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The relationship of long term global temperature change and human fertility

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Summary According to the United Nations, global fertility has declined in the last century as reflected by a decline in birth rates. The earth's surface air temperature has increased considerably and is referred to as global warming. Since changes in temperature are well known to influence fertility we sought to determine if a statistical relationship exists between long-term changes in global air temperatures and birth rates. The most complete and reliable birth rate data in the 20th century was available in 19 industrialized countries. Using bivariate and multiple regression analysis, we compared yearly birth rates from these countries to global air temperatures from 1900 to 1994.

A common pattern of change in birth rates was noted for the 19 industrialized countries studied. In general, birth rates declined markedly throughout the century except during the baby boom period of approximately 1940 to 1964. An inverse relationship was found between changes in global temperatures and birth rates in all 19 countries. Controlling for the linear yearly decline in birth rates over time, this relationship remained statistically significant for all the 19 countries in aggregate and in seven countries individually ($p < 0.05$).

Conclusions. The results of our analyses are consistent with the underlying premise that temperature change affects fertility and suggests that human fertility may have been influenced by change in environmental temperatures.

INTRODUCTION

A worldwide decline in birth rates in the 20th century is well documented and has resulted in a slowing of world population growth (1–3). This decline is evident in the less and least developed countries including sub-Saharan Africa, but it is most marked in the industrialized countries where it is estimated that by 2040, these countries will experience negative population growth (3). While various social, cultural and economic changes have been thought to affect birth rates (1,4–8), no direct link has ever been made between declining birth rates and prolonged change in physical environment.

Global warming, an increase in the earth's air temperature, is considered by some scientists to be an adverse environmental consequence of human activity (9,10). It is believed to be caused by excess accumulation of carbon dioxide, methane and other greenhouse gases that allow the sun's energy to enter, but hinder the escape of infrared radiation from the earth's atmosphere (9,10). Although yearly global air temperatures have increased dramatically in the past 100 years (11), no study has demonstrated an association between global warming and any direct effect on human physiology.

Since transient changes in environmental temperature are known to influence human reproductive function

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(12–21), the goal of our study was to determine if a relationship exists between long-term changes in global air temperatures and human birth rates.

COMPARISON OF BIRTH RATES FROM INDUSTRIALIZED COUNTRIES AND GLOBAL AIR TEMPERATURE CHANGE

According to the United Nations Population Division, birth rate data are considered substantially complete and reliable only in the 20th century (2). From 1900 to 1994 complete national birth rate data in five-year intervals was available for the following 17 industrialized countries: Australia, Austria, Belgium, Denmark, Finland, France, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Birth rate data from Argentina was available from 1905 to 1994, and in the United States from 1910 to 1994 (1,3). These 19 countries constituted our study group. Birth rate data from eastern European countries and Germany, as well as the developing countries before 1940, are considered either unreliable or incomplete and, therefore, were not included in this study (1,2).

Mean global air temperature for each year from 1900 to 1994 was obtained from the National Aeronautics and Space Administration (NASA)-Goddard Institute for Space Studies (GISS) (11). The methodology for calculating mean yearly global air temperature from data gathered at meteorological stations has been previously described (11). Five-year mean global air temperatures (corresponding to the time period used for birth rates) were determined by averaging mean annual temperatures. The year of onset of each five-year period is used to refer to the period as a whole; for example, '1900' refers to the period 1900–1904.

Bivariate and multiple regression analyses were performed to determine whether there is a relationship between changes in global air temperature and national birth rates. The linear relationship between change in global air temperatures and time (year), as well as change in birth rates and time (year) was determined. Since decline in birth rate is thought to be influenced by many factors such as social, cultural and economic changes (1,4–8), all of which are impossible to quantitate; multiple regression analysis was used when the linear decline in birth rate was controlled.

A Principal Components Factor analysis was also conducted to determine whether a common pattern of change over time in birth rates exists among the 19 countries under study. Factors with an eigenvalue greater than 1 were extracted and subjected to a varimax rotation. The first principal component (factor) was very strong (eigenvalue = 13.63) and accounted for 80.2% of the year-to-year variability in birth rates in all countries. A second, much weaker orthogonal factor (eigenvalue = 1.18) accounted for an additional 6.9% of variance. In the final rotation, a single factor was extracted which represents the common pattern of change in birth rates over time for all countries studied, which we refer to as the Composite Birth Rate. The conformity (loading) of individual countries on this factor ranged from a high of 0.96 (Netherlands, Denmark) to a low of 0.42 (Ireland). The Composite Birth Rate was transformed for presentation purposes into a variable with the same mean and standard deviation as obtained when yearly data from all 19 countries were averaged.

