Original Research Article

Perinatal Winter Conditions Affect Later Reproductive Performance in Romanian Women: Intra and Intergenerational Effects

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Objectives: To compare epidemiological studies on Austrian and New Zealand women that report below average reproductive performance after birth in summer, with a similar study in Romanian women.

Methods: We examined the association between birth month and offspring count analyzing census data from Romania obtained from IPUMS International (Population and Housing Census of Romania, year 2002), totaling 411,270 women aged older than 45 years. We investigated whether socio-economic status affected this association, and whether intergenerational effects exist for mother’s birth month in relation to their daughter’s offspring number.

Results: The time series of mean offspring count per birth month has a highly significant period of 12 months. Contrary to our expectations, average offspring count is highest in women born in June and lowest in those born in December, with a strong coincidence between negative peak values of residuals of mean offspring count per birth month and corresponding monthly means of ambient temperature in Romania. The association between winter birth and lower offspring number is significant in poorly educated women only. For mothers born in winter there is also an association with a lower daughters’ offspring count.

Conclusions: Conflicting results exist between Romania and Austria/New Zealand, and may be most easily explained by women’s different exposure to winter conditions in these countries. Am. J. Hum. Biol. 23:546–552, 2011. © 2011 Wiley-Liss, Inc.

It is increasingly acknowledged that the environmental and maternal conditions experienced during the prenatal and early postnatal period influence early developmental processes with potential long-term consequences for later life events (Barker, 1992; Godfrey, 1998). In many parts of the world, the external environment varies with season, the month of birth representing an indicator for the seasonal variation of environmental and maternal factors. The month of birth may thus be associated with various physical, physiological, and psychological traits (e.g., Doblhammer and Vaupel, 2001; Fieder et al., 2006; Weber et al., 1998), and also reproductive performance (Huber et al., 2004; Lummaa and Tremblay, 2003). In women, several studies demonstrated lower average reproductive performance after birth in summer months, both in the Northern and the Southern hemisphere (Huber et al., 2004, 2008; Lummaa and Tremblay, 2003; Smits et al., 1997).

We analyzed Romanian census data to examine whether birth in summer is associated with lower average offspring number. We expected birth season to exert a pronounced effect in this population as Romania has a climate characterized by strong seasonality with harsh winters and warm summers. In addition, the overall socio-economic standard of the census population is poor, thereby likely increasing the exposure to environmental conditions. To examine whether an association existed between birth month and later offspring count, population census data from Romania for the year 2002 was obtained from IPUMS International. This data was analyzed for post-reproductive women (>45 years). We further examined whether this putative association differed with socio-economic status as indicated by educational level (a rather constant measure of social status over an individual’s lifetime; Kwon and Yankaskas, 2001). We predicted that birth in summer, corresponding to early pregnancy experienced during winter should be associated with lower reproductive performance in adulthood consistent with our recent study that pointed to a critical period of reproductive development during early pregnancy (Huber and Fieder, 2009). We further predicted that this association should be stronger in women of low socio-economic background, as these women typically have low income and, consequently, lower protection from environmental exposures such as temperature extremes, seasonal variation in diet quality, and infectious diseases. Finally, we examined the potential intergenerational effect of mother’s birth months on their daughter’s offspring count. The latter analysis is based on the assumptions that (1) epigenetic alterations (i.e., change in gene expression without change in base sequence; Jirtle and Skinner, 2007) represent one potential mechanism by which environmental exposures during early development might be linked to reproductive performance later in life, and (2) epigenetic phenomena are heritable (Jirtle and Skinner, 2007).

METHODS

We used the Population and Housing Census of Romania from the year 2002 (census date March 18, 2002) provided by IPUMS International and the National Institute
of Statistics (NIS) of Romania (Minneapolis Population Center, Integrated Public Use Microdata Series—International: Version 4.0. Minneapolis: University of Minnesota, 2008; and National Institute of Statistics Romania; https://international.ipums.org/international/sample_designs/sample_designs_ro.html) for our analysis. IPUMS is a collection of publically available deidentified census data with a very large sample size. IPUMS-International is composed of microdata, which means that it provides information about individual persons and households. In this census, a randomly selected 10% sample is used, representative for the entire Romanian population. The census contains, among others, data on birth month, the number of liveborn children born up to 2002, and the highest level of education attained.

