sample of 304 healthy normotense volunteers, 152 men and 152 women, with ages between 18 and 84 years in Mexico City during the period 2008–2014, corresponding to the minimum, ascending and maximum phases of the solar cycle 24. The data was divided by gender, age and day/night cycle. We studied the time series using three methods: Correlations, bivariate and superposed epochs (within a window of three days around the day of occurrence of a geomagnetic storm) analysis, between the SBP and DBP and the natural variables (AtmP and H). The correlation analysis indicated correlation between the SBP and DBP and AtmP and H, being the largest during the night. Furthermore, the correlation and bivariate analysis showed that the largest correlations are between the SBP and DBP and the AtmP. The superposed epoch analysis found that the largest number of significant SBP and DBP changes occurred for women. Finally, the blood pressure changes are larger during the solar minimum and ascending solar cycle phases than during the solar maximum; the storms of the minimum were more intense than those of the maximum and this could be the reason of behavior of the blood pressure changes along the solar cycle.

Keywords: Natural variables; Atmospheric pressure; Geomagnetic activity; Geomagnetic storms; Blood pressure; Solar activity

1. Introduction

Among the most frequent mortality causes in our planet are those of cardiac origin. In addition to the risk factors associated with heart diseases such as hypertension, obesity, diabetes and circadian hyper-amplitude tension, epidemiologists have also considered other risk factors, for instance, it is possible that solar/geomagnetic activity or related phenomena, have a role on cardiovascular or neurovascular pathologies (see for instance reviews by Zhadin, 2001; Breus et al., 2002; Palmer et al., 2006; Mendoza and Sánchez de la Peña, 2009).

Recent works have presented evidences that solar/geomagnetic activity alters the arterial pressure in humans. Caswell et al. (2015a,b) found significant correlations between space weather, geomagnetic activity and hypertensive mortality. Gmitrov (2007) found an association between geomagnetic field variations and cardiovascular accidents related with blood pressure circulation. Stoilova and Dimitrova (2008) examined blood pressure, heart rate and electrocardiograms during perturbed and quiet days according to the Ap index; in particular there was a clear tendency for changes in blood pressure during increased geomagnetic activity. Dimitrova et al. (2009)

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found an increase in systolic (SBP) and diastolic (DBP) blood pressures some days before major and severe storms, and for the case of a moderate storm they found an increase during the day of the storm. Stoupel (2006) found that temporal links exist between cardiac arrhythmia and the level of cosmophysical activity; the atrial fibrillation, ventricular tachycardia/fibrillation and sudden cardiac death are occurring in inverse relationship to the level of geomagnetic activity. Also, Dimitrova (2008) found that average values of SBP and DBP and pulse, and subjective complaints were significantly increased with geomagnetic activity increments during the maximum of solar activity. Zenchenko et al. (2009) found that half of the group they studied experienced arterial pressure elevation with increased geomagnetic activity independent of age and gender, pointing out that in this subset the participants had mild cardiovascular pathologies. Papailiou et al. (2011) studied a group of Slovak aviators. They analyzed the relation to daily variations of cosmic ray and geomagnetic activity, finding that there is a possible effect of geomagnetic activity and cosmic ray intensity variations on the cardiovascular functionality. Azcárate et al. (2012) found statistically significant change of blood pressure in normotense men and women during occurrence of the moderate geomagnetic storm. Papailiou et al. (2011) found statistically significant increases of SBP and DBP few days before and after geomagnetic storms in a group of few thousands of Slovak aviators. However in a review, Okano (2008) mentions studies indicating that blood pressure is affected in animals but not in humans as a response to static magnetic field intensity, being the geomagnetic field a type of such fields.

The largest geomagnetic field disturbances are the magnetic storms. They involve changes of up to 500 nT, ~1%, compared with the intensity of the background geomagnetic field at the magnetic poles (~60,000 nT). In middle and low latitudes the changes are normally up to ~150 nT, ~0.33%, of the background geomagnetic field intensity at the magnetic equator (~30,000 nT) (Campbell, 1997). If the solar/geomagnetic activity can affect human health, the populations living at higher geomagnetic latitudes would be more vulnerable as they are exposed to larger geomagnetic variations. So it is natural that research on this topic has been firstly and mainly carried out at high latitudes, while at middle and low latitudes such studies are scarce. Other studies have shown that changes in barometric pressure are associated with cardiovascular problems (Danet et al., 1999; Jehn et al., 2002; Houck et al., 2005).

In the present paper we work with SBP and DBP of a group of volunteers from three age groups: adolescents, adults and seniors (volunteers older than 60 years old) living in Mexico City located at middle geomagnetic latitudes (geomagnetic coordinates 19.3° 45″ 11 N, 99° 11″ 15 W). The data were divided by gender and considering the circadian rhythm (day/night). Our objective was to assess the effect of two natural variables such as atmospheric pressure and geomagnetic field in SBP and DBP during solar cycle 24.

2. Data

2.1. The sample

We worked with a sample of 304 healthy normotense volunteers, 152 men and 152 women divided by gender and in three age groups: adolescents, adults and seniors, with ages between 18 and 84 years old. Also the sample was studied in the day/night cycle. The study was carried out during the period 2008–2014, corresponding to the minimum, ascending and maximum phases of solar cycle 24. We divided the data by gender because it has been shown that hormonal activity produces different arterial pressure responses (Oelkers, 1996; Pechere-Bertschi and Burnier, 2004). We also divided the analysis in the day (between 07:00 and 22:00 h) and night (between 22:01 and 06:59 h) cycle because the arterial pressure behaves differently during such cycle (Halberg et al., 2009). The arterial pressure was measured each 30 min during the day and every 60 min during the night. The arterial pressure also presents different values according to age (Landahl et al. 1986; Reckelhoff, 2001).

2.2. The arterial pressure monitoring

The participants monitored their SBP and DBP at the Centro de Investigación Cronómica, Escuela Nacional de Medicina y Homeopatía del Instituto Politécnico Nacional, in Mexico City along the years 2008 to 2014. They kept a healthy life style during the study: no smoking, no drinking of alcoholic beverage or coffee, no intake of medicaments or any other substance that could alter their arterial pressure, had a sufficient sleep time and a healthy diet and avoided stressful situations. Moreover, they kept a diary to annotate any emotional or physical stress.

The volunteer self-monitored their SBP and DBP for periods of seven days. These arterial pressure measurements were obtained by the oscillatory method with the TM-2421 Ambulatory Blood Pressure-AND Japan Co. instrument. Its minimum scale is 1 mmHg, with an associated uncertainty of ±0.5 mmHg.

2.3. Selection of data

We selected the data with the following criteria: we averaged each volunteer daily SBP and DBP time series, those values that were 20 mmHg above or below these averages were discarded; as the volunteers are normotense, we considered that such extreme values were caused by their accidental movements.

2.4. The natural variables

The H data was obtained from the Tucson geomagnetic station (geomagnetic coordinates 32.1745°N, 110.7337°W, http://geomag.usgs.gov, belonging to the USGS

Table 1
Geomagnetic storms found during the years 2008–2014.

Year	Date	Dst index (nT)
2008	6 April	−27.8
	4 September	−26.3
2010	25 August	−21.5
	23 October	−17.4
2014	13 March	−17.9

The first column is the year. The second column is the date of the geomagnetic storm. The third column is the Dst index value.

Geomagnetism Program). The geomagnetic stations of this program follow the standard procedure for data filtering: the geomagnetic field components are filtered with the Gaussian method of integration to eliminate peaks produced by seasonal variations and other factors that generate noise, the resultant data do not have associated uncertainties. The AtmP data were obtained from the Programa de Estaciones Meteorológicas del Bachillerato Universitario (PEMBU-UNAM http://pembu.atmosfcu.unam.mx/), using the meteorological station which was

Table 2
Levels (*p*-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Women, year 2008.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.093	0.140	0.076	0.143	0.432	0.409
	AtmP	0.000**	0.039*	0.000**	0.061	0.007*	0.145
Coefficients correlation	H	0.06	0.05	0.07	0.05	−0.02	0.06
	AtmP	−0.21	−0.09	−0.20	−0.08	**−0.42**	−0.19
Adult							
	H	0.170	0.334	0.053	0.219	0.134	0.491
	AtmP	0.040*	0.385	0.228	0.252	0.007**	0.484
Coefficients correlation	H	0.05	0.02	0.08	0.04	−0.12	0.00
	AtmP	−0.08	0.01	−0.04	0.03	−0.26	−0.01
Seniors							
	H	0.245	0.059	0.065	0.226	0.065	0.226
	AtmP	0.000*	0.000**	0.074	0.019*	0.074	0.019*
Coefficients correlation	H	0.05	0.10	0.07	0.12	−0.25	−0.13
	AtmP	0.31	0.24	0.32	0.19	0.24	0.34

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level.