Birth rates (the number of births per 1000 population) from 1900 to 1994 in the 19 industrialized countries are shown in Fig. 1. In each of the 19 countries, there was a marked statistically significant decline in birth rates over the study period. The strength of relationship (R^2) varied from 0.28 in Ireland to 0.94 in Portugal (Table 1). The Composite Birth Rate, reflecting the common pattern of birth rates in the 19 countries studied also declined significantly between 1900 and 1994 ($R^2 = 0.87$, $p < 0.00001$) (Fig. 2). Despite the overall linear decline over time, there were periods when birth rates increased or remained stable. As illustrated in Fig. 2, birth rates generally declined from 1900 to 1939 and from 1965 to 1994. Birth rates increased from 1940 to 1949 and remained relatively stable from 1950 to 1964.

The results of the bivariate and multiple regression analyses, which establish the relationship between birth rate, year and global air temperature for each country, are shown in Tables 1 and 2, respectively. The inverse relationship between birth rate and global air temperatures was statistically significant and negative in all countries. The relationship of the Composite Birth Rate and global air temperature from 1900 to 1994 ($R^2 = 0.81$, $p < 0.00001$) is illustrated in Fig. 3. In general, global air temperatures increased from 1900 to 1944 and 1970 to 1994, and declined from 1945 to 1969. The relationship between global air temperature and birth rate controlling for the yearly decline in birth rate was significant ($p < 0.05$) in seven of the 19 countries (Australia, Ireland, New Zealand, Norway, Spain, Switzerland and the United Kingdom) (Table 2). In these seven countries, the percentage of additional variance in birth rate accounted for by the significant global warming effect ranged from 3% (Spain) to 22% (New Zealand). The independent effect of mean global air temperature was also significant ($p = 0.0262$) for the Composite Birth Rate, accounting for an additional 4% of variance.

When multiple statistical tests are done, the likelihood of obtaining at least one significant result by chance increases with the number of tests performed. We, therefore, conducted a binomial test to evaluate the

