Biogerontology (2009) 10:671–675
DOI 10.1007/s10522-009-9214-6

RESEARCH ARTICLE

Solar activity during gestation does not affect human lifespan: evidence from national data

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Received: 29 October 2008 / Accepted: 22 January 2009 / Published online: 8 February 2009

Abstract Human lifespan has been reported to relate to solar activity during prenatal development. The likely key mechanism behind this association is increased mutagenic ultraviolet (UVB) radiation during high solar activity that damages DNA. Here, the aim was to replicate the findings of those previous few studies that have suggested a reduced lifespan of individuals born during the years of high solar activity, measured as the sunspot numbers. We used data on annual cohort life expectancy at birth of both women and men born between 1751 and 1915, obtained from ten nations located mainly in Europe. These data, however, provided no evidence that human life expectancy at birth was related to solar activity during gestation among the countries studied.

Keywords Sunspots · Ageing · Prenatal programming · The high initial damage load hypothesis

Introduction

It has become increasingly recognised that prenatal conditions may exert important long-term consequences on many aspects of individual adult life (Barker 1994; Gluckman and Hanson 2005). Several studies have recently shown that human disease burden (Foster and Roenneberg 2008) and mortality during both early- and late-life (Lummaa et al. 1998; Dolbhammer and Vaupel 1999; Gavrolov and Gavrilova 1999; Vaiserman et al. 2002; Lerchl 2004; Dolbhammer et al. 2005; Munoz-Tuduri and Garcia-Moro 2008) may also respond to such prenatal programming in a seasonal fashion.

Prenatal conditions are likely influenced by several biotic and abiotic conditions experienced by the pregnant mothers. One of such recently highlighted abiotic factor is solar activity, which affects organisms, for example, through the increases in the mutagenic ultraviolet (UVB) radiation that damages DNA (Davis and Lowell 2004; Bancroft et al. 2007). The activity of the sun, measured as the sunspot numbers, has recently been speculated to affect human lifespan (Juckett and Rosenberg 1993; Lowell and Davis 2008), particularly males being at the higher disadvantage (Davis and Lowell 2008). These studies have reported that individuals born during the years of sunspot maximum had 1.5–3 years shorter lifespan than those born outside the sunspot maximum (Juckett and Rosenberg 1993; Lowell and Davis 2008). Such solar radiation-induced reduction of lifespan may be mediated by the increased mortality from cancer (Juckett and Rosenberg 1997) and higher incidence of different diseases (Davis and Lowell 2006). These findings have been taken to support the high initial damage load hypothesis of ageing, which

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states that even small developmental problems during prenatal period can have large and irreversible costs to survival later in life (Gavrolov and Gavrilova 2004). Similar association between solar activity and lifespan has not, however, been observed in *Drosophila* in laboratory conditions (Izmaylov et al. 2005).

The aim of this study was to investigate whether solar activity affected human lifespan by using national data on the annual cohort life expectancy at birth of both women and men born during the nineteenth and twentieth centuries from ten countries.

Materials and methods

The data on annual cohort life expectancy at birth from Denmark (1875–1915), Finland (1878–1915), Iceland (1838–1915), Italy (1872–1913), Netherlands (1850–1915), New Zealand (1876–1912), Norway (1846–1915), Sweden (1751–1915), Switzerland (1876–1912) and United Kingdom (1841–1914) were extracted from Human Mortality Database (www.mortality.org). The sunspot data (Wolf numbers; see Fig. 1) was obtained from the NOAA web site (http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.).

Following the approach of Lowell and Davis (2008), we divided the years either into having the sunspot maximum (including the years preceding and following the peak year of maximum number of sunspots) or minimum. We used general linear mixed models (Littell et al. 2006) to examine whether life