Table 3
Levels (*p*-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Men, year 2008.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.417	0.099	0.132	0.159	0.119	0.342
	AtmP	0.352	0.319	0.184	0.330	0.033*	0.005**
Coefficients correlation	H	0.01	−0.04	0.05	−0.04	−0.09	−0.02
	AtmP	−0.01	0.02	−0.04	−0.02	0.16	0.22
Adult							
	H	0.189	0.000**	0.353	0.000**	0.394	0.106
	AtmP	0.019*	0.155	0.067	0.237	0.092	0.074
Coefficients correlation	H	−0.04	−0.22	−0.02	−0.22	−0.03	−0.14
	AtmP	−0.09	0.05	−0.07	0.04	−0.15	0.16
Seniors							
	H	0.103	0.331	0.13	0.384	0.289	0.328
	AtmP	0.043*	0.009**	0.03*	0.035*	0.228	0.320
Coefficients correlation	H	−0.17	−0.06	−0.21	−0.10	−0.06	−0.09
	AtmP	0.11	0.15	−0.25	−0.26	−0.12	0.08

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 4
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Women, year 2009.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.086	0.008**	0.041	0.012*	0.133	0.288
	AtmP	0.111	0.004**	0.069	0.008**	0.065	0.357
Coefficients correlation	H	−0.10	−0.17	−0.13	−0.17	0.22	−0.11
	AtmP	−0.09	−0.19	−0.11	−0.18	0.30	−0.07
Adult							
	H	0.088	0.110	0.190	0.471	0.431	0.31
	AtmP	0.000**	0.137	0.000**	0.076	0.232	0.059
Coefficients correlation	H	0.04	0.03	0.03	0.00	0.01	0.07
	AtmP	−0.11	0.03	−0.10	0.04	−0.05	0.10
Seniors							
	H	0.223	0.024*	0.085	0.023*	0.005**	0.231
	AtmP	0.252	0.355	0.189	0.230	0.282	0.113
Coefficients correlation	H	−0.07	−0.17	−0.13	−0.19	–	−0.20
	AtmP	−0.06	0.03	−0.08	0.07	0.16	−0.32

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg. The numbers in black cases are the largest coefficients
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 5
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Men, year 2009.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.038*	0.175	0.069	0.333	0.373	0.094
	AtmP	0.231	0.163	0.045*	0.376	0.370	0.022*
Coefficients correlation	H	0.12	0.06	0.11	0.03	0.06	0.23
	AtmP	0.05	−0.06	0.12	0.02	0.06	−0.34
Adult							
	H	0.449	0.002**	0.375	0.000**	0.268	0.081
	AtmP	0.299	0.000**	0.256	0.000**	0.015*	0.011*
Coefficients correlation	H	0.00	0.10	0.01	0.14	−0.12	−0.04
	AtmP	0.02	0.13	0.03	0.17	0.17	0.15
Seniors							
	H	0.000**	0.083	0.375	0.000**	0.063	0.491
	AtmP	0.153	0.000**	0.256	0.000**	0.069	0.174
Coefficients correlation	H	0.23	−0.07	0.25	−0.08	0.18	0.00
	AtmP	−0.05	−0.22	−0.01	−0.22	−0.18	−0.11

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

the closest to the place where the participants monitored their arterial pressure (Preparatoria 9).

2.5. The time series

The final data base consisted of 386,400 data corresponding to the SBP and DBP, the atmospheric pressure (AtmP) and the horizontal component of the geomagnetic field (H).

We constructed average time series for each gender, age group and the day/night cycle. The volunteers in each series have similar health and age conditions. We further normalized the series using the following algorithm: average data/standard deviation.

Table 6
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Women, year 2010.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.498	0.140	0.000**	0.122	0.410	0.219
	AtmP	0.279	0.253	0.004**	0.147	0.106	0.007**
Coefficients correlation	H	−0.14	−0.07	−0.18	−0.06	−0.02	−0.08
	AtmP	−0.09	0.09	−0.14	0.06	0.12	0.24
Adult							
	H	0.389	0.485	0.003**	0.012*	0.002**	0.001**
	AtmP	0.000**	0.008**	0.004**	0.257	0.000**	0.001**
Coefficients correlation	H	0.01	0.00	0.08	0.07	−0.16	−0.17
	AtmP	−0.12	−0.07	−0.08	−0.02	−0.22	−0.18
Seniors							
	H	0.182	0.325	0.059	0.245	0.176	0.363
	AtmP	0.258	0.235	0.268	0.125	0.463	0.195
Coefficients correlation	H	0.08	0.04	0.15	0.07	−0.17	−0.06
	AtmP	−0.06	0.06	−0.06	0.11	0.02	−0.16

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 7
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Men, year 2010.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.000**	0.441	0.001**	0.083	0.000**	0.060
	AtmP	0.000**	0.045*	0.000**	0.129	0.000**	0.004**
Coefficients correlation	H	0.29	0.01	0.22	−0.10	**0.40**	0.17
	AtmP	0.27	0.10	0.26	0.08	**0.42**	0.30
Adult							
	H	0.042*	0.331	0.000*	0.244	0.014*	0.019*
	AtmP	0.141	0.022*	0.465	0.316	0.192	0.037*
Coefficients correlation	H	−0.05	0.01	−0.10	0.02	0.13	0.12
	AtmP	−0.03	−0.05	0.00	−0.01	−0.05	−0.10
Seniors							
	H	0.348	0.189	0.303	0.363	0.498	0.140
	AtmP	0.069	0.009**	0.047*	0.021*	0.279	0.253
Coefficients correlation	H	0.02	0.05	0.04	0.02	0.00	0.11
	AtmP	−0.08	−0.13	−0.11	−0.14	0.06	−0.07

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

For the years 2008 to 2011 the series were obtained randomly and therefore were not necessarily associated to geomagnetic events, then we looked for geomagnetic storms that occurred within that time period. The series for the years 2012–2014 were obtained specifically for perturbed geomagnetic conditions. Table 1 shows the corresponding geomagnetic storms, we point out that these storms are those for which we have SBP and DBP time-series per gender and age, corresponding to few days before, during and after the storm.

3. Results and discussion

We analyzed the time series using three methods: Correlations between the SBP and DBP and the natural variables (AtmP and H), bivariate analysis between the SBP and

Table 8
Levels (*p*-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Women, year 2011.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.420	0.485	0.424	0.460	0.176	0.185
	AtmP	0.294	0.386	0.325	0.254	0.433	0.397
Coefficients correlation	H	0.01	0.11	−0.03	0.08	0.08	0.15
	AtmP	−0.08	0.06	−0.11	0.12	0.15	0.00
Adult							
	H	0.021*	0.004**	0.113	0.022*	0.003**	0.001**
	AtmP	0.315	0.295	0.0252	0.277	0.059	0.002**
Coefficients correlation	H	−0.08	−0.11	−0.06	−0.10	−0.19	−0.22
	AtmP	0.02	0.02	0.03	0.03	0.11	0.20

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 9
Levels (*p*-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Men, year 2011.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Adolescents							
	H	0.038*	0.084	0.109	0.112	0.407	0.307
	AtmP	0.240	0.273	0.340	0.307	0.392	0.420
Coefficients correlation	H	0.18	0.14	0.13	0.13	0.08	0.16
	AtmP	−0.07	−0.06	−0.04	−0.05	0.09	−0.07
Adult							
	H	0.434	0.025*	0.317	0.119	0.234	0.094
	AtmP	0.069	0.140	0.052	0.035*	0.091	0.494
Coefficients correlation	H	−0.04	−0.22	−0.03	0.08	0.01	0.11
	AtmP	−0.09	0.05	−0.11	0.12	−0.08	0.06

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg. The numbers in black cases are the largest coefficients.
* The correlation is significant at the 0.05 level.

Table 10
Levels (*p*-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Adult men and women sample, year 2012.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Men							
	H	0.048*	0.051	0.080	0.001**	0.273	0.318
	AtmP	0.018*	0.001**	0.141	0.343	0.069	0.113
Coefficients correlation	H	0.18	0.17	0.21	**0.43**	0.10	−0.08
	AtmP	0.22	0.32	−0.16	0.06	0.23	0.19
Women							
	H	0.459	0.417	0.138	0.143	0.026	0.029*
	AtmP	0.000**	0.039	0.007**	0.081	0.008**	0.013*
Coefficients correlation	H	−0.01	0.02	−0.09	−0.09	0.32	0.39
	AtmP	0.25	0.13	0.21	0.12	0.39	0.36

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg. The numbers in black cases are the largest coefficients.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 11
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Adult men and women sample, year 2013.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Men							
	H	0.103	0.032*	0.435	0.095	0.046*	0.158
	AtmP	0.001**	0.003**	0.000**	0.013*	0.000**	0.198
Coefficients correlation	H	0.12	0.18	0.02	0.15	0.34	0.21
	AtmP	−0.31	−0.26	**−0.43**	−0.24	**0.69**	0.18
Women							
	H	0.119	0.026*	0.202	0.170	0.497	0.043*
	AtmP	0.103	0.042*	0.317	0.134	0.293	0.379
Coefficients correlation	H	0.11	0.18	0.08	0.10	0.02	**0.40**
	AtmP	−0.11	−0.16	−0.05	−0.11	−0.13	−0.08

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg. The numbers in black cases are the largest coefficients.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

Table 12
Levels (p-values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure. Adult men and women, year 2014.