The climate of Romania is transitional between temperate and continental. In Bucharest, temperatures average from –3°C in January to 23°C in July, ranging between −29°C in January and 29°C in July. Even though Romania entered the European Union in 2007, in 2008 its per head Gross Domestic Product was only about 50% of the European Union average (CIA, 2008). The average per head Gross National Product in Romania compared to the European Union average (CIA, 2008). The average per head Gross National Product in Romania compared to the European Union average.

Intragenерational effects

We used the statistical package SPSS 15.0, Mathematica 6.0, and R 2.6.0. For the analysis of intragenерational effects, i.e., the analysis of the association between a woman’s birth month and her own offspring number, we restricted our analysis to women aged older than 45 years to obtain data about lifetime reproductive success (typically >99% of women have finished reproduction by the age of 45). This yielded a total of 411,270 women born between 1920 and 1955. We calculated the mean number of biological children per birth month (i) averaged over the whole period of 36 years, thereby yielding 12 monthly mean values, as well as (ii) separately for each individual birth month from January 1920 to December 1955, yielding a time series totaling 432 months. To remove the nonlinear trend from the time series, we performed a local regression of span 0.8 of mean offspring count per month of birth and used the residuals of this local regression for all further analyses. (We chose a span of 0.8 as smoothing parameter because 0.8 was the highest value to remove the nonlinear trend from the time series and no trend remained in the autocorrelation of the time series thereafter). We tested both the unsmoothed and smoothed (moving average of 2) residuals of the time series for significant periods using Lomb-Scargle periodograms. In addition, we calculated a cosine regression of the form a * cos((2 π/12)*x + Acrophase [a = amplitude; acrophase = phase shift] on the unsmoothed residuals for the time series.

RESULTS

Intragenерational effects

The time series of mean offspring count of women born between January 1920 and December 1955 shows a long-term trend as well as a cyclic component (Fig. 1a). The long-term trend is represented by a sigmoid curve with maximum average offspring count found in women born around months 1 and 300 (corresponding to 1920 and 1945) and minimum average offspring count in women born around months 100 and 432 (corresponding to 1928 and 1955). After removal of this long-term trend via local regression span 0.8, the cyclic component remains (Fig. 1b). A Lomb Scargle periodogram of the residuals of the local regression shows a highly significant period at 12 months, indicating a clear 12 month periodicity of the cyclic component of the time series (Fig. 1c). Averaged over the whole period, contrary to our expectations, we find maximum offspring count in women born in June and minimum offspring count in those born in December (Fig. 1d). In addition, the highs and lows of the z-transformed residuals of the local regression of mean offspring count (blue curve, Fig. 2) roughly coincide with the highs and lows of the z-transformed monthly mean ambient temperature in Romania from January 1920 through December 1955 (red curve, Fig. 2). A particularly strong coincidence is found between the negative peaks of both curves (see Fig. 2). The coincidence of the two time series is supported by a cross-correlation analysis. Both the autocorrelations of the residuals of the local regression of mean offspring count per birth month (Fig. 3a) and the monthly means of ambient temperature in Romania from January 1920 through December 1955 (Fig. 3d), as well as the cross-correlations between the two time series (Fig. 3b, c) exhibit.
significant peaks. Significant positive peaks are found around lags 0, 12, and 24, significant negative peaks around lag 6 (except the autocorrelation of the residuals of mean offspring count per birth month) and 18. These peaks indicate a 12-month- and a 6-month rhythm within as well as between these time series.
The relationship between birth month and offspring count differs by education group: in women with lower educational attainment, average offspring count is highest after birth in June and lowest after birth in December (Fig. 4a), with a highly significant 12-month peak found in the Lomb Scargle periodogram (Fig. 4b). In women of higher educational attainment, on the other hand, no clear association between birth month and offspring count emerged (Fig. 4a), and the 12-month peak in the Lomb Scargle periodogram is not significant (Fig. 4c).