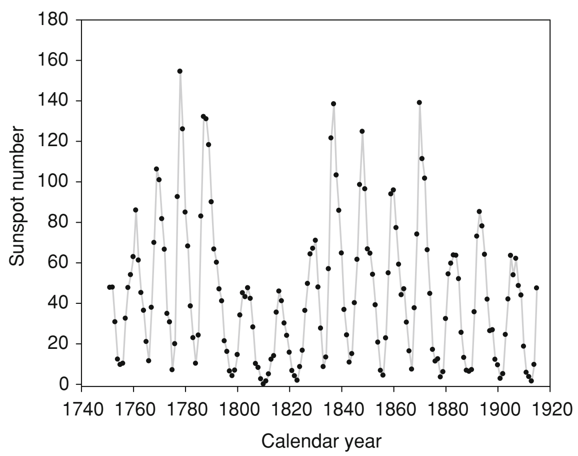

Fig. 1 Temporal variation of sunspot numbers during the study period

expectancy at birth differed between the years of sunspot maximum and minimum. These models were conducted separately for women and men, and for women and men combined. Mixed models were applied, because country was used as a random factor to account for variation of life expectancies at birth between nations and since we were not interested in between-country variation of life expectancy per se. Accordingly, Kenward–Roger correction was used to determine the denominator degrees of freedom of fixed effects (Littell et al. 2006). Calendar year was included into the models as a fixed factor in order to control for the increasing life expectancy at birth towards the twentieth century.

In order to confirm these results, we also studied whether the annual number of sunspots was associated with annual cohort life expectancy at birth using time-series analysis (Yaffee and McGee 2000). This approach might provide a better answer to the question asked here, since the intensity of sunspot peaks varied markedly between the cycles during the study period (Fig. 1). In other words, not all sunspot peaks had an equal number of sunspots. Because this approach is not suitable for time-series shorter than 50 time points (years), we analysed data on Denmark, Iceland, Netherlands, Norway, Sweden and UK only. Analyses were conducted separately for each country. Since conceptions taking place approximately from the April likely resulted in births on the next calendar year, we also included the previous year's sunspot number in our analyses. Due to increasing life expectancy at birth towards the twentieth century in all the countries studied, the response series were differenced once by subtracting the past value from the current one to obtain the stationarity of the series (Yaffee and McGee 2000). The same differencing was also applied to sunspot numbers. Furthermore, the response series were centered to their mean and thus the intercept was omitted from the models (Yaffee and McGee 2000). When necessary, a proper ARIMA-model (autoregressive integrated moving-average) was used to account for the serial autocorrelation of the response series (Yaffee and McGee 2000). Before accepting the models, the estimated parameters of explanatory variables were confirmed to be uncorrelated with the model residuals using cross-correlation functions (Yaffee and McGee 2000). This procedure tests for the potential unaccounted delayed effects of sunspot numbers on the life expectancy at birth. Analyses were conducted with SAS statistical software package version 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

Table 1 shows the results of the general linear mixed models. Cohorts born during the years of sunspot maximum did not have significantly shorter life expectancy at birth than those born during the non-peak years. This result was evident for both men and women, as well as when both sexes were combined. No evidence for the country-specific effects of sunspot maximum on life expectancy at birth, examined by interaction effects, was found (results not shown).

The results of time-series analyses confirmed the earlier analyses by showing that neither the current nor the previous year's sunspot number was associated with annual cohort life expectancy at birth in women or men, or in both sexes combined (Table 2).

Discussion

These findings run encounter to those previously published reports that have suggested a shorter lifespan for men and women born during high solar activity (Juckett and Rosenberg 1993; Lowell and Davis 2008; Davis and Lowell 2008). The reason for these different outcomes is unclear. Differences in statistical approach may explain some of these discrepancies. For example, Lowell and Davis (2008) appear not to control for individuals' birth year in their analysis, although there was a clear downward trend in mean lifespan with birth cohort (see their Fig. 1). This trend is in clear contrast with the well-known increase of mean life expectancy towards the twenty-first century and it must have resulted from the fact that most individuals from the most recent cohorts were still alive during the conduction of the Lowell and Davis's (2008) study. These authors also calculated correlation coefficients between mean cohort lifespan and sunspot number, which were -0.31 and -0.28 ($P < 0.0001$ for both cases) for men and women, respectively (Lowell and Davis 2008). For the data used here (calculated for pooled data), the corresponding Spearman correlation coefficients were -0.19 and -0.21 ($P < 0.0001$ for both cases) for males and females, respectively. Country-specific correlation coefficients showed some variability [e.g. not statistically significant for Finland, Italy, New Zealand, Sweden and Switzerland ($P > 0.12$)], but in all cases the association between annual cohort life expectancy at birth and sunspot numbers was negative ($r_{\text{Spearman}} = -0.03$ to -0.38). Adjusting for time-trends in life expectancy at birth eliminated those significant correlations ($r_{\text{Spearman}} = -0.32$ to 0.26, $P > 0.05$). It thus seems obvious that whether the statistical approach used accounted for confounding annual variation in cohort life expectancy at birth or not markedly affects the biological conclusion drawn on the effect of solar activity during prenatal development on human lifespan.