Age group	Variable	24 h		Day time		Night time	
		SBP	DBP	SBP	DBP	SBP	DBP
Men							
	H	0.250	0.090	0.018*	0.001**	0.008**	0.043*
	AtmP	0.000**	0.000**	0.000**	0.000**	0.087	0.380
Coefficients correlation	H	−0.03	−0.07	−0.12	−0.18	−0.26	−0.28
	AtmP	−0.23	−0.24	−0.25	−0.25	0.14	−0.03
Women							
	H	0.220	0.231	0.008*	0.270	0.343	0.290
	AtmP	0.486	0.259	0.074	0.053	0.030*	0.172
Coefficients correlation	H	−0.05	0.05	−0.17	−0.04	0.06	0.08
	AtmP	0.00	−0.04	−0.10	−0.11	0.26	0.13

H = horizontal component of the geomagnetic field in nT. AtmP = atmospheric pressure in mmHg. SBP = systolic blood pressure in mmHg. DBP = diastolic blood pressure in mmHg. The numbers in black cases are the largest coefficients.
* The correlation is significant at the 0.05 level.
** The correlation is significant at the 0.01 level

DBP and the natural variables (AtmP and H), and superposed epoch analysis of the SBP and DBP within a window of three days around the day of occurrence of a geomagnetic storm.

3.1. Correlation coefficients

Tables 2–12 show the correlation coefficients. The largest correlations are shown in black cases. The time series have been analyzed to test stationarity, for that we used the unit root test, that consists in obtaining the contrast hypothesis at the 95% of confidence (p-values), that in turn is supported by the statistic Dickey–Fuller and the Durbin–Watson tests (Dickey and Fuller, 1979; Montgomery et al., 2001). The p-values are shown in Table 14. According to the unitary root test all the time series analyzed are stationarity except the H component of the geomagnetic field in 2009 for the case of senior women.

3.2. Bivariate analysis

This analysis allowed us to obtain the statistical significance between the SBP and DBP and the AtmP and H. Tables 2–12 show the variables that have the largest correlation with the SBP and DBP, indicated by the p-values (** = 0.01 significance level and * = 0.05 significance level). The tables refer to the years 2008–2014.

3.3. Superposed epoch analysis

We used the averages of SBP and DBP in a window of three days around the geomagnetic storms (day 0) presented in Table 1. We have time series for both sexes with similar ages. Figs. 1–5 present the results.

Tables 2–12 show the correlations between the natural variables (AtmP and H) and the men and women DBP and SBP according to age and the day/night cycle along

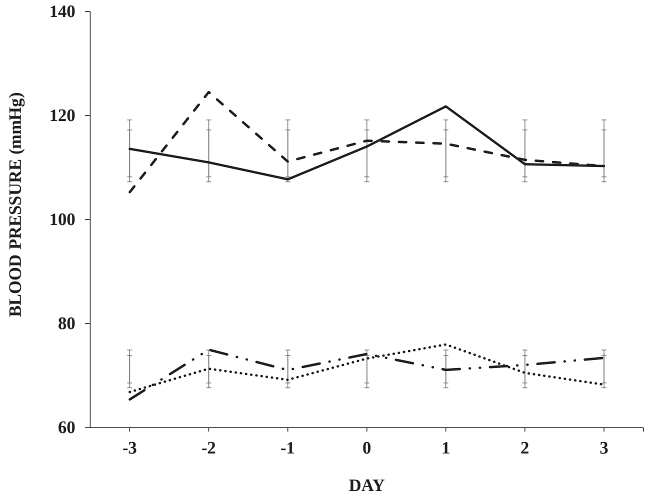

Fig. 1. Behavior of the blood pressure within a three-days window around the 6th April, 2008 geomagnetic storm. SBP for adolescent women (▬) and adolescent men (- - -); DBP for adolescent women (.....) and adolescent men (•• _ •• _). The vertical error bars correspond to ±1 standard deviation.

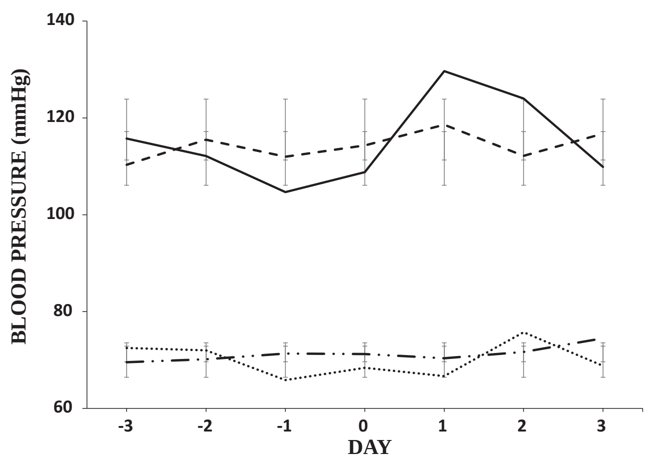

Fig. 2. Behavior of the blood pressure within a three-days window around the 4th September, 2008 geomagnetic storm. SBP for adolescent women (▬) and adolescent men (- - -); DBP for adolescent women (.....) and adolescent men (•• _ •• _). The vertical error bars correspond to ±1 standard deviation.

2008–2014. The largest correlations ($r \geqslant 0.4$) occur during the night between the SBP and DBP, the AtmP (0.9% of the cases with respect to the total of the correlations in Tables 2–12) and H (0.9% of the cases with respect to the total of the correlations in Tables 2–12). In particular, for men the correlation is between SBP and AtmP (0.6% of the cases with respect to the total of the correlations in Tables 2–12) and for women the correlation is between SBP and AtmP (0.3% of the cases with respect to the total of the correlations in Tables 2–12). Also, correlations with $r \geqslant 0.4$ exist for H: during the night for the men SBP (0.3% of the cases with respect to the total of the correlations in Tables 2–12) and for the women SBP and DBP (0.3% for each blood pressure component, of the cases with respect

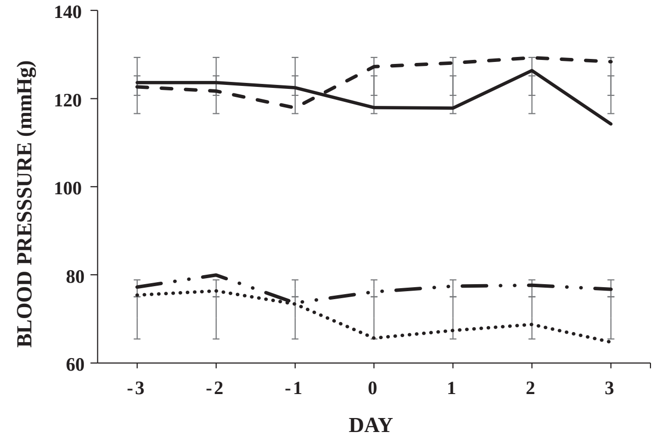

Fig. 3. Behavior of the blood pressure within a three-days window around the 25th August, 2010 geomagnetic storm. SBP for adult women (▬) and adult men (- - -); DBP for adult women (.....) and adult men (•• _ •• _). The vertical error bars correspond to ±1 standard deviation.

Table 13
Average percentage changes of the blood pressure during a 3-days window around the geomagnetic storms of the years 2008, 2010 and 2014.

Date	Women		Men	
	SBP (%)	DBP (%)	SBP (%)	DBP (%)
2008 (adolescents)				
April 6	**11.76**	8.66	6.52	1.37
September 4	0.71	0.57	**7.40**	4.40
2010 (adults)				
August 25	0.73	**16.24**	8.44	3.41
October 23	3.26	**4.62**	1.20	0.37
2014 (adults)				
March 13	3.97	1.77	3.47	**5.78**

SBP = systolic blood pressure. DBP = diastolic blood pressure. The numbers in columns 2–5 are the absolute value of the blood pressures average percentage differences. The numbers in black cases are the largest percentages.

to the total of the correlations in Tables 2–12). During the day correlations with $r \geqslant 0.4$ exist for the adult men between SBP and AtmP (0.3% of the cases with respect to the total of the correlations in Tables 2–12) and between DBP and H (0.3% of the cases with respect to the total of the correlations in Tables 2–12).

Tables 2–12 present the bivariate analysis results. It is clear that for all the cases, DBP and SBP were affected by changes in both the AtmP and the H, however the largest variations in arterial blood pressure were caused by changes in the AtmP.