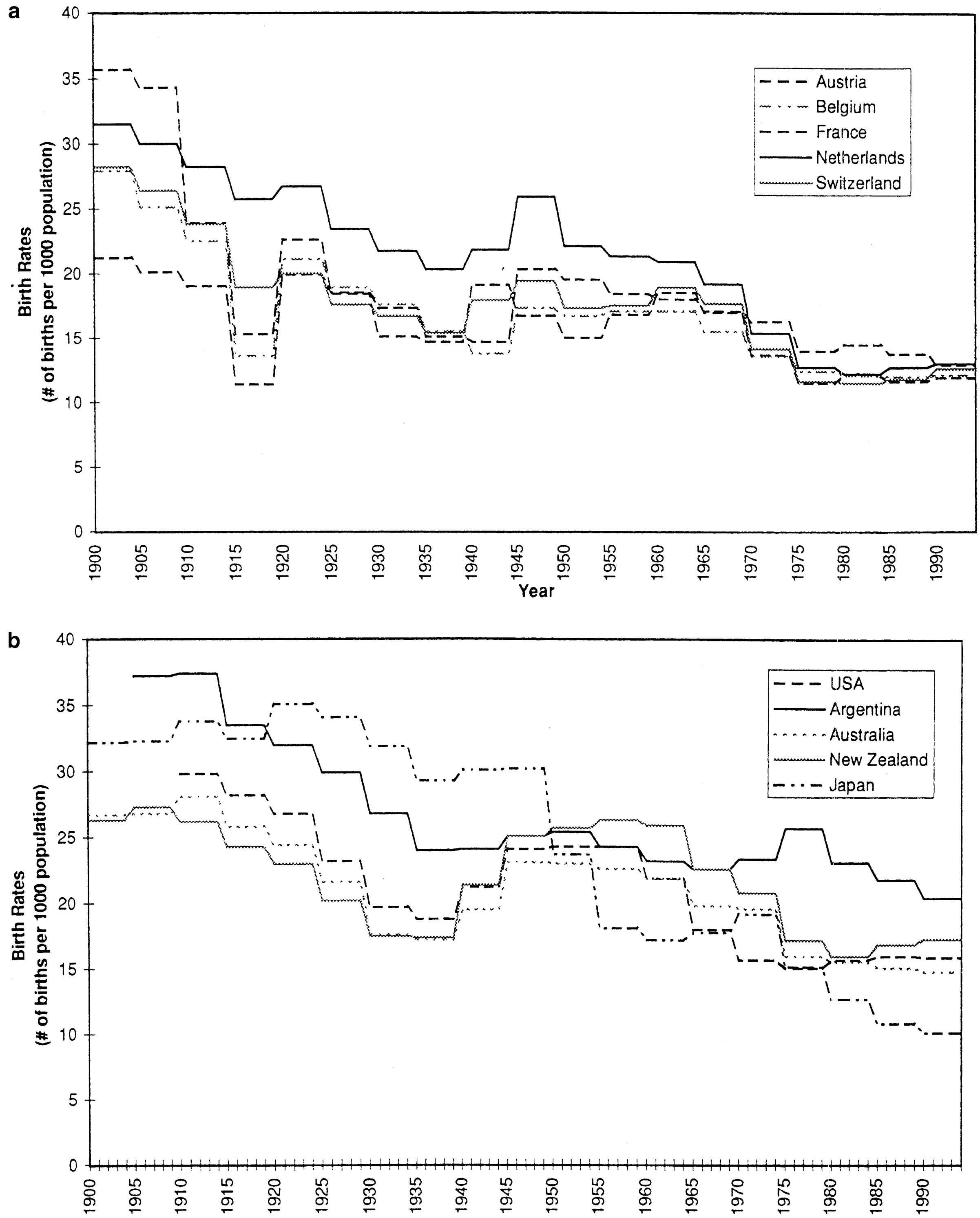

Fig. 1 The change in birth rates (number of births per 1000 population) over time in 19 industrialized countries.

probability that of the 19 multiple regression analyses performed, the regression coefficient for the effect of global warming would be significant ($p < 0.05$) in seven or more tests. Under the null hypothesis that there is no independent effect of global warming on birth rate, it is highly unlikely that the obtained result of seven significant coefficients would be obtained (binomial probability < 0.00001).