It should also be noted that the potential association between human lifespan and solar activity, if it exists at all, may be indirect as well. There is evidence that in Medieval England and in the twentieth century USA crop prices followed sunspot numbers (Pustilnik and Yom Din 2004). In countries relying mainly on agriculture, it is likely that fluctuations in annual crop yields were related to the nutritional status of pregnant women, which consequently influences the mean lifespan of cohorts born (Scott and Duncan 2002). Such indirect effects should have been likely evident in the pre-industrial population studied here. However, time-series models that allowed for the delayed effects of solar activity on life expectancy at birth, which were more likely to capture such potential nutrition-related effects of solar activity, suggested no association between

Table 1 The effect of solar maximum on life expectancy at birth in women and men, and women and men combined, after controlling for the study year and country

	Solar activity		$df_{\text{num,den}}$	F	P
	Maximum	Minimum			
Women	50.38 (±1.79)	50.83 (±1.78)	1, 679	2.06	0.15
Men	45.92 (±1.82)	46.29 (±1.81)	1, 679	1.92	0.17
Combined	48.13 (±1.79)	48.54 (±1.78)	1, 679	2.05	0.15

The values in solar activity columns are least square means (±SE) from these models. In all models, life expectancy at birth increased with the study year ($\beta = 0.22-0.24$, $P < 0.0001$) and country explained, depending on the model, 71–78% of variation in life expectancy at birth

Table 2 The results of time-series analysis of current and previous year's sunspot numbers on the life expectancy at birth in women and men, and women and men combined across selected countries

	Sunspot numbers$_t$		Sunspot numbers$_{t-1}$		Autocorrelation structure
	β (±SE)	*P*	β (±SE)	*P*	
Denmark					
Women	0.0038 (0.0037)	0.30	−0.0016 (0.0037)	0.67	ARIMA (2,1,0)
Men	0.0026 (0.0036)	0.46	−0.0007 (0.0036)	0.85	ARIMA (2,1,0)
Combined	0.0030 (0.0035)	0.39	−0.0011 (0.0036)	0.76	ARIMA (2,1,0)
Iceland					
Women	−0.0180 (0.0177)	0.31	0.0030 (0.0162)	0.85	ARIMA (4,1,0)
Men	0.0007 (0.0173)	0.97	−0.0194 (0.0159)	0.22	ARIMA (3,1,0)
Combined	−0.0047 (0.0163)	0.77	−0.0072 (0.0150)	0.63	ARIMA (4,1,0)
Netherlands					
Women	−0.0026 (0.0051)	0.61	0.0025 (0.0048)	0.60	–
Men	−0.0010 (0.0057)	0.86	0.0006 (0.0054)	0.92	–
Combined	−0.0018 (0.0053)	0.74	0.0015 (0.0050)	0.76	–
Norway					
Women	−0.0018 (0.0047)	0.70	0.0044 (0.0045)	0.32	–
Men	−0.0043 (0.0053)	0.41	0.0054 (0.0051)	0.28	ARIMA (1,1,0)
Combined	−0.0027 (0.0050)	0.59	0.0048 (0.0048)	0.32	–
Sweden					
Women	−0.0051 (0.0039)	0.19	0.0028 (0.0039)	0.47	–
Men	−0.0046 (0.0036)	0.20	0.0024 (0.0036)	0.51	ARIMA (2,1,0)
Combined	−0.0043 (0.0037)	0.24	0.0022 (0.0037)	0.55	ARIMA (1,1,0)
United Kingdom					
Women	0.0030 (0.0034)	0.38	0.0006 (0.0034)	0.85	–
Men	0.0007 (0.0041)	0.87	0.0013 (0.0041)	0.76	ARIMA (1,1,0)
Combined	0.0027 (0.0038)	0.47	0.0001 (0.0038)	0.99	–

sunspot number and life expectancy at birth in these data.

In sum, our analyses of annual historical populations, where most people succumbed to an infectious disease, provide no evidence that human life expectancy at birth was related to solar activity during gestation among the countries studied. Further studies on this issue should concentrate on investigating whether solar activity during estimated time of conception or during different semesters of pregnancy influences human disease susceptibility and lifespan. These studies should focus on individuals born during the end of the twentieth century, because solar activity has increased since the 1940s (Uskin et al. 2003; Muscheler et al. 2007) and this effect is likely to be magnified by the simultaneous degradation of stratospheric ozone layer (Solomon 1999).

Acknowledgments This study was funded by the Academy of Finland (grant no. 207270).

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