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# Reduced Solar Activity Favors Twin Maternities

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Mechanisms underlying effects of physical factors on twin births are unclear. The present work studied an association between monthly and yearly multiple birth rates (MBRs) in the Novosibirsk region, south-west Siberia, in relation to solar activity (sunspot numbers) and geomagnetic activity (Ap index) from 1957 to 2008. The difference was verified by comparing the yearly MBR observed in 3-year peaks ($M$ = 7.36, $SD$ = 0.33 per 1,000 births) and 3-year troughs ($M$ = 8.10, $SD$ = 0.31 per 1,000 births, $p < .001$) of an 11-year solar cycle. An inverse correlation ($r = -.60$, $p < .001$) was found between sunspot numbers and MBR for a lag of 1 year. Cross-spectral analysis of a 52-year time series established a common signal with the period of 10.5 years, as well as high coherence (K(2) = 0.87). The multiple regression analysis revealed a significant interaction of solar and geomagnetic effects upon the frequency of twin maternities. The results show that elevated solar activity within the 11-year cycle coinciding with the time of conception inhibits multiple births in a manner depending on geomagnetic activity. It is hypothesized that the likely mechanism underlying the association is early fetal loss induced by solar radiation/flux and its terrestrial mediators.

■ **Keywords:** twins, multiple births, secular trend, solar activity, geomagnetic activity

Recent studies have investigated environmental, genetic, and physiological factors that influence human reproduction, including such forces as cosmic weather (Stoupel, Abramson, Israelevich, Shohat, & Sulkes, 2010; Stoupel et al., 2007). The only paper available on the effects of these factors on twin maternities is from a Siberian study (Borovik, Ivanova, Zolotuev, Vlasukova, & Zhdanov, 2007), which presents a visual comparison of two curves (yearly dynamics of twin rate and Wolf's numbers) during the years 1983–2003 in the Irkutsk region near Baikal Lake. The curves show several peaks, some of which follow each other and some that do not. The paper does not contain any statistical analysis or adjustment for linear trends, and it is therefore not possible to conclude with certainty whether any association exists. Another article reports an inverse relationship between monthly sunspot numbers 9 months before the time of delivery and the total number of births in Lithuania in 1995–2002 (Stoupel et al., 2006). In contrast to the latter result, an analysis of yearly data on birth rates carried out on 20th century figures for seven countries from various regions revealed a near 10-year periodicity and a direct association with solar activity (SA) (Randall, 1991; Randall & Moos, 1993).

This small number of publications shows that findings on the relationship between SA and birth rate are controversial, and that the possible influences of cosmic factors on multiple maternities have not been a high priority for researchers. Meanwhile, there are facts that allow the assumption of such influences. Thus, SA at the onset of life has been found to determine sex ratio at birth (Stoupel et al., 2010) and human lifespan (Juckett & Rosenberg, 1993), due to hypothesized damaging effects of ultraviolet radiation on the DNA of the fetuses (Lowell & Davis, 2008). Because a large proportion of pregnancies end in spontaneous abortion (Landy & Keith, 1998), it is even more difficult for multiple birth fetuses to survive.

The objective of the present study was to verify an association between SA within a 10-year cycle, as assessed by sunspot numbers, and twin births probability, under the

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assumption of negative influences of space weather factors on the frequency of multiple conceptions and/or survival of twin fetuses.

## Methods

### Population and Source of Data

The population of the Novosibirsk region was 2.9 million in 1989, the majority urbanized. The rural population in the region was approximately 25%. The official data on the annual number of singleton and multiple births for 1957–2008 ($N$ = 52) were drawn from the regular reports of the Novosibirsk State Regional Committee for Statistics. Within this dataset, the Committee provided monthly data from January 1958 to December 1996 (468 consecutive months). The multiple maternities reported were confined to twins. Thus, in Novosibirsk city, the ratios of the number of twin births to the number of triplet births were 146:1 in 2000, 101:2 in 2003, 98:0 in 2004, and 118:0 in 2005 (data for other years were not available). For the analysis, the index of multiple births was calculated (number of multiple births/total number of births * 1000).