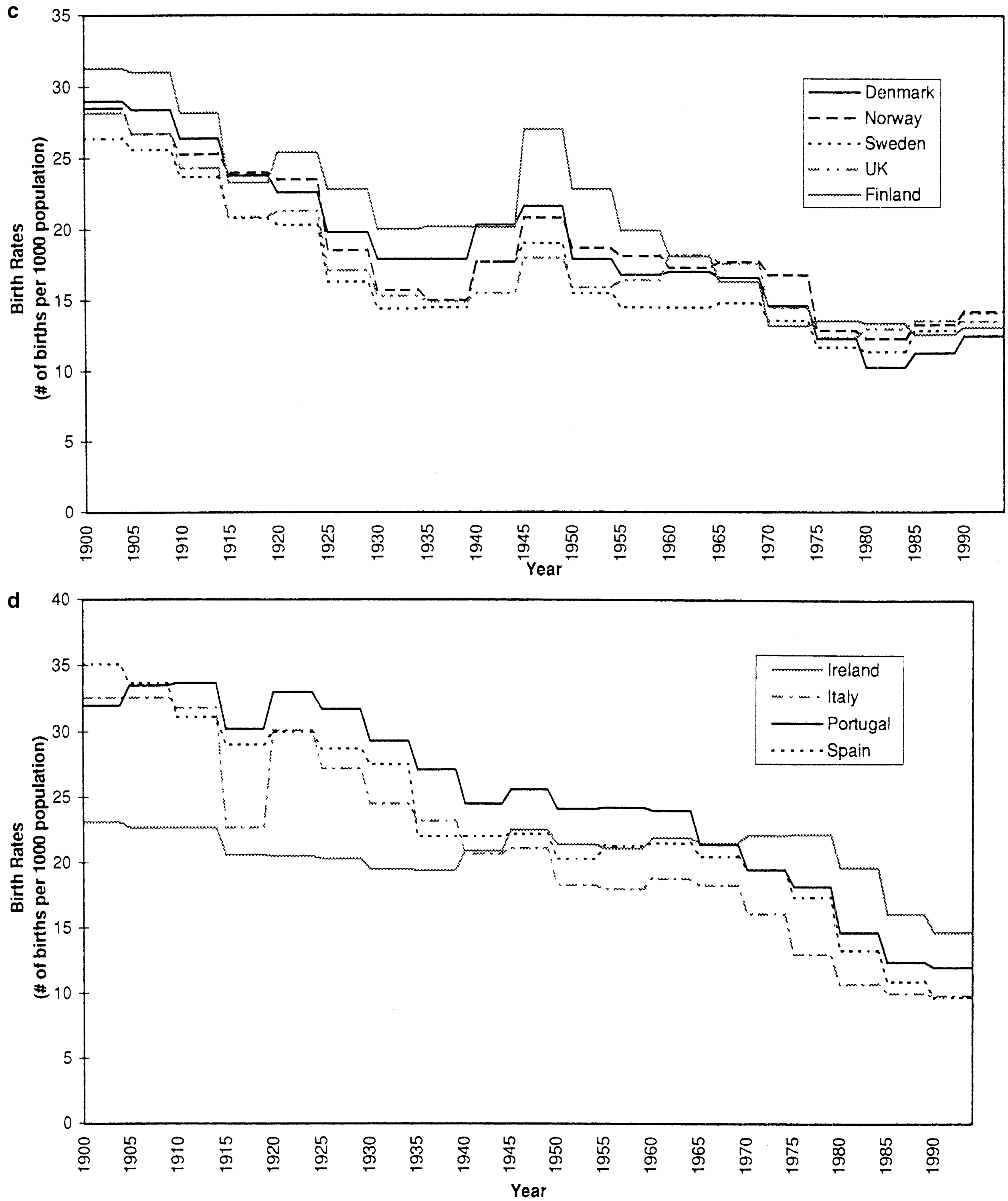

Fig. 1 *(continued)*

Moreover, the seven significant coefficients were all negative in sign, consistent with the hypothesis that global warming has a negative impact on birth rate. In fact, as shown in Table 1, of the 19 multiple regression analyses conducted on individual countries, the regression coefficient for the effect of global warming after

Table 1 Results of bivariate regression analyses: effects of year and global temperatures on birth rates

Country	Year			Global temperature		
	Coeff.	R^2	*p*	Coeff.	R^2	*p*
Argentina	−0.18	0.80	0.0000	−29.21	0.74	0.0000
Australia	−0.12	0.67	0.0001	−22.92	0.79	0.0000
Austria	−0.19	0.60	0.0000	−31.09	0.55	0.0003
Belgium	−0.13	0.67	0.0000	−21.07	0.59	0.0001
Denmark	−0.18	0.89	0.0000	−29.33	0.75	0.0000
Finland	−0.20	0.84	0.0000	−29.69	0.64	0.0000
France	−0.05	0.28	0.0209	−9.29	0.29	0.0117
Ireland	−0.04	0.28	0.0210	−9.89	0.56	0.0003
Italy	−0.26	0.93	0.0000	−39.02	0.74	0.0000
Japan	−0.29	0.88	0.0000	−40.27	0.56	0.0002
Netherlands	−0.20	0.88	0.0000	−31.26	0.74	0.0000
New Zealand	−0.08	0.34	0.0092	−17.71	0.54	0.0003
Norway	−0.15	0.74	0.0000	25.50	0.76	0.0000
Portugal	−0.24	0.94	0.0000	−37.47	0.77	0.0000
Spain	−0.25	0.94	0.0000	−40.96	0.86	0.0000
Sweden	−0.14	0.75	0.0000	−21.93	0.64	0.0000
Switzerland	−0.14	0.74	0.0000	−23.93	0.71	0.0000
United Kingdom	−0.14	0.70	0.0000	−23.76	0.73	0.0000
United States	−0.16	0.78	0.0000	−26.51	0.69	0.0000
Composite	−0.03	0.87	0.0000	−5.48	0.81	0.0000

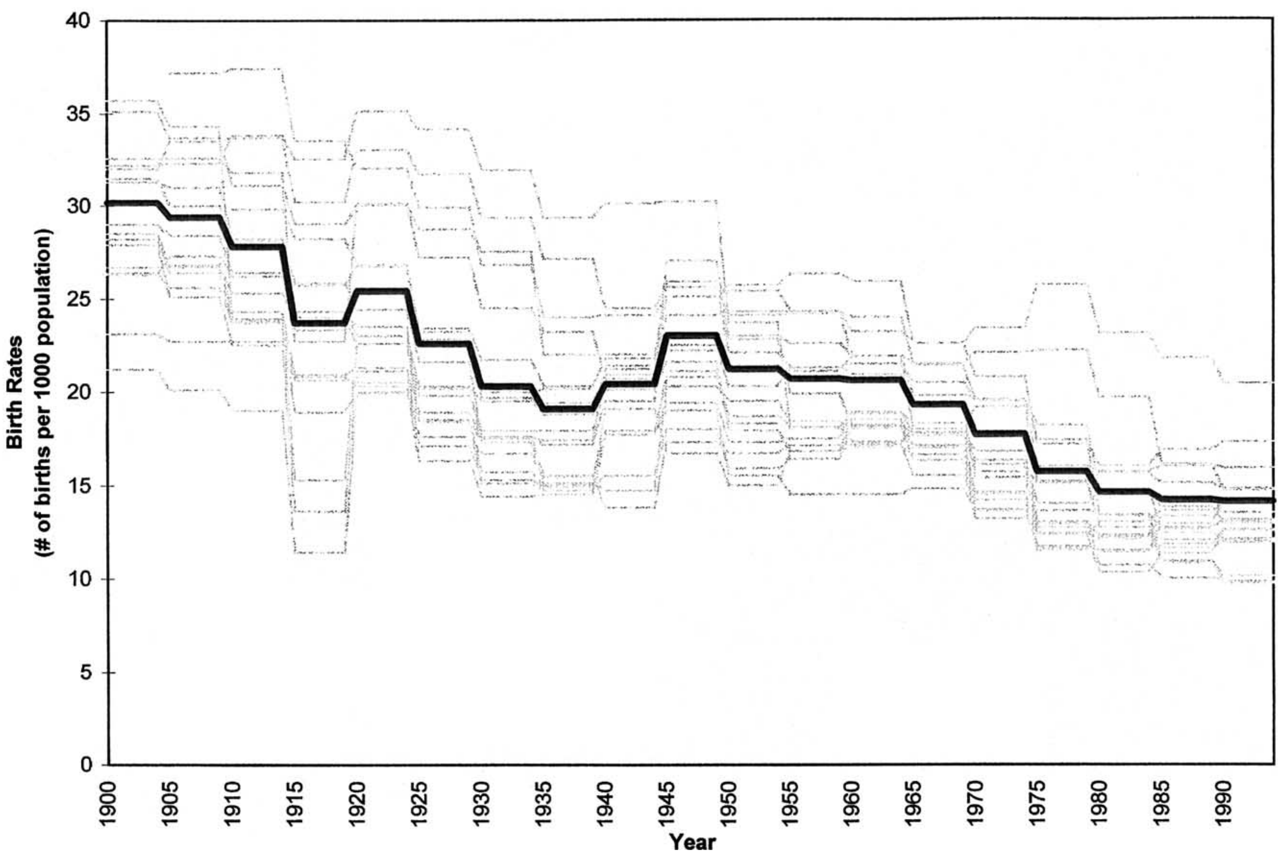

Fig. 2 The composite birth rate (▬) reflecting the common pattern of birth rates in the 19 countries studied (—). These countries included: Argentina, Austria, Australia, Belgium, Denmark, France, Finland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States.

controlling for year was negative in 18 cases. Under the null hypothesis that there is no independent effect of global warming on birth rate, it is extremely unlikely that 18 of 19 negative regression coefficients would be obtained (binomial probability < 0.00001).

Table 2 Results of multiple regression analyses: effects of global temperature on birth rates controlling for the yearly decline in birth rates

Country	Coeff.	R^2	p
Argentina	−12.30	0.03	0.0939
Australia	−18.42	0.01	0.0051
Austria	−11.80	0.02	0.3659
Belgium	−6.60	0.01	0.4037
Denmark	−7.75	0.01	0.1505
Finland	−1.75	0.00	0.8134
France	−5.67	0.03	0.4389
Ireland	−15.16	0.33	0.0020
Italy	−4.99	0.00	0.3949
Japan	12.96	0.01	0.1511
Netherlands	−6.91	0.01	0.2614
New Zealand	−22.11	0.22	0.0136
Norway	−14.87	0.07	0.0320
Portugal	−7.62	0.01	0.1557
Spain	−15.77	0.03	0.0006
Sweden	−5.72	0.01	0.4067
Switzerland	−11.28	0.10	0.0405
United Kingdom	−14.35	0.07	0.0473
United States	−8.61	0.02	0.2399
Composite	−2.29	0.04	0.0262

DISCUSSION

There has been much concern recently about whether human fertility has been adversely affected by environmental toxins. In a landmark study, Carlsen, et al. (22), suggested that sperm counts had declined worldwide over the last 50 years, and then hypothesized that the decline was related to manmade chemicals. The study, a meta-analysis of 61 different publications from different countries has been sharply criticized and its conclusions questioned (23–25). When the data from the meta-analysis were adjusted for geographic variability and statistically reanalyzed, no decline in sperm count was evident (23–25). The results of more recent studies are also inconsistent with regard to long term changes in sperm counts, with some studies indicating an increase while others show a decline over time (26–29). These inconsistencies in results probably relate to differences in the population of men evaluated, duration of study and geographic location (23–29).

Although the issue of whether sperm counts have changed in the 20th century is currently unresolved. According to the United Nations there has been a well-documented global decline in human fertility as reflected by a decline in birth rates (1–3). This decline has been most marked in industrialized countries where review of the available birth rate data indicates a common pattern of change. In general, birth rates fell from 1900

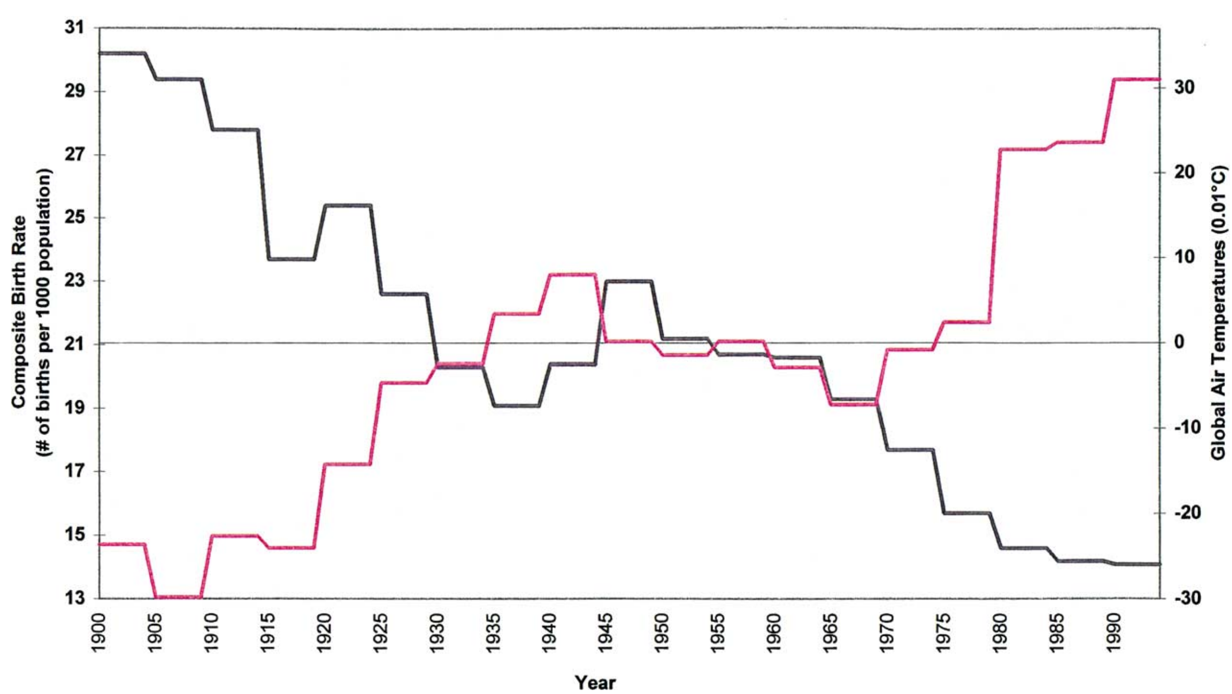

Fig. 3 The relationship of composite birth rate (black line) to global air temperatures (red line) from 1900 to 1994 ($R^2 = 0.81$, $p < 0.00001$). The mean composite birth rate is 21.06 births per 1000 population. Global air temperatures are represented as deviations of the mean global air temperature from 1951 to 1980.

to 1939 and from 1965 to 1994. The only time period that birth rates consistently increased or remained relatively stable occurred during the baby boom of approximately 1940 to 1964 (5).

Many factors have been hypothesized to influence birth rates. Birth rate decline has been attributed primarily to social, cultural and economical changes, such as increases in the cost of living, postponement of marriage and child bearing, the increase use of contraception and legalized abortions (1,4–8). Factors associated with increased birth rates may also be related to social, cultural and economical changes, but are less obvious and more difficult to assess (1,4–8). However, of all factors hypothesized, no specific environmental factor has been shown to influence birth rates long term.

Numerous studies have suggested a causal relationship between transient environmental temperature changes and fertility (14–17). In certain temperate regions, fertility is seasonal with fewer conceptions in the summer and reduced births nine months later (14–17). Temperature-mediated changes in fertility are thought to be influenced by changes in sperm quality. It is well known that sperm counts are lowest in the summer months and highest in the winter months (16,18–20). In addition, animal and clinical studies indicate that transient increases in scrotal temperature can directly inhibit spermatogenesis and reduce fertility and that these changes are reversible (10,13,21).

Global warming is a consequence of long term increases in the earth's air temperature (9,10). Although many consider global warming to be a major environmental concern (9,10), no direct impact on human physiology has been demonstrated. The goal of our study was to determine if long-term changes in environmental temperature are related in any way to the long-term changes in birth rates.

According to the United Nations, the most complete and reliable measure of fertility in the last century represents birth rate data from 19 industrialized countries (1–3). Global air temperature data are readily available from NASA-GISS (11). Comparing the data from these two independent sources, we found a remarkably strong inverse relationship between changes in temperature and birth rates in all 19 countries. In order to determine if temperature has an independent influence on birth rate change, all factors known to decrease birth rates (such as, social, cultural, economical changes, etc.) must be accounted and controlled for statistically. Since quantifying these factors is impossible, we used a separate statistical model where we negated the influence of birth rate decline over time. The results of this more complex analysis still revealed a significant inverse relationship between temperature and birth rates in all the countries in aggregate (composite birth rate), and in seven countries individually. In other words, while many factors including temperature increase may have contributed to the decline in birth rates, the strength of our statistical analysis lies in the fact that temperature decline was associated with an increase in birth rates.

Our analysis leads us to believe that long-term changes in air temperature could influence human fertility. Similar to transient environmental temperature change, long term environmental temperature change may mediate fertility by changes in sperm counts. It is certainly possible that as a result of global air temperature changes, sperm counts may have fluctuated, thereby affecting birth rates. In a recent study, changes in sperm counts over a 25-year period were found to correlate directly with changes in birth rates in a single geographic location (19). If this relationship is true worldwide, sperm counts may indeed have been higher 100 years ago than they are today.

It is, however, difficult to understand how an overall increase in global temperature by approximately 1 °C in the past 100 years could significantly impact fertility. One possibility may be due to the fact that global warming has resulted in marked fluctuations in seasonal climate patterns, specifically hotter summers and colder winters (9,10). Since fertility is known to be seasonal, it is reasonable to suggest that long-term changes in seasonal climate may have had a dramatic affect on sperm counts and ultimately fertility.

In summary, our analysis is consistent with the possibility that global warming may have contributed to changes in human fertility. Further research is needed to determine whether regional environmental temperature change, particularly seasonal patterns, has influenced regional fertility trends. It is possible that certain regions are affected by temperature change more than others. Furthermore, if human fertility is influenced by long-term temperature change, other ecological systems may also be at risk and must also be studied. Lastly, if the relationship we found between temperature change and fertility is correct, then a drop in global temperatures may actually result in an increase in human fertility.

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