**Intergenerational effects**

We find that a woman’s offspring count is also associated with her mother’s month of birth. The times series of women’s mean offspring count as a function of their mother’s birth month also shows a long term trend and a cyclic component (Fig. 5a). In contrast to Figure 1a, where the long-term trend is mainly caused by cohort effects, this long term trend of decreasing average offspring count with decreasing mother’s age is the result of their daughter’s decreasing age. The cyclic component still remains after removal of the long-term trend via local regression span 0.5 (Fig. 5b). Applying a Lomb Scargle periodogram to the residuals of this local regression, we find a significant period at 12 and 13.75 months if the time series has been smoothed ($P < 0.05$) (Fig. 5c). In the unsmoothed time series, the periodogram failed a significant peak ($P = 0.77$). Fitting a cosine regression on the residuals of the local regression of women’s mean offspring count as a function of their mother’s birth months (unsmoothed time series), both the amplitude and the acrophase are significant $[-0.0243^{**}, \cos(12.6704^{***}-(\pi x)/6); ^{**}P < 0.01, ^{***}P < 0.001]$. Plotted over one year, the cosine regression on the residuals of the mother’s birth month has a maximum between May and June and a minimum in December (Fig. 5d).

**DISCUSSION**

**Intragenerational effects**

We find a strong association between birth month and later offspring count in Romanian women: on average, women born in winter months have the fewest and those born in summer the most offspring. This is in contrast to our findings from contemporary Austria and New Zealand, where the average number of children was lowest among women born in summer months (Huber et al., 2004, 2008). Even though the present data would support scenarios such as that spring conditions around conception and during early gestation might be detrimental to...
later reproduction of Romanian women, coincidence between decreased reproductive success and low ambient temperature around birth rather points to a detrimental effect of winter conditions during the perinatal period. Different photoperiod or vitamin D either around conception or around birth might also affect later reproduction via a potential influence on gamete quality or development of the reproductive axis. The striking differences in the birth month patterns between Romania and Austria, however, are not readily explicable by differences in exposure to photoperiod and vitamin D between these countries. These differences can be more easily explained by different exposure to winter conditions made up among others by low ambient temperature, short photoperiod, increased infectious disease exposure, lower nutritional quality, changes in maternal physiology and psychology, and higher risk for birth complications (Eisenberg et al., 2007).

Nutrition might be a candidate to bridge the effects of birth season and later reproductive performance because it is established that nutritional stimuli at critical ontogenetic stages may yield morphological and epigenetic changes in the developing individual (Rhind et al., 2001; Waterland and Michels, 2007). If epigenetic changes occur in the gametes, these changes may even be heritable across generations (Waterland and Jirtle, 2004). In addition, inadequate nutrition during pregnancy may directly influence pregnancy outcome (Hobel and Culhane, 2003). Low ambient temperature during the perinatal period may be another candidate. This view is supported by two additional tendencial, albeit not-significant findings (data not shown): an even lower offspring count found in women born in the 10% coldest winter months as well as a female biased sex ratio in the offspring of winter born mothers. The latter supports studies showing that cold ambient temperature may reduce the proportion of male births (Catalano et al., 2008; Helle et al., 2008), possibly because of an increased mortality of more vulnerable male fetuses (Catalano et al., 2005).

What might explain the conflicting results between the present Romanian and the former Austrian and New Zealand studies? Various explanatory models are conceivable such as, for instance, population specific cultural differences concerning potential effects of timing of marriage and expectations of family size on later offspring count. Another explanatory model might indicate that different perinatal factors affect later reproduction in Romanian women on the one hand, and New Zealand and Austrian women on the other. Still another explanatory model is based on the assumption that it is not the underlying factors that differ, but that there may be more than one critical periods of early development. As exposure-risk relationships are not necessarily linear, different populations facing different doses of exposure may lead to contrary associations found in these populations (McGrath et al., 2007).