### Solar and Geomagnetic Activity (GMA)

The data on average monthly and yearly sunspot numbers (W, the proxy for solar radiation intensity) and the Ap index, a planetary characteristic of equivalent amplitude of the horizontal geomagnetic field, were obtained from the official web site of the National Geophysical Data Center (NGDC) of the National Oceanic and Atmospheric Administration of the US Department of Commerce (ftp://ftp.ngdc.noaa.gov/) for the period studied. The first indicator of the variations of SA within the 10-year cycle (W), as well as another characteristic, the solar radio flux at a frequency of 2,800 MHz, correspond to mild X-ray (Hargreaves, 1992) and ultraviolet (Tapping, 1987) radiation of the sun.

### Statistical Analysis

Because linear trends substantially modify the association between harmonically varying processes, the birth raw data were linearly de-trended according to regression equations. Figure 1 presents the resultant curve as a 3-point moving average, calculated in order to smooth the yearly variations. These smoothed data were used for assessing an association with the physical factors.

As sunspot numbers, the Ap index, and the twin rate were non-normally distributed according to the Kolmogorov-Smirnov test, nonparametric methods were used to evaluate the association between them. The relationship was evaluated by the Mann-Whitney test after the split of the set of annual average solar data by median, and by cross-correlation analysis to verify a lag between the characteristics compared (two-tailed Spearman's correlations). Partial correlation and multiple regression were computed to assess separate and joint effects of W and the Ap index on MBRs.

In order to test whether observed variations in the MBR and the SA readings shared any temporal association, cross-spectral analysis was undertaken after removing the linear trends (Kay, 1991). A bivariate model was fitted to the yearly time series to quantify the frequency-related squared coherence and phase shift between SA (the independent variable) and MBR (the dependent variable). The spectral estimates were smoothed with a Hamming window of width 5.

Data analysis was performed using the statistical package SPSS 19.

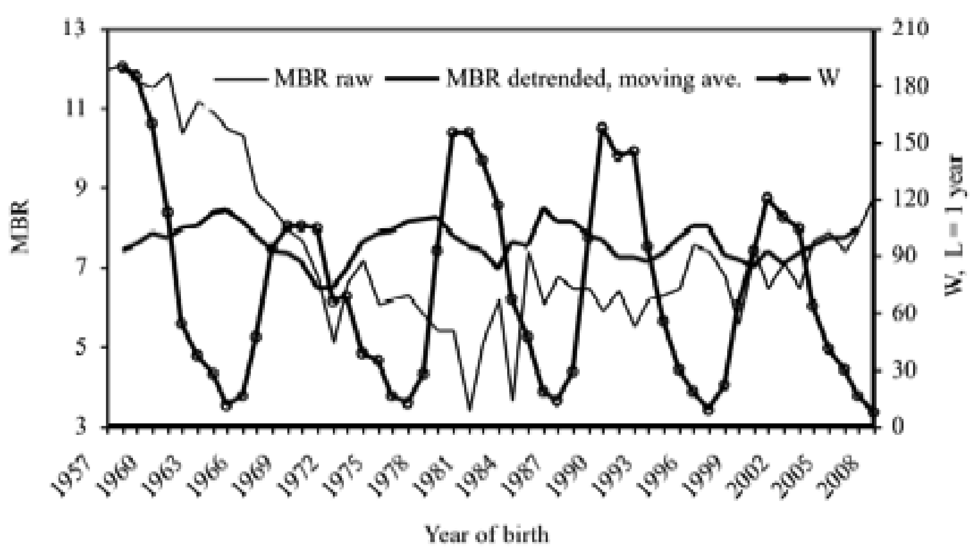


**FIGURE 1**
Yearly multiple birth rate (per 1,000 births) in the Novosibirsk region 1957–2008, and yearly sunspot numbers one year before birth, by year of birth.



