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Sex Ratios, Family Size, and Birth Order

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In many countries, the male:female ratio at birth has varied significantly over the past century, but the reasons for these changes have been unclear. The authors observed a close parallel between decreasing family size and declining male:female sex ratio in Denmark from 1960 to 1994. To explain this finding, they examined the sex ratio and birth order of 1,403,021 children born to 700,030 couples. Overall, 51.2% of the first births were male. However, families with boys were significantly more likely than expected to have another boy (biologic heterogeneity). By the fourth birth to families with three prior boys, 52.4% were male. The increase varied directly with the number of prior boys (p for trend = 0.0007). Furthermore, couples with boys were more likely to continue to have children. In summary, the authors found that the declining male:female ratio in Denmark and probably other European populations is mainly attributable to three effects: declining family size, biologic heterogeneity, and child sex preference. Why families with boys are more likely to have additional boys is unknown. *Am J Epidemiol* 1999;150:957–62.

birth order; family characteristics; infant; reproduction; sex distribution; sex ratio

In Europe, the proportion of children born male has varied considerably over the past century. High male:female sex ratios followed both world wars. Since World War II, the proportion of male births in Denmark (1), Holland (2, 3), Germany (4), and England and Wales (5) has declined from about 51.6 percent in the 1950s to 51.3 percent in the 1990s. Similar findings have recently been reported for the United States and Canada (6, 7). Given the large populations involved, these declines are highly significant. Therefore, sex ratio has been proposed as a sentinel indicator of avoidable health exposures (7).

Until we conducted the present study, the reasons for this variation were unknown. Possible influences such as race, season of birth, smoking, parents' age at conception of the child, parents' handedness, fertility, artificial insemination, site of implantation, and