Finally, we applied a superposed epoch analysis to the occurrence of the geomagnetic storms of Table 1. These storms are those for which we have SBP and DBP time-series per gender and age corresponding to few days before, during and after the storm. In Table 13 we present the absolute value of the average percentage changes of the blood pressure during a 3-days window around the geomagnetic

Table 14
p-Values the unit root stationarity test, 95% confidence. These values correspond to the highest correlations.

VARIABLE	Adolescent women 2008	Senior women 2009	Adolescent men 2010	Adult men 2012	Adult men 2013 Day	Adult men 2013 Night
SBP	0.0000	0.0431	0.0077	–	0.0000	–
DBP	–	–	–	0.049	–	0.0000
H	–	0.0939	0.0001	0.0001	–	–
AtmP	0.0084	–	0.0086	–	0.0334	0.028

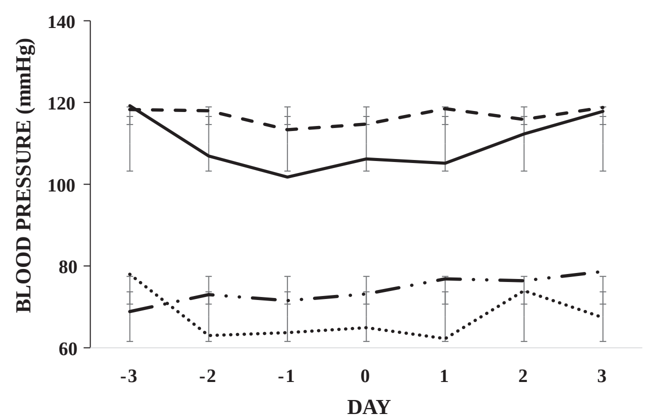

Fig. 4. Behavior of the blood pressure within a three-days window around the 23rd October, 2010 geomagnetic storm. SBP for adult women (▬) and adult men (- - -); DBP for adult women (.....) and adult men (•• __ •• __). The vertical error bars correspond to ±1 standard deviation.

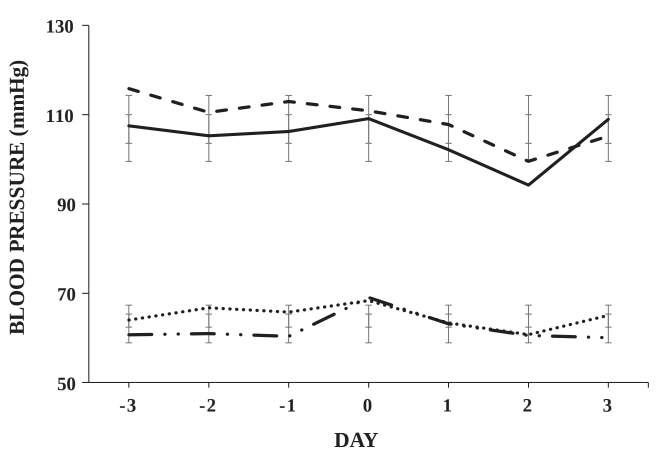

Fig. 5. Behavior of the blood pressure within a three-days window around the 13th March, 2014 geomagnetic storm. SBP for adult women (▬) and adult men (- - -); DBP for adult women (.....) and adult men (•• __ •• __). The vertical error bars correspond to ±1 standard deviation.

storms of the Table 1. These percentages were obtained as follows: [(basal average value - average of ±3 days around the storm)/basal average value] × 100. The basal average value corresponds to the blood pressure average daily value during a quiet geomagnetic day one week before the storm. The table indicates that the largest percentage changes appear for women: in the SBP for adolescents during the geomagnetic storm of the 6th of April, 2008 and in the DBP for adults during the geomagnetic storm of the 25th of August, 2010.

The analysis bay gender showed that during the 6th of April, 2008 storm the largest changes occurred for women, during the 4th of September, 2008 storm the largest changes occurred for men, during the 25th of August, 2010 storm the largest changes occurred for women, during the 23rd of October, 2010 storm the largest changes occurred for women and finally, during the 13th of March, 2014 storm the largest changes occurred for men. Then the 60% of the largest changes were for women and the 40% for men. Dimitrova (2008) found SBP and DBP changes for moderate geomagnetic storm; also she found that women are more responsive than men to geomagnetic field variations. Both findings agree with our results.

In Figs. 3 and 5 we observed different behavior in SBP and DBP in the same age group and sex for two different geomagnetic storms, possibly the electrons involved in the electrical activity of the heart play a role in this difference (Stoupel, 2002).

Our results also allowed us to assess the effect of geomagnetic activity on blood pressure during the solar cycle 24: To compare the behavior of the adult group during the years 2008–2014, we attend to Tables 2–12. These tables indicate that the greatest influence of both H and AtmP on SBP and DBP occurred during the years 2009 and 2010, corresponding to the minimum and ascending phase of the solar cycle, while during 2014, corresponding to the solar maximum, these changes are comparatively smaller. We point out that the storms of the minimum were more intense than the storm of the maximum (see Table 1) and this could be a reason for the behavior of the blood pressure changes along the solar cycle.

The volunteers during this study never present health problems at geomagnetic storm times. Then we may speculate that as the geomagnetic storms were moderate, they did not produce important blood pressure changes that could jeopardize the subject's health.

4. Conclusions

We present the following conclusions:

- Correlation analysis found correlation between the SBP and DBP and the AtmP and H, being the largest during the night.
- However, the largest number of the highest correlations are between SBP and the natural variables (AtmP and H) for men during day and night.
- Concerning H, there is a correlation with SBP during the night and DBP during the day for men; and with SBP and DBP during the night for women.
- The bivariate analysis indicated statistically significant responses of the blood pressure components to AtmP and H for both genders and all age groups. The largest number of cases is between SBP and DBP and AtmP.
- The superposed epoch analysis showed that the largest number of significant blood pressure changes occurred for women.
- The pressure blood changes are larger during the solar minimum and ascending phase than during the solar maximum, probably due to the existence of more intense storms during the minimum than during the maximum.

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PRESENTACIÓN DEL ARTÍCULO*:* "Influence of geomagnetic activity and atmospheric pressure in hypertensive adults."

Durante la revisión de las series de tiempo obtenidas para el artículo anterior, identificamos la existencia de un grupo de 8 voluntarios del grupo de adultos jóvenes con la condición médica de hipertensión. Las pocas investigaciones existentes con personas que presentan este padecimiento reportan que tienen mayor magnetosensibilidad que los normotensos bajo la influencia de las tormentas geomagnéticas.

La revisión detallada que realizamos a cada una de las series temporales de la PAS y la PAD nos llevó a identificar que en los inidividuos normotensos no hay variaciones significativas en los valores de estas componentes y se encuentran en el rango de valores permitido para su grupo de edad. Sin embargo, en cada uno de los individuos hipertensos el comportamiento y los valores de cada componente de la presión arterial es inestable, en particular en la PAS. Las series temporales presentan varios picos en un solo ciclo de 24 horas. Notamos que al realizar el análisis estadístico a la muestra total el efecto se ve atenuado respecto a cada análisis individual. Esta situación motivó la realización del presente artículo, donde se muestra el análisis por caso.

En el tercer artículo que presentamos, se estudia el comportamiento de las componentes de la presión PAS y PAD bajo la influencia de las variaciones de la Patm y H en un grupo de 8 voluntarios con hipertensión sistólica aislada, con edades entre 18 y 27 años en la Ciudad de México, cuatro hombres y cuatro mujeres durante la ocurrencia de una tormenta geomagnética el 13 de marzo del 2014. Analizamos las series de tiempo divididas por sexo y ciclo día-noche mediante los métodos estadísticos de correlaciones, análisis bivariado y épocas superpuestas (en una ventana temporal de dos días alrededor de la ocurrencia de la tormenta geomagnética). Los resultados muestran que existe una correlación entre la PAS, la PAD y la Patm y H y que es mayor durante la noche. Los análisis de correlación y bivariado muestran que las correlaciones mayores ocurren entre la

PAS, la PAD y H. El análisis de épocas superpuestas muestra que los cambios más significativos en la PAS y la PAD bajo la influencia de H ocurren en la PAS en los hombres.

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ORIGINAL PAPER

Influence of geomagnetic activity and atmospheric pressure in hypertensive adults

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Abstract We performed a study of the systolic and diastolic arterial blood pressure behavior under natural variables such as the atmospheric pressure and the horizontal geomagnetic field component. We worked with a group of eight adult hypertensive volunteers, four men and four women, with ages between 18 and 27 years in Mexico City during a geomagnetic storm in 2014. The data was divided by gender, age, and day/night cycle. We studied the time series using three methods: correlations, bivariate analysis, and superposed epoch (within a window of 2 days around the day of occurrence of a geomagnetic storm) analysis, between the systolic and diastolic blood pressure and the natural variables. The correlation analysis indicated a correlation between the systolic and diastolic blood pressure and the atmospheric pressure and the horizontal geomagnetic field component, being the largest during the night. Furthermore, the correlation and bivariate analyses showed that the largest correlations are between the systolic and diastolic blood pressure and the horizontal geomagnetic field component. Finally, the superposed epoch analysis showed that the largest number of significant changes in the blood pressure under the influence of geomagnetic field occurred in the systolic blood pressure for men.