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**TABLE 1**

Spearman Coefficients of Cross-Correlation of De-Trended Smoothed Multiple Birth Rate in the Novosibirsk Region with Sunspot Numbers and Index of Geomagnetic Activity, by Lag

| Lag | *R* | *p* | Lag | *R* | *p* |
|---|---|---|---|---|---|
| **W** *N* = 466, (1958–1996) | | | **Ap** *N* = 466, (1958–1996) | | |
| 0 month | –.14 | .002 | 0 month | –.11 | .024 |
| 1 | –.16 | .001 | 1 | –.09 | .049 |
| 2 | –.16 | .001 | 2 | –.12 | .007 |
| 3 | –.18 | < .001 | 3 | –.13 | .005 |
| 4 | –.20 | < .001 | 4 | –.14 | .003 |
| 5 | –.23 | < .001 | 5 | –.16 | < .001 |
| 6 | –.24 | < .001 | 6 | –.14 | .002 |
| 7 | –.25 | < .001 | 7 | –.12 | .009 |
| 8 | –.26 | < .001 | 8 | –.08 | .072 |
| 9 | –.28 | < .001 | 9 | –.09 | .051 |
| 10 | –.28 | < .001 | 10 | –.09 | .053 |
| *N* = 50, (1957–2008) | | | *N* = 50 (1957–2008) | | |
| 0 year | –.41 | .003 | 0 year | –.38 | .007 |
| 1 | –.60 | .001 | 1 | –.15 | .290 |
| 2 | –.57 | .001 | 2 | .12 | .410 |
| 3 | –.35 | .016 | 3 | .15 | .310 |

Note: *R* = Spearman coefficient of cross-correlation, W = average sunspot numbers, Ap = Index of Geomagnetic Activity.

## Results

There was a total of 1,974,725 twin births over the study period, with an overall yearly mean of 7.49 (*SD* = 2.15) per 1,000 births. The rate ranged from 12.15 in 1958 to 3.36 in 1981 (Figure 1).

The data were analyzed in three ways to identify relationships between SA and MBR. The first approach compared years of median-split high and low SA. The mean MBR in years when spot numbers were more than, or equal to, the median was 7.42 (*SD* = 0.45), and that in years when W was less than the median was 7.84 (*SD* = 0.38, $p$ = .002), a significant negative association. When the periods of high and low SA were restricted by 3-year intervals encompassing the peak and trough of every 10-year solar cycle, the corresponding mean multiple birth frequencies were 7.36 (*SD* = 0.33) and 8.10 (*SD* = 0.31), respectively ($p < .001$).

In order to verify preconceptional and gestational periods of women's and fetuses' vulnerability to physical factors, the data were then analyzed on a year-to-year basis by performing cross-correlation analysis with lag from 0 to 3 years (Table 1). The maximum coefficient between yearly MBRs and sunspot numbers occurred for a lag of 1 year; other lags showed weaker correlations. To improve temporal resolution of the analysis, the association was also assessed for monthly data with lags of 0–10 months. Further lags were not examined because there was a risk of finding noncausal relationship due to chance or autocorrelation. The coefficients progressively increased in modules from the lag of zero months to the lag of 9 months. The coefficients remained unchanged thereafter, thus showing that the negative influences of SA increased from the month of birth to the month of conception. This probably indicates that increased SA exerts minor influences on the survival of fetuses during late gestation, and has more significant effects before, and at the time of, conception, as well as during the early stage of embryonic development.

The third step consisted of carrying out the cross-spectral analysis in order to quantify the precise common frequency and phase relations between yearly de-trended MBRs and W time series. The bivariate spectral analysis yielded one strongly synchronized periodicity in both series over the 52 years, with a maximum cross-amplitude corresponding to the period of 10.4 years (squared coherence, .87; phase angle, –2.17 radian). Thus, the near-10-year periodicities seen in Figure 1 in both parameters are also confirmed by spectral analysis. The phase angle of –2.17 radian corresponds to a 7.8-year delay and indicates that the MBR rhythm is almost out of phase, relative to a 10.4-year SA cycle.