Among other things, Romania differs distinctly from New Zealand and Austria as regards socio-economic standards, which are much higher in the latter two countries. At a population level, Austrian and New Zealand women might therefore have been more protected from detrimental effects of winter conditions during the perinatal period than Romanians. Hence, one possible explanation would be that the exposure-risk relationship as to critical period might differ with socio-economic status. Perinatal winter conditions may be particularly detrimental to women of low socio-economic background because poorer women and their neonates are more likely to be exposed, among others, to cold stress and nutritional deficiencies. Rickard et al. (2010), for instance, demonstrated that food availability at the time of birth affected later reproductive success of 18th century Finns in landless but
not in landowning individuals. Correspondingly, in this study, the association between birth month and later offspring number is only significant among the lower educated but not the higher educated Romanian women. A similar effect of education and income, respectively, on the association between birth month and later reproduction has been reported on New Zealand and Vietnamese women: likewise the association was significant only in the poorer, lower educated women (Huber and Fieder, 2009; Huber et al., 2008). In Austria and New Zealand, where overall socio-economic standards are much higher than in Romania, then maybe more subtle effects of perinatal summer conditions (or early prenatal winter conditions) on later reproductive performance have appeared. Similarly, the birth month pattern found among the higher educated Romanian women lacks a significant winter low yet shows a slight summer depression.

The data set has limitations as it does not contain information about perinatal death, birth weight, or gestation duration. In case winter birth is associated with high neonatal mortality, short duration of gestation and/or low birth weight, this information would have been important as a potential explanatory factor for the lower mean offspring number in winter born Romanians. We do not have data about seasonal variation of those parameters in Romania. In other countries, however, a seasonal variation of prenatal

Fig. 5. (a) Time series of women’s mean offspring count per the women’s mother’s birth month from January 1920 to December 1950 (i.e., month 1–360); (b) Residuals of a local regression span 0.5 of women’s mean offspring count per the women’s mother’s month of birth; (c) Lomb-Scargle periodogram of the smoothed residuals (moving average of 2) of the local regression of mean offspring count per the women’s mother’s month of birth. Horizontal line: significance level at $P = 0.05$; (d) Cosine regression plotted over one year of women’s mean offspring count per their mother’s birth month from January 1920 to December 1950. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
Intergenerational effects

We find a similarly shaped albeit much smaller intergenerational effect of mother’s birth month on their daughter’s offspring count: mother’s birth during winter was associated with slightly lower offspring count in their daughters, indicating that winter conditions experienced during the perinatal period not only affected an individual’s own reproduction but also that of their progeny. Gluckman et al. (2005) suggests three possible mechanisms to be involved in such intergenerational effects: (1) epigenetic alterations, by which DNA is modified without a change in DNA sequence by environmental effects, resulting in changes in gene expression that may be inherited in the subsequent generation. Heijmans et al. (2008) contributed the first empirical support for the hypothesis that early-life environmental conditions can cause epigenetic changes in humans that persist throughout life; (2) uterine effects: if uterine size is reduced, this may lead to reproductive impairment; (3) changes in metabolic homeostasis during fetal or neonatal life may affect metabolic function when these individuals become pregnant, thereby affecting the offspring. Social effects, however, cannot be ruled out: the birth month effect on offspring count found in this study indicates that daughters of winter born mothers are likely to have fewer siblings. As the family size perceived during childhood affects expectations of own family size (Axinn et al., 1994), an intergenerational effect of mother’s birth month on daughter’s offspring count could also emerge via differences in expected family size.

CONCLUSIONS

In Romanian women, in contrast to women from Austria and New Zealand, winter experienced during the perinatal period is associated with lower offspring count. This only holds true for women from the lowest measured tier of education, suggesting that perinatal winter conditions are detrimental only if socio-economic conditions are poor. The month of birth also exerts intergenerational effects as indicated by similarly shaped but much smaller effects of mother’s birth month on daughter’s offspring count could thus also emerge via differences in expected family size.

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LITERATURE CITED