Keywords Natural variables, atmospheric pressure, geomagnetic activity, geomagnetic storms · Blood pressure · Arterial hypertension · Solar activity

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Introduction

Among the most frequent mortality causes in our planet are those of cardiac origin. In addition to the risk factors associated with heart diseases such as hypertension, obesity, diabetes, and circadian hyperamplitude tension, epidemiologists have also considered other risk factors; for instance, it is possible that solar/geomagnetic activity or related phenomena have a role on cardiovascular or neurovascular pathologies (see for instance reviews by Zhadin 2001; Breus et al. 2002; Palmer et al. 2006; Mendoza and Sánchez de la Peña 2009).

Recent works have shown evidences that meteorological parameters and solar/geomagnetic activity alters the arterial pressure in humans and mammals. Danet et al. (1999) presented a linear relation between the temperature and the number of myocardial infarctions and coronary deaths. Furthermore, they noticed a V-shaped relation between the average daily atmospheric pressure and the same cardiovascular problems. Dimitrova (2006a, b) and Dimitrova and Stoilova (2002, 2003) have investigated the influence of the changes in geomagnetic activity on the blood pressure, pulse rate, and behavior reactions on humans. Zenchenko et al. (2009) studied a group of healthy volunteers; almost half of them experienced blood pressure elevation with increased geomagnetic activity. Also, Dimitrova et al. (2009) found an increase in systolic (SBP) and diastolic (DBP) blood pressures some days before major and severe storms, and for the case of a moderate storm they reported an increase during the day of the storm. Azcárate et al. (2012) found a statistically significant change of blood pressure in normotense men and women during the occurrence of moderate geomagnetic storm. Azcárate et al. (2016) found a correlation between SBP and DBP and the atmospheric pressure (AtmP) and horizontal component of the geomagnetic field H, being largest during the night, and mainly with AtmP, also, the largest of significant SBP and

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DBP changes occurred for women. They found that the changes are larger during the solar minimum and ascending solar cycle phases than during the solar maximum.

Studies of hypertensive volunteers have shown that there is a relationship between blood pressure and natural variables. Ghione et al. (1998) studied a group of 447 hypertensive patients and found a significant correlation between the arterial pressure components (SBP and DBP) and the k geomagnetic index for day, night, and 24 h. The pressure values increased between 6 and 8 mmHg in 24 h during geomagnetically perturbed days compared to geomagnetically quiet days. However, Argilés et al. (1998) found a significant correlation between atmospheric pressure and temperature, suggesting that there was a strong independent correlation between atmospheric pressure and blood pressure in a group of 53 hypertense patients with renal diseases in terminal stage and treated with dialysis. Dimitrova (2005) studied a group of 86 volunteers divided by gender and arterial pressure type (hypotense, normotense, and hypertense); she found that the hypertense group are more sensitive to geomagnetic storms. Dimitrova (2006a, b) used a subset of 26 volunteers of the same group studied in Dimitrova (2005). This subset corresponded to people using medicaments mainly for hypertension. She found that the average arterial blood pressure and pulse pressure and the percentage of the persons in the group with subjective psycho-physiological complaints increased significantly with the increase in magnetic activity. The maximum SBP and DBP increase was between 10 and 11% and 13.6% for the pulse pressure. She concluded that women and medicated people are more sensitive by the increase in geomagnetic activity than men and non-medicated people. Zenchenko et al. (2007) studied two groups of medicated patients with I and II degrees of hypertension; they found that the effects of antihypertensive therapy are correlated with geomagnetic and meteorological activity. Gmitrov (2007) found an association between geomagnetic field variations and cardiovascular accidents related with blood pressure microcirculation. Memmedhasanov et al. (2008) studied the impact of a geomagnetic storm on the mechanism of change of the natriuretic peptide and andrenal gland hormone blood levels in a group of healthy and hypertense people. Caswell et al. (2015) found significant correlations between space weather, geomagnetic activity, and hypertensive mortality. Okano (2008) presented studies indicating that blood pressure and microcirculation are affected in animals as a response to static or weak intensity magnetic field; in humans, there is little evidence to suggest that the SMF exposure of up to 8 T can alter blood pressure. They found that during a geomagnetic storm, the cortisol, adrenalina, and noradrenalina blood levels increased; however, this increase was larger for the hypertense people than healthy persons.

Some studies search for the interaction mechanisms that may explain the observations. Gmitrov and Chiyoji (2002) observed in rabbits exposed to a static or weak intensity magnetic field that attenuation of the geomagnetic disturbance induced a decrease in baroreflex sensitivity. Gmitrov and Chiyoji (2002) and Gmitrov and Gmitrova 2004) studied for a group of rabbits the relationship between baroreceptors and static magnetic and geomagnetic fields, finding that after exposure to static fields the diminishing of geomagnetic fields induced a decrease of the baroreflex sensitivity. These results showed that the baroreflex sensitivity may be a mechanism of interaction. Gmitrov (2005) found that geomagnetic disturbances worsened both microcirculation and arterial baroreflex sensitivity. A larger inverse correlation of the geomagnetic activity with arterial baroreflex sensitivity and with microcirculation suggested that changes in the geomagnetic field primarily attenuate the arterial baroreflex vascular control mechanism leading to a decrease in microcirculation. Stoupel (2006) found that temporal links exist between cardiac arrhythmia and the level of cosmophysical activity; the atrial fibrillation, ventricular tachycardia/fibrillation, and sudden cardiac death are occurring in inverse relationship to the level of geomagnetic activity. Gmitrov and Ohkubo (2009) found a significant positive correlation of geomagnetic activity with mean arterial blood pressure and hemodynamic index and a negative correlation with arterial blood pressure and heart rate; diminished baroreflex sensitivity and sympathetic hyperactivity may participate in the observed effects and explain the greater incidence of severe cardiovascular events during magnetic storms.

The largest geomagnetic field disturbances are the magnetic storms. They involve changes of up to 500 nT, ~1%, compared with the intensity of the background geomagnetic field at the magnetic poles (~60,000 nT). In middle and low latitudes, the changes are normally up to ~150 nT, ~0.33%, of the background geomagnetic field intensity at the magnetic equator (~30,000 nT) (Campbell 1997). If the solar/geomagnetic activity can affect human health, the populations living at higher geomagnetic latitudes would be more vulnerable as they are exposed to larger geomagnetic variations. So it is natural that research on this topic has been firstly and mainly carried out at high latitudes, while at middle and low latitudes such studies are scarce. Other studies have shown that changes in barometric pressure are associated with cardiovascular problems (Danet et al. 1999; Houck et al. 2005).

In the present paper, we work with SBP and DBP of a group of eight volunteer hypertensive adults who live in Mexico City located at middle geomagnetic latitudes (geomagnetic coordinates 19.3° 45′ 11″ N, 99° 11′ 15″ W). The data were divided by gender and the circadian rhythm (day/night) considered. Our objective was to assess the effect of two natural variables such as atmospheric pressure and geomagnetic field in SBP and DBP during a geomagnetic storm in 2014.

Data

The sample

We worked with a group of eight volunteer hypertensive adults, four men and four women divided by gender with ages between 18 and 27 years. The volunteers present isolated systolic hypertension, defined as SBP ≥140 mmHg and DBP ≤90 mmHg; this variant of hypertension is the most prevalent in young adults (Grebla et al. 2010). Figure 1 is an example of the behavior of SBP and DBP in a hypertensive subject of this study.

The group was studied in the day/night cycle. The study was carried out during geomagnetic storm in 2014. We divided the data by gender because it has been shown that hormonal activity produces different arterial pressure responses (Oelkers 1996; Pechere-Bertschi and Burnier 2004). We also divided the analysis in the day (between 07:00 and 22:00 h) and night (between 22:01 and 06:59 h) cycle because the arterial pressure behaves differently during such cycle (Halberg et al. 2009). The arterial pressure was measured each 30 min during the day and every 60 min during the night. The arterial pressure also presents different values according to age (Landahl et al. 1986; Reckelhoff 2001).

The arterial pressure monitoring

The participants monitored their SBP and DBP at the Centro de Investigación Cronómica, Escuela Nacional de Medicina y Homeopatía del Instituto Politécnico Nacional, in Mexico City during a geomagnetic storm in March 13, 2014. They kept a healthy lifestyle during the study: no smoking, no drinking of alcoholic beverage or coffee, no intake of medicaments or any other substance that could alter their arterial pressure, had a sufficient sleep time and a healthy diet, and avoided stressful situations. Moreover, they kept a diary to annotate any emotional or physical stress. The volunteers did not take medicaments to control hypertension.

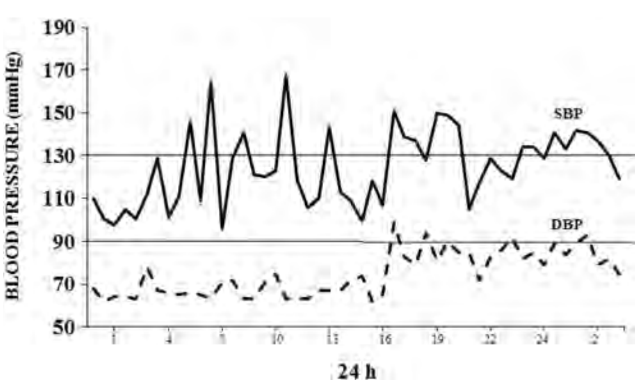

Fig. 1 A 24-h blood pressure behavior of a man with isolated hypertensive disease. SBP (—) and DBP (- - -). The horizontal solid lines show the reference values for this condition

The volunteer self-monitored their SBP and DBP for periods of 5 days. These arterial pressure measurements were obtained by the oscillatory method with a TM-2421 Ambulatory Blood Pressure (A&D Co., Japan) instrument. Its minimum scale is 1 mmHg, with an associated uncertainty of ±0.5 mmHg.

Selection of data

We selected the data with the following criteria: we averaged each hypertensive volunteer's daily SBP and DBP time series, and we found average 24-h values of SBP ≥130 mmHg and DBP <90 mmHg. However, we considered that these extreme values were due to accidental movements.

The natural variables

The H data was obtained from the Tucson geomagnetic station (geomagnetic coordinates 32.1745° N, 110.7337° W, http://geomag.usgs.gov, belonging to the USGS Geomagnetism Program). The geomagnetic stations of this program follow the standard procedure for data filtering: the geomagnetic field components are filtered with the Gaussian method of integration to eliminate peaks produced by seasonal variations and other factors that generate noise, and the resultant data do not have associated uncertainties. The AtmP data were obtained from the Programa de Estaciones Meteorológicas del Bachillerato Universitario (PEMBU-UNAM http://pembu.atmosfcu.unam.mx/), using the meteorological station which was the closest to the place where the participants monitored their arterial pressure (Preparatoria 9).

The time series

The final data base consisted of 5440 data corresponding to SBP and DBP, the atmospheric pressure (AtmP), and the horizontal component of the geomagnetic field (H).

We constructed time series for each gender, age group, and the day/night cycle. The volunteers in each study have isolated hypertension. The SBP and DBP time series per gender and age correspond to a few days before, during, and after the storm.

Results and discussion

We analyzed the time series using three methods: correlations between the SBP and DBP and the natural variables (AtmP and H), bivariate analysis between the SBP and DBP and the natural variables (AtmP and H), and superposed epoch analysis of the SBP and DBP within a window of 2 days around the day of occurrence of a geomagnetic storm to four cases, because they were larger series data applied in this method.

Correlation coefficients

Tables 1 and 2 show the correlation coefficients. The largest correlations are shown in black cases. The time series have been analyzed to test stationarity; for that, we used the unit root test, which consists in obtaining the contrast hypothesis at the 95% of confidence (*p*-values), which in turn is supported by the statistic Dickey-Fuller and the Durbin-Watson tests (Dickey and Fuller 1979; Montgomery et al. 2001). The *p* values are shown in Table 3.

Bivariate analysis

This analysis allowed us to obtain the statistical significance between the SBP and DBP and AtmP and H. Tables 1 and 2 show that the variables that have the largest correlation with SBP and DBP, indicated by the *p* values (**0.01 significance level and *0.05 significance level), are similar to that reported by Azcárate et al. (2016).

Superposed epoch analysis

We used the averages of SBP and DBP in a window of 2 days around the geomagnetic storm (day 0) presented in March 13, 2014. We have time series for four cases, two women and two men. Figures 2 and 3 present the results.

Tables 1 and 2 show the correlations between the natural variables (AtmP and H) and the men and women's DBP and SBP according to age and the day/night during geomagnetic storm.

For the women group, three of them presented the highest correlations ($r \geq 0.4$) during the night, between the DBP and H (2.1% of the cases with respect to the total correlations of Table 1) and between the AtmP, the DBP (2.1% of the cases with respect to the total correlations of Table 1), and the SBP (2.1% of the cases with respect to the total correlations of Table 1). During the daytime, the correlation was between the DBP and H (2.1% of the cases with respect to the total correlations of Table 1). One of the women showed no important correlations.

Fort the men group, in three of them, there were the highest correlations ($r \geq 0.4$), found between SBP and H (8.3% of the cases with respect to the total correlations of Table 2), during daytime (2.1% of the cases respect to the total correlations of Table 2) and during nighttime (4.2% of the cases with respect

Table 1 Levels (*p* values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure

Age group	Variable	24 h		Daytime		Nighttime	
		SBP	DBP	SBP	DBP	SBP	DBP
Women 1							
	H	0.357	0.251	0.421	0.495	0.205	0.014*
	AtmP	0.344	0.276	0.181	0.127	0.238	0.027*
Correlation	H	−0.045	−0. 082	0.027	0.002	−0.214	**−0.532**
Coefficients	AtmP	0.049	0.072	0.125	0.156	0.186	**0.474**
Women 2							
	H	0.010*	0.001**	0.029*	0.000**	0.107	0.383
	AtmP	0.106	0.403	0.064	0.429	0.095	0.433
Correlation	H	0.293	0.399	0.281	**0.517**	0.328	−0.081
Coefficients	AtmP	0.161	−0.032	0.227	0.027	0.346	0.046
Women 3							
	H	0.082	0.017*	0.295	0.065	0.332	0.158
	AtmP	0.174	0.082	0.221	0.161	0.069	0.093
Correlation	H	0.184	0. 277	0.083	0.229	−0.128	-0.289
Coefficients	AtmP	−0.124	−0.184	−0.177	−0.151	**0.418**	0.375
Women 4							
	H	0.184	0.479	0.458	0.224	0.462	0.202
	AtmP	0.004**	0.104	0.017*	0.181	0.109	0.360
Correlation	H	0.113	−0.007	−0.016	−0.111	0.026	−0.224
Coefficients	AtmP	−0.325	−0.158	−0.303	−0.133	−0.326	−0.097

Adult hypertensive women cases, March 13, 2014. The numbers in bold are the largest coefficients

H horizontal component of the geomagnetic field in nT, *AtmP* atmospheric pressure in mmHg, *SBP* systolic blood pressure in mmHg, *DBP* diastolic blood pressure in mmHg

*The correlation is significant at the 0.05 level; **the correlation is significant at the 0.01 level

Table 2 Levels (*p* values) of the bivariate analysis concerning the effect of geomagnetic storms and AtmP on blood pressure and correlation coefficients between the values of blood pressure and the geomagnetic field and atmospheric pressure

Age group	Variable	24 h		Daytime		Nighttime	
		SBP	DBP	SBP	DBP	SBP	DBP
Men 1							
	H	0.204	0.063	0.091	0.298	0.260	0.065
	AtmP	0.241	0.140	0.498	0.400	0.059	0.314
Correlation	H	0.091	0. 168	−0.167	−0.067	0.162	0.371
Coefficients	AtmP	−0.078	−0.119	−0.001	−0.032	0.382	0.123
Men 2							
	H	0.026*	0.293	0.372	0.267	0.085	0.059
	AtmP	0.052	0.063	0.447	0.497	0.460	0.369
Correlation	H	0.232	0.066	0.044	0.082	0.388	**0.438**
Coefficients	AtmP	−0.195	−0.183	−0.018	−0.001	0.030	−0.098
Men 3							
	H	0.000**	0.380	0.006*	0.148	0.022**	0.403
	AtmP	0.285	0.267	0.376	0.101	0.136	0.275
Correlation	H	**−0. 447**	0. 041	**−0.401**	0.172	**−0.465**	−0.060
Coefficients	AtmP	−0.076	−0.083	−0.052	−0.209	0.265	0.147
Men 4							
	H	0.012*	0.003**	0.483	0.175	0.035*	0.336
	AtmP	0.478	0.397	0.307	0.409	0.046*	0.355
Correlation	H	0.269	0.326	0.006	0.128	**0.497**	0.124
Coefficients	AtmP	−0.007	−0.031	0.070	0.032	**−0.468**	−0.109

Adult hypertensive men cases, March 13, 2014. The numbers in bold are the largest coefficients

H horizontal component of the geomagnetic field in nT, *AtmP* atmospheric pressure in mmHg, *SBP* systolic blood pressure in mmHg, *DBP* diastolic blood pressure in mmHg

*The correlation is significant at the 0.05 level; **the correlation is significant at the 0.01 level

to the total correlations of Table 2). We found high correlations between DBP and H during the night (2.1% of the cases with respect to the total correlations of Table 2). We also found for nighttime a correlation with SBP and AtmP (2.1% of the cases with respect to the total correlations of Table 2). One of the men showed no important correlations. For men and women, the highest correlations occur during nighttime, coinciding with the findings of Azcárate et al. (2016).

Tables 1 and 2 present the bivariate analysis results. It is clear that for the three cases, DBP and SBP were affected by changes in both AtmP and H; however, the largest variations in arterial blood pressure were caused by changes in H. This result is different to that reported by Azcárate et al. (2016), who found the largest correlations between AtmP and SBP and DBP; however, we would like to point out that in such work the authors had a much higher statistical significance correlation between PAS, PAD, and AtmP.

Finally, we applied a superposed epoch analysis to the occurrence of the geomagnetic storms for four cases. We have SBP and DBP time series per gender corresponding to a few days before, during, and after the storm. In Table 4, we present the absolute value of the average percentage changes of the

Table 3 *p* Values of the test unit root stationarity, 95% confidence

Variable	Women 1	Women 2	Women 3	Men 2	Men 3	Men 4
SBP		–	0.0095	–	0.0000	0.0001
DBP	0.0000	0.0001	−0.0006	0.0730	–	–
H	0.0075	0.0052	–	0.0001	0.0007	0.0032
AtmP	0.0093	–	0.0082	–	–	0.0246

Time series, March 13, 2014

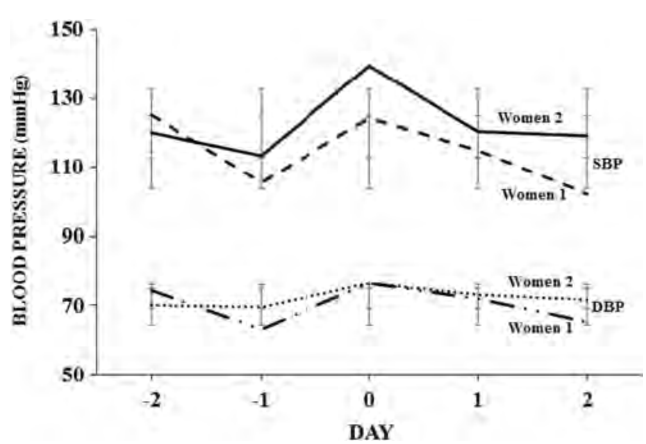

Fig. 2 Behavior of the blood pressure within a 2-day window around the March 13, 2014 geomagnetic storm. SBP for women 1 (- - -) and women 2 (▬); DBP for women 1 (. _ . _) and women 2 (…..). The *vertical error bars* correspond to ±1 standard deviation

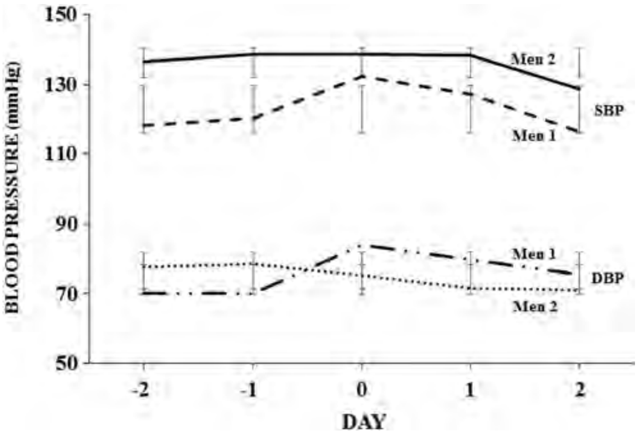

Fig. 3 Behavior of the blood pressure within a 2-day window around the March 13, 2014 geomagnetic storm. SBP for men 1 (- - -) and men 2 (**—**); DBP for men 1 (. _ . _) and men 2 (…..). The *vertical error bars* correspond to ±1 standard deviation

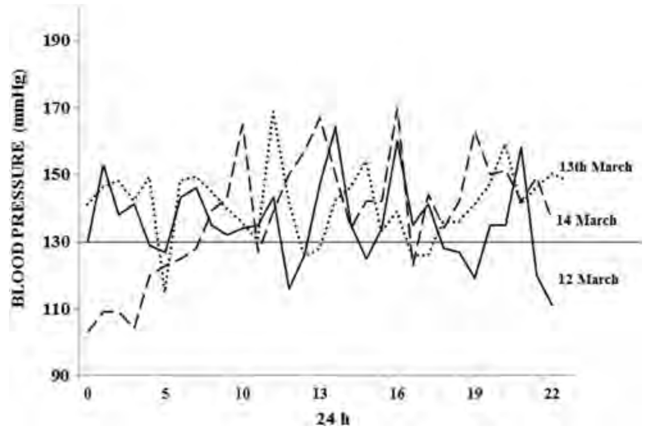

Fig. 4 A 24-h SBP behavior of a man with the highest magneto-sensitive and isolated hypertensive disease during the days March 12 (**—**), March 13 (……), and March 14 (- - -). The *horizontal solid lines* show the reference values

blood pressure during a 2-day window around the geomagnetic storm. These percentages were obtained as follows: [(basal average value − average of ±2 days around the storm) / basal average value] × 100. The basal average value corresponds to the blood pressure average daily value during a quiet geomagnetic day 1 week before the storm. The table indicates that the largest percentage changes appear for women, in case 1 for SBP and in case 2 for DBP; for men, in case 1 for SBP and in case 2 for SBP. The largest changes occurred in SBP; this result is similar to that reported by Azcárate et al. (2012, 2016) where they found a statistically significant change of blood pressure in normotense men and women during the occurrence of moderate geomagnetic storm. They also found that women are more sensitive to changes in the geomagnetic field. In the present study, with hypertensive volunteers, the men are more sensitive to changes in H. Figure 4 shows the behavior of the hypertensive volunteer with the highest magneto-sensitivity 1 day before, during, and 1 day after the occurrence of the geomagnetic storm in March 13, 2014. Table 5 shows the absolute value of the SBP percentage variability 1 day before, during, and 1 day after this geomagnetic storm.

The observed behavior of the arterial pressure values in Figs. 2 and 3, showing increases of SBP and DBP 1 day before and during the geomagnetic storms, is similar to that reported by Dimitrova et al. (2004) and Azcárate et al. (2012). Both findings agree with our results.

In Figs. 2 and 3, we observed different behaviors in SBP and DBP in the same sex; possibly, the electrons involved in the electrical activity of the heart play a role in this difference (Stoupel 2002).

Several studies indicate that the incidence of myocardial infarctions associated to geomagnetic storms is higher during solar activity maximum times compared to solar activity minimum times. This could be due to changes in the cardiac rhythm (Papailiou et al. 2011; Shaposhnikov et al. 2014) and a variability of the blood pressure (Gmitrov 2007). An opportune health service attention would lower the risk of morbidity and/or mortality due to cardiovascular diseases in the population at risk, such as hypertensive people.

Table 4 Average percentage changes of the blood pressure during a 2-day window around the geomagnetic storm in March 13, 2014

	Case 1		Case 2	
	SBP %	DBP	SBP %	DBP
Women				
	4.39	2.49	1.86	**3.09**
Men				
	8.69	2.50	**6.59**	5.87

The numbers in columns are the absolute value of the blood pressures average percentage differences. The numbers in bold are the largest percentages per case

SBP systolic blood pressure, *DBP* diastolic blood pressure

Table 5 Percentage changes of the SBP in a magneto-sensitive man during a 1-day window around the geomagnetic storm in March 13, 2014

Day	−1	0	1
	3.0	**7.4**	4.9

The numbers in the columns are the absolute values of the systolic blood pressure percentage differences. The number in bold is the largest percentage

Conclusions

We present the following conclusions:

- The behavior of SBP and DBP is different for men and women.
- Correlation analysis found a correlation between SBP and DBP and AtmP and H, being the largest during the night.
- However, the largest number of the highest correlations occurs for the men group during nighttime, particularly between SBP and H.
- Within the men group, one case showed to be particularly sensitive to geomagnetic field variations, finding high correlations between H and the SBP during daytime, nighttime, and 24 h. On the other hand, there was another case that showed no correlations between the same variables.
- Within the women group, in one case we found the highest correlations between H, AtmP, and DBP during nighttime, while there was another case that showed no correlations between the same variables.
- The bivariate analysis indicated that there are statistically significant responses between SBP and DBP and AtmP and H being higher with the latter.
- The superposed epoch analysis showed that the largest number of arterial pressure significant changes occur in the SBP for both men and women.

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DISCUSIÓN Y CONCLUSIONES GENERALES

El efecto de las variables naturales en la salud de los humanos es un tema ampliamente discutido en la actualidad y es abordado por diversos grupos multidisciplinarios de investigación en todo el mundo. Los estudios no han sido concluyentes ya que muestran discrepancias en los resultados, lo que ha originado polémica sobre el tema.

Una de las partes fundamentales de los estudios presentados en la esta tesis, consistió en obtener datos de calidad de cada una de las variables involucradas, geofísicas y fisiológicas. Las series series de tiempo de la PAS y la PAD se obtuvieron mediante el monitoreo ambulatorio por parte de cada uno de los voluntarios, que fueron capacitados en el uso y calibración del equipo de monitoreo de la presión arterial TM-2421.

Durante los periodos de tiempo en que los estudiantes portaban el monitor realizaban sus actividades normalmente, se lo quitaban para bañarse y realizaban movimientos involuntarios, por esta razón en las series ocasionalmente había huecos o valores pico, sin embargo, esta situación no afectaba la calidad de la muestra.

Se elaboró una exploración y resumen clínco de los participantes, así como una carta de consentimiento informado para formar parte del estudio. Los participantes fueron estudiantes de la Escuela Nacional de Medicina y Homeopatía del IPN y familiares de los mismos. Se comprometieron a llevar un estilo de vida saludable y durante los días del monitoreo no ingerir algún alimento o sustancia que pudieran modificar los valores de la presión arterial.

Los voluntarios fueron coordinados en un primer momento por el Dr. Salvador Sánchez de la Peña, quien estaba a cargo del laboratorio de Cronobiología de la Escuela y posteriormente por el entonces estudiante de medicina Jonathan Levi, con quienes los voluntarios se reunían periódicamente.

Cabe señalar que el grupo de hipertensos se identificó mediante el análisis de las gráficas del comportamiento de la PA, en el 2014. Los participantes desconocían su padecimiento y no estaban controlados con medicamentos. Estos datos corresponden a los analizados en el tercer artículo.

Los datos de la componente H del campo geomagnético para el primer artículo se obtuvieron de la estación de Teoloyucan, la cual tuvo problemas técnicos posteriormente. Por ello, para comparar la similitud en el comportamiento de las series de los dos artículos posteriores usamos los datos de la estación de Tucson, (en las coordenadas geomagnéticas 32.1745ºN, 110.7337ºW, http://geomag.usgs.gov). Usamos los datos de esta estación porque al momento en que hicimos el análisis los datos de los observatorios geomagnéticos de Honolulú y de San Juan, los de latitud más cercana a Teoloyucan, no tenían completos los datos que necesitabamos, por lo que el siguiente más cercano es Tucson.

Los datos de Patm se obtuvieron de la Estación Meteorológica de la Preparatoria 9, perteneciente al Programa de Estaciones Meteorológicas del Bachillerato Universitario (PEMBU-UNAM). Usamos los datos de esta estación porque es la más cercana al lugar donde se monitoreo la presión arterial de los participantes.

Para reforzar la validez estadística de nuestros análisis se realizó una revisión exhaustiva a las series temporales, además de normalizarlas se aplicaron los test de Dickey-Fulley y Durbin Watson para verificar la condición de estacionariedad. Es importante mencionar que se descartó una cantidad importante de series temporales de la PAS y la PAD debido a que presentaban huecos e inconsistencias.

Las tormentas geomagnéticas bajo las cuales se realizó nuestro estudio fueron moderadas, (los índices Dst fueron para el primer artículo de -43 nT, para el segundo artículo de -27.8 nT y -26.3 nT en el 2008, de -21-5 nT y -17.4 nT en el 2010 y -17.9 nT en el 2014, y para el tercer artículo de -17.9 nT), lo que probablemente originó que las variaciones observadas en la PAS y la PAD fueran pequeñas.

El análisis realizado al clima espacial durante la tormenta geomagnética que se reportó en el primer artículo, muestra la posibilidad de que los cambios observados en la PA antes del día de la tormenta pueden deberse a la ocurrencia de una Eyección de Masa Coronal (EMC), que en muchas ocasiones está antecedida por una ráfaga y en otras ocurre casi simultáneamente con la EMC. Las ráfagas o la combinación EMC/ráfaga produce partículas energéticas que son capaces de generar perturbaciones en la densidad ionosférica terrestre, lo cual a su vez produce alteraciones de la componente H del campo geomagnético. Estas partículas arriban a la ionosfera varias horas después de que son generadas. Las ráfagas además producen emisiones electromagnéticas en todo el espectro, las cuales llegan a la ionosfera minutos después de ser generadas, en particular los rayos X y UV tienen un efecto sobre la ionosfera parecido al de las partículas energéticas. Hay que recordar que la EMC impacta a la magnetosfera tres o más días después de haberse originado en el Sol produciendo una tormenta. Entonces, las alteraciones que aparecen en la PA uno o dos días antes de la manifestación de la tormenta magnética pudieran estar asociadas a estas partículas energéticas y emisiones de onda corta.

En cuanto al diferente comportamiento observado según el sexo en el presente trabajo, éste es de esperarse, ya que se ha reportado que las variaciones en las hormonas juegan un papel importante en la variación de la PA (Girdler, 1993; Smolensky, 1996; Oelkers, 1996; Pechere-Bertschi, 2004).

El análisis de correlaciones con normotensos mostró respuestas distintas a las variaciones de Patm y H, se encontraron correlaciones positivas y negativas en todos los grupos estudiados, en particular en el grupo de hombres el mayor número fueron positivas entre la PAS y la Patm, lo que nos indica que en este caso el incremento en los valores de la Patm está asociado a un incremento en la PAS. En cuanto a los casos de hipertensos el mayor número de correlaciones más altas fueron negativas entre la PAS y H y se presentaron en los hombres durante el ciclo día-noche, lo que quiere decir que el decremento en los valores de H produce un incremento en los valores de la PAS.

Durante la ocurrencia de las tormentas geomagnéticas que se presentaron en este estudio los participantes no presentaron problemas de salud o reacciones adversas derivadas de los cambios de presión arterial encontrados, posiblemente porque se trató de tormentas moderadas.

Cabe señalar que nuestro estudio, es el primer trabajo en que se estudia la respuesta de la PA ante las variables naturales, Patm y la actividad solar-geomagnética de acuerdo con el sexo, el grupo de edad y ciclo día-noche durante un ciclo solar completo.

De acuerdo a los resultados presentados podemos concluir que:

1. Las componentes de la presión arterial sistólica y diastólica presentan una correlación estadísticamente significativa a las variaciones importantes de los parámetros naturales (presión atmosférica y campo geomagnético) en todos los grupos estudiados.
2. La Patm es la variable natural que más influye en las variaciones de la PAS y la PAD observadas.
3. El comportamiento de la PAS y de la PAD bajo la influencia de las variaciones de las variables naturales es distinto según la condición de salud, el sexo, grupo de edad y ciclo día-noche.
4. En los grupos de normotensos estudiados se presentan correlaciones positivas (71. 4% del total de correlaciones positivas más altas) y negativas (28.5% del total de correlaciones más altas) entre la PAS, la PAD y la Patm y H.
5. El mayor número de correlaciones positivas más altas ocurre entre la PAS y Patm en el grupo de hombres durante la noche, el aumento de la Patm se relaciona con un incremento en la PAS.
6. El grupo de mujeres normotensas presentó mayores cambios significativos en la PA durante la ocurrencia de una tormenta geomagnética que el de hombres.
7. En los grupos de normotensos e hipertensos, los cambios más importantes en los valores de la PAS y la PAD bajo la influencia de la Patm y H se presentaron durante la noche.
8. La componente de la presión arterial más sensible a las variaciones de Patm y H es la PAS.
9. En los individuos normotensos e hipertensos, los valores de la PAS y la PAD presentan cambios respecto a sus valores promedio durante la ocurrencia de

una tormenta geomagnética (en una ventana temporal de 3 días en torno a la tormenta).

10. El comportamiento es distinto en personas normotensas y en hipertensas.
11. En el análisis de los casos de hipertensos, el mayor número de correlaciones más altas fueron negativas y ocurrió en el grupo de hombres durante la noche, particularmente entre PAS y H, el decremento de los valores de H provocó un aumento en los valores de la PAS.
12. Los cambios más grandes en la PAS y la PAD se observó durante el mínimo y la fase ascendente del ciclo solar 24.

Cada vez son más los estudios que se desarrollan en torno al problema de conocer cuáles son los efectos de los factores del medio ambiente en la salud de los humanos, los resultados muestran que la influencia es indiscutible y es necesario seguir desarrollando trabajos de investigación en esta dirección con la intervención de grupos multidisciplinarios. Los resultados serían de apoyo para una atención oportuna en los servicios de salud, lo cual reduciría el riesgo de morbilidad y / o mortalidad por enfermedades cardiovasculares en la población de riesgo, como las personas hipertensas.

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