The mean annual index of GMA, the Ap, also displayed a negative association with MBRs for L = 0 year (Table 1), but not for L = 1, 2, and 3 years. The associations disappeared after adjusting for the solar effects. On the contrary, the inverse correlation between MBR and $SA_{L=1\ year}$ remained reliable when the effects of the Ap index were statistically controlled for by partial correlation analysis ($r = -.40$, $p$ = .006, $Ap_{L=0\ year}$ = constant). Over the study period, the value of the Ap index was directly related to the sunspot numbers in the same year ($r = .57$, $p < .001$) and, more robustly, in the previous year ($r = .66$, $p < .001$). The coefficients of cross-correlation between monthly MBRs and Ap values reached a maximum at L = 5 months and progressively decreased thereafter up to the lag of 8 months.

The multiple regression analysis (Table 2) yielded separate as well as joint statistically reliable effects, though weak, of solar and geomagnetic indexes. A significant interaction between the two factors indicates that solar influence on MBR for L = 1 year depends upon the annual Ap index in the year of birth and can be partially attributed to perturbations in geomagnetic field. The partial eta-squared values demonstrate a small contribution of both predictors to the total variance in MBR (21.2% for W; 8.2% for Ap). A comparison of the sums of squares (1.92 for W and 0.63 for Ap) shows an approximate 3-fold preponderance of the first factor over the second factor. This conclusion is consistent with the result of the regression analysis performed on the month-to-month basis. The positive regression coefficient for the term of interaction shows that the higher the Ap index 5 months before birth, the greater the negative effect of SA on MBR at the time of conception, and vice versa.



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**TABLE 2**

Results of Multiple Regression Analysis (General Linear Model) between De-Trended Multiple Birth Rate (dependent variable), Yearly and Monthly Sunspot Numbers, and Indexes of Geomagnetic Activity (covariates)

| Parameter of the model | Type III sum of squares | *p* | B | Partial eta-squared |
|---|---|---|---|---|
| Model | 3.60 | .000 | – | .336 |
| Intercept | 3.16 | .000 | 1.681 | .307 |
| W (L = 1 year) | 1.92 | .001 | –0.014 | .212 |
| Ap (L = 0 year) | 0.63 | .049 | –0.059 | .082 |
| W × Ap | 1.03 | .013 | 0.001 | .127 |
| Model | 28.7 | .000 | – | .061 |
| Intercept | 14.0 | .000 | 1.049 | .031 |
| W (L = 9 months) | 12.4 | .000 | –0.010 | .027 |
| Ap (L = 5 months) | 7.9 | .004 | –0.056 | .018 |
| W × Ap | 6.6 | .009 | 0.005 | .015 |

Note: *p* = probability, B = regression coefficient; the partial eta-squared statistic reports the significance of each term, and characterizes the ratio of the variation (sum of squares) accounted for by the term (model) to the total variation of the dependent variable.

## Discussion

The paper reports a negative association between SA within the 10-year cycle and multiple birth frequency in Siberia. The closest relationship that cannot entirely be explained by changes in GMA is observed for the lag of 1 year or 9–10 months.

The minimum of the 23rd solar cycle was abnormally long for the 3 years from 2007 to 2009. In Russia, this period was characterized by an unusual increase in the frequency of multiple maternities. Thus, the numbers of twin births were 10,102, 11,940, and 13,800 in 2007, 2008, and 2009, respectively. The corresponding figures for triplets were 147, 188, and 229. In 2008, the number of quadruplet maternities (six) equaled the total number of such maternities observed during the previous 5-year period. In 2009, again, six quadruplets appeared. According to Russian medical legislation, the maximum number of blastocytes implanted in a course of extracorporal fertilization is restricted to two; hence, the increased numbers of triplets and quadruplets cannot be attributed to this cause. Therefore, the progressively increasing number of multiple births in the total Russian population at the minimum phase of solar cycle supports this result obtained in the Novosibirsk region.

