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Original Contribution

The Association Between Living Through a Prolonged Economic Depression and the Male:Female Birth Ratio—A Longitudinal Study From Cuba, 1960–2008

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The Trivers-Willard hypothesis suggests that populations respond to scarcity by decreasing the ratio of males to females at livebirth. Cuba experienced an extreme economic depression in the 1990s called the "special period." Using time-series analysis, the authors studied the impact of this event on the male:female sex ratio at birth in Cuba from 1960 to 2008. From 1990 to 1993, the per capita gross domestic product in Cuba decreased by 36%. By use of a definition of the special period from 1991 to 1998, there was a prolonged increase in the male:female ratio of livebirths during this period of economic depression ($P < 0.001$), from 1.06 at baseline to a peak of 1.18. This association persisted when using alternative definitions of the duration of economic depression in sensitivity analyses. Once the period of economic depression was over, the male:female ratio returned to the baseline value. These data suggest that, in Cuba, contrary to the Trivers-Willard hypothesis, the human population responded to conditions of scarcity by increasing the ratio of males to females at livebirth. These data may be relevant in the modeling of demographic projections in countries that experience prolonged economic depression and in understanding adaptive human reproductive responses to environmental change.

Cuba; economic recession; sex ratio

Abbreviation: GDP, gross domestic product.

Editor's note: *An invited commentary on this article appears on page 1332, and the authors' response is published on page 1335.*

In 1973, Trivers and Willard (1) advanced a hypothesis, largely based on animal studies, that populations respond to conditions of scarcity by decreasing the ratio of males to females at livebirth, from a normal value of approximately 1.05 (2, 3). This theory, which initially was largely based on observations from animal studies, is often applied to human populations. Testing this hypothesis is difficult in human populations, however, and relies on use of observational data that have produced conflicting results (4–7). For example, in 1991 when East Germany's economy collapsed, it was reported that East Germany had a lower sex ratio than the ethnically similar West Germany (8), while data from the Dutch famine from 1944 to 1945 demonstrate an excess of male offspring (9). Thus, the response of the sex ratio in populations that experience scarcity is uncertain, and while there has been much speculation as to a potential biologic mechanism that may explain these observations, such as changes in family size and child gender preference (10), diet (11), and psychological stress and coital rates (12), no clear biologic explanation exists to explain them. Furthermore, reliable data on the livebirth sex ratio are rare in the context of conditions of acute-onset, extreme-sustained economic depression.

Cuba possesses an extensive primary health-care network, which places an emphasis on maternal and child health and publishes annual health statistics with high levels of ascertainment (13, 14). The recent economic history of Cuba is unique, as it has experienced a prolonged economic embargo by the United States since the 1960s, and after the economic collapse of the former Soviet Union and other countries within its sphere of influence, Cuba experienced a severe sustained decline in living standards during a time known as

the ''special period.'' During this period that spanned the 1990s and was exacerbated by further tightening of the economic embargo by the United States (15), severe economic depression was experienced by Cuban society, with a decrease in gross domestic product that was estimated to be 36% lower than the 1990 baseline value (16) and with a decrease in imported goods by 78% of the baseline value (15). One impact of this economic contraction was increased physical exercise in the general population, a reduction in the prevalence of obesity from 14% to 7%, and a decline in mortality from both all causes and cardiovascular disease (17). We have used routine health-care data from the past 50 years to investigate the changes that occurred in the sex ratio at livebirth during this time of severe economic depression in Cuba.

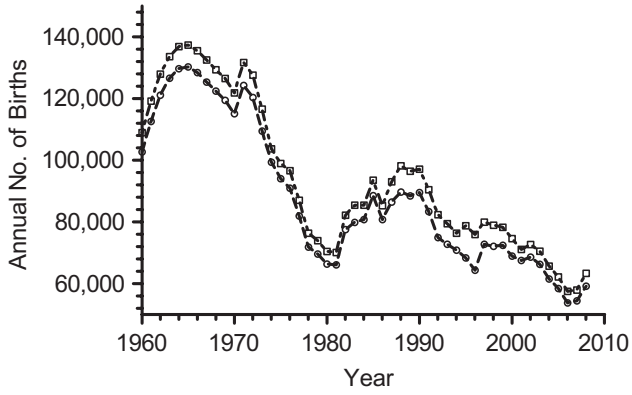

Figure 1. The number of livebirths in Cuba, 1960–2008, including the extreme economic depression from 1991 to 1998 called the ''special period.'' □, males; ○, females.

MATERIALS AND METHODS

The study population consists of all livebirths in Cuba from 1960 to 2008 using data from the National Statistics Agency of Cuba that collects and publishes data on all births on the island (18). As these data are anonymous and routinely available, the approval of an ethics committee was not required.

Definition of the special period of economic depression

We have used the adjusted estimates available from Maddison (16) for gross domestic product (GDP) in Cuba, which are presented in 1990 international Geary-Khamis dollars to represent the changes in macroeconomic activity in the study period and to permit standardized comparisons to be made over time. These data are available from 1960 to 2001. The special period of economic depression in Cuba occurred after the collapse of the Soviet Union, and macroeconomic estimates of the economic activity (Figure 2) suggest that 1991 was the first year when a large decline was observed (19), resulting in an annual decrease of 10.7%–11.6% in GDP (16, 20) and 24.0% in the global social product, a measure of economic activity in a socialized economy (20), that year. The National Bank of Cuba estimated that the economy had contracted by 34.8% by 1993 (15), although other estimates have been higher (20). By 1999, the adjusted GDP had increased to 82% of the 1990 baseline value (16) and, similarly, other measures of well-being, such as energy intake per capita, were returning to 1990 baseline levels (17). As a consequence, 1998 was selected as the last year of the special period for our primary analysis. Thus, the period from 1991 to 1998 was selected as the a priori primary definition of the special period for this study. Different end dates for the special period definitions were used as secondary outcome measures in sensitivity analyses on the basis of historical records (21) as outlined below, and the raw data are presented in Figure 2.

The data are presented graphically to demonstrate the temporal patterns in the sex ratio at livebirth and their associations with the special period of economic depression, by using a primary definition of the special period from 1991 to 1998. The analysis compared the sex ratio at livebirth in years that were part of the defined special period compared with the rest of the baseline data from all of the other years both before and after the special period years. A sensitivity analysis was performed that considered these comparisons while defining the special period as lasting a variety of different timespans (1991–1996, 1991–1997). Time-series analysis with autoregressive integrated moving-average modeling to adjust for autocorrelation was used to compare these differences between the sex ratio in the special period with that at baseline by use of STATA, version 10, software (StataCorp LP, College Station, Texas). The raw sex ratio data for each year were used with no additional transformation, with a binary indicator used to indicate the years of the special period for the primary definition and the secondary definitions used in the sensitivity analyses. The autocorrelation function and the partial autocorrelation function were examined to identify whether autoregressive or moving average parameters needed to be added to the model. The final model that was used for analysis was autoregressive integrated moving average (1, 0, 0). All significance testing used the *P* value for the association between sex ratio and definition of the special period.

RESULTS

The absolute numbers of male and female livebirths in Cuba are presented in Figure 1. In 1960, the absolute numbers of livebirths for males and females were 108,940 events and 102,680 events, respectively. By the end of the period of study in 2008, these numbers were 63,378 and 59,191 livebirths, respectively. The highest number of annual total livebirths was in 1965 when 267,611 births were recorded, and this dropped to a minimum of 111,323 livebirths in 2006.

Trends in the sex ratio at livebirth and GDP data in the period from 1960 to 2001 are plotted in Figure 2. Over the period of time from 1991 to 1998 that was selected as the primary definition of the special period, GDP decreased from a baseline of 31,087 million Geary-Khamis dollars to a nadir of 19,898 million Geary-Khamis dollars in 1993, increasing to 25,494 million Geary-Khamis dollars in 1999 (Figure 2).

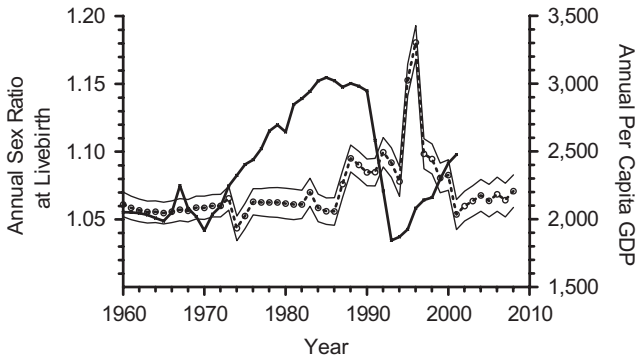

Figure 2. Sex ratio at livebirth and gross domestic product (GDP) in Cuba, 1960–2008, including the extreme economic depression from 1991 to 1998 called the "special period." ○, sex ratio; –, sex ratio (95% confidence interval); —, per capita annual GDP in million 1990 Geary-Khamis dollars. The annual GDP was taken from the report by Maddison (16).

The sex ratio increased from a baseline value of 1.06 to a maximum of 1.18 in 1995, returning to the baseline values from 2001 to 2008. By use of the primary definition of the special period from 1991 to 1998, this increase was statistically significant ($P < 0.001$). Sensitivity analyses demonstrated a consistent difference between the sex ratios in the various definitions for the special period compared with that at baseline ($P < 0.001$).

DISCUSSION

These data demonstrate that a prolonged severe economic depression with a well-defined time of onset is associated with an increase in the male:female sex ratio of livebirths in a clearly delineated study population. This association ceases to be present once the period of severe economic depression has ended.

The combination of the longstanding embargo by the United States and the abrupt withdrawal of economic support by the former Soviet Union accompanied by a drop in the global price of sugar, one of the main export crops for Cuba, created a ''perfect storm'' in terms of economic collapse in Cuba in the 1990s (21). The impact and severity of the special period on the population in Cuba can be described by a variety of parameters that are summarized in a study of this period by Franco et al. (17). These authors describe a decrease in the average per capita daily energy intake from 2,899 kcal in 1988 to 1,863 kcal in 1993, a decrease in the prevalence of obesity in Havana from a baseline of 11.9% in 1982 to 5.4% in 1994, and an increase in individuals who define themselves as physically active from a baseline of 30% in 1987 to 70% from 1991 to 1995. The prevalence of smoking did not change substantially during this time, although the annual number of cigarettes smoked per smoker almost halved during this period, and this may be considered a reflection on the reduced disposable income of the population over this period. These changes were associated with declines in deaths attributed to diabetes, coronary heart disease, stroke, and all causes of 51%, 35%, 20%, and 18%, respectively (17). Thus, the data from Franco et al. (17) demonstrate impact of the special period on the health of the population, and our data suggest that the economic recession experienced during this period may also have impacted on reproductive biologic processes.

We therefore conclude that the increase in the male:female ratio during the special period in Cuba is a real phenomenon that requires explanation. The size of the change in sex ratio observed in our data is large compared with other published data. For example, Davis et al. (2) reported a reduction in the ratio of male to female births in several industrialized countries over the past decades but, although significant, this change represents a reduction from a baseline of approximately 1.066 to 1.053 over this time period. By contrast, our data demonstrate an increase in the livebirth sex ratio to a peak of 1.18 from a baseline of 1.06, suggesting that a different scale of environmental change occurred during the special period in Cuba from that observed in more industrialized countries.

Any time of prolonged severe economic depression will be associated with a wide variety of potential exposures that may impact on the male:female ratio of newborn infants. Thus, our data are consistent with the observation that the liveborn sex ratio slightly increased to a peak of approximately 1.083 during World War I and World War II in Germany, decreasing once conflict had ceased (22, 23), with similarly sized trends being reported from Finland (24). In a like manner, an excess of males with a male:female ratio of 1.22 at birth was observed in women who were exposed to acute and extreme calorific deprivation during the Dutch Famine of World War II at the time of conception (9), suggesting a possible nutritional cause. This is supported by data from the Central African Republic, where women in the lower quartile for weight had a sex ratio of 1.16 compared with a value of 0.88 for those in the highest quartile (25). The increase in the proportion of infants with a low birth weight was observed in Cuba during the special period, suggesting that the environmental changes impacted on in utero development during this time (14). Other commentators have also concluded that maternal diet may influence the sex ratio (11), although most of the data are from animal studies, and it is difficult to confidently extrapolate these findings to humans.

There are several potential explanations for this phenomenon. One is that the decrease in the absolute amount of cigarette smoking during the special period in Cuba may influence the sex ratio in a manner compatible with our data (17). Data from Japan reported that the sex ratio declined (i.e., less boys were born) with increasing numbers of cigarettes smoked by mothers and fathers during the periconceptional period, from a value of 1.21 in the group where neither the mother nor father smoked to a value of 0.82 for those whose mothers and fathers smoked more than 20 cigarettes a day (26). However, subsequent other studies have reported little or no impact of cigarette smoking on the sex ratio (27, 28). Other commentators have considered that exposure to environmental chemicals may explain the decline in the male:female sex ratio observed in industrialized countries in recent decades (28, 29), and it is likely that this would have been a consequence of a reduction of economic activity

during the special period as the amount of hard currency available to purchase non-food imports in 1993 decreased to 17% of the 1989 amount. Increase in maternal weight has also been implicated as a potential risk factor for an increase in the male:female ratio at livebirth (30), and this is an unlikely explanation for our data as the predominant trend was for weight loss during the special period (17). Although a period of prolonged economic depression may be expected to increase psychological stress, the literature suggests that this would result in a decreasing male:female ratio of liveborn infants, as opposed to the increased ratio that we observed (3, 31). Thus, this does not appear to be a likely explanation for the changes in the sex ratio that we report.

There have been few other opportunities to study the impact of economic depression on the sex livebirth ratio. One such study compared East and West Germany in 1991 when East Germany's economy collapsed and reported that East Germany had a lower sex ratio of 1.04 than West Germany (8), although no such differential was seen in 1992. However, it is unclear how comparable these data are compared with the data that we present, as East and West Germany formally reunited in October 1990. While the economy in the former East Germany was ailing, it is unlikely that the impact on the population was as severe or as prolonged as that experienced in Cuba in the 1990s, as those living in the former East Germany would probably have received some support from the reunified state.

The strengths of these data are the fact that they constitute complete national data before, during, and after the special period in Cuba, and they are provided by the Cuban state that maintained and recorded the provision of health-care services to its population during this time of extreme hardship. As such, while other nations have experienced severe economic difficulties, few have collected such complete data during such periods, making these data a rare resource for study. The fact that Cuba is an island with secure borders provides a stable, well-defined population, and the return of the sex ratio to baseline values after the end of the 1990s suggests that selective migration would not account for our observations. Although we consider it unlikely, we are unable to exclude the possibility that some births were not included in these data. However, any unrecorded birth data are unlikely to be sex specific and, hence, would not bias our observations or account for the large changes in the sex ratio of livebirths observed in our data. As the special period was precipitated by well-documented political events, the beginning of the special period is reasonably well defined. The end of the special period is less clear-cut and, hence, we have used as our primary definition one based on a subjective measure of the point where the recovery of the national annual GDP returns to over 80% of the 1990 baseline (Figure 2) supported by the return of the daily per capita energy intake toward the 1990 baseline (17). However, regardless of the definition of the special period, the consistency of the associations observed in our sensitivity analyses demonstrates that these associations are real.

These results have some limitations that require consideration. Although in many parts of the world selective abortions of female fetuses are reported to influence the sex ratio at livebirth (32, 33), we do not consider this to be a likely explanation for the increase in the male:female ratio at livebirth observed in our data, because sex-specific abortions are not considered part of the culture of Cuba. This is supported by the baseline sex ratio at livebirth of approximately 1.06 (which is considered to be within the normal range) and the return of the male:female sex ratio to baseline values after the special period in Cuba had passed, which is not consistent with the cultural practice of feticide. Similarly, we are unable to adjust for potential changes in parental age (34), ethnicity (29), socioeconomic status (35), or family size (36) in Cuba in the 1990s—factors that may modify the offspring sex ratio.

A further limitation of our data is the use of routinely collected national statistics on sex ratio at livebirth and economic activity over a period of 49 years, 8 years of which constitute the special period. This permits crude associations to be observed but does not permit reliable establishment of causality, identification of the biologic processes involved, or the confident study of factors such as the rate of economic change or threshold of GDP at which these associations may occur. The study of the impact of environmental influences on the sex ratio in humans often utilizes historical data sets, where a well-defined population has been exposed to an event which is hypothesized to impact on the sex ratio, such as war (7), earthquake (37), and terrorist attacks (38). This is a consequence of the limited number of study designs available to investigate the impact of different environmental changes on the human sex ratio and the difficulties of confidently extrapolating data from animal models to humans. As a consequence, the biologic mechanisms by which the physiological and psychological impacts of environmental change modify the human sex ratio are unknown and, if present, probably differ according to the exposure and its time course. Environmental change may impact on the sex ratio at livebirth either by modifying the ratio at conception and implantation (primary sex ratio) or by modifying the sex ratio of abortion and of implanted fetuses (secondary sex ratio (39)). However, our data do not permit consideration of how the change in economic circumstances in Cuba may impact on these primary and secondary sex ratios. Ideally, we would have been able to determine the association between date of conception and the period of economic recession that would have given more detail on the potential mechanisms by which economic recession may impact on sex ratio, but as we did not have any data on individual birth dates, this was not possible. Similarly, we had data on only the sex ratio at livebirth and not on the gender of late-term miscarriages or stillbirths, which would have helped our analysis.

In summary, we report the association between a clearly defined time of prolonged economic depression and an increase in the male:female sex ratio at livebirth in a well-delineated population. These observations of a large, prolonged, and reversible impact on the sex ratio are contrary to the hypothesis of Trivers and Willard (1) that, in times of material scarcity and stress, the proportion of females born will increase. Hence, these data may be relevant in the modeling of demographic projections in areas that experience prolonged severe economic depression. However, the mechanism by which economic hardship may impact on the sex of livebirths is unknown.

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