The practice of assisted reproduction is not a likely cause for the positive linear trend observed in MBR after 1981. In the Novosibirsk region, this practice was first introduced in 2005 and contributed little to the birth statistics: only 247 newborns, with 54 twin babies among them, were born via this method in the region over the subsequent 3 years. These figures correspond, respectively, to 0.27% of the total number of newborns and 7.3% of multiple maternities in the region during this period.

Unfortunately, the present phenomenological study does not allow us to conclude whether episodes of increased solar activity affect twin fertilization or survival of fetuses, and the numbers of monozygotic or dizygotic twins. Also, the mechanisms by which solar outflows might influence the processes involved in producing and/or eliminating multiple fetuses remain unknown. One possible explanation is that cosmic factors negatively influence gametes, blastocytes, and embryos (Stoupel et al., 2005, 2007). Ultrasonographic monitoring shows that about 40% of spontaneous dizygotic twin pregnancies end in single births (Landy & Keith, 1998). Although multiple conceptions are not rare, many fewer multiple pregnancies reach the final stages of gestation, and multiple fetuses experience strong negative selection, particularly during the very early stages of embryonic development. Many factors work together to determine the success of a multiple pregnancy; however, in poor circumstances, heliogeophysical challenges might act as a last or additional trigger for early fetal loss, and may constitute a signal or a proxy for an undesirable outcome of the just-initiated pregnancy.

Juckett and Rosenberg (1993) found a strong inverse correlation between SA during the prenatal period and human longevity. They explained the relationship by ionizing-radiation-induced changes in developing fetal germinal cells. Subsequently, Lowell and Davis (2008) used sunspot numbers as a direct measure of potentially mutagenic radiation, hypothesizing that the radiation wavelength most damaging to fetal DNA lies in the ultraviolet range. Further, the effects of increased SA, either directly or mediated by terrestrial challenges, might affect the human embryo early in gestation and lead to malimplantation or spontaneous abortion, particularly in multiple pregnancies. The results of experiments in which animals were subjected to artificial magnetic fields support this proposal (Frolen, Svendenstal, & Paulsson, 1993; Huuskonen, Juutilainen, & Komulainen, 1993).

A geomagnetic sensitivity of melatonin production in humans (Burch, Reif, & Yost, 2008; Weydahl, Sothern, Cornélissen, & Wetterberg, 2001), could be hypothesized as a mechanism underlying the heliogeophysical effects under question, although this concept is debated (Touitou, Sothern, Cornélissen, & Wetterberg, 2003; Touitou, Bogdan,



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Lambrozo, & Selmaoui, 2006). Although no evidence exists for an association between melatonin secretion and twin conceptions, a direct relationship has been found between discordant-sex twins, all of whom are dizygotic, and sunlight luminosity (Dionne, Soderstrom, & Schwartz, 1993). This relationship has recently been linked to the length of the menstrual cycle (Danilenko, Sergeeva, & Verevkin, 2010). However, the proposed pathways of solar and magnetic influences on the human embryo currently remain speculative.

The secular trend in multiple birth frequency during the study period in the Novosibirsk region is consistent with the dynamics observed in European countries during the second half of the 20th century (Astolfi, Ulizzi, & Zonta, 2003): that is, a downward temporal trend until 1980, then an upward trend thereafter. Researchers explain such pattern by changes in maternal age, parity, birth order, and the introduction of assisted reproductive technologies. Regardless of economic crises and a substantial decrease in the birth rate in Russia in the 1990s, particularly in Siberia, the frequency of twin births continued to rise in the Novosibirsk region after the turning point in 1981 (Figure 1).

Geographic and interpopulation comparisons would clarify whether the association found here is a peculiar feature of the Siberian population or is also observed in other regions and geomagnetic latitudes. Multiple pregnancies experience many adverse challenges, especially of a regional and country-specific medical, social, and economic nature. Therefore, because the GMA exhibits latitudinal and geographic differences, one might expect the association to vary across territories, populations, and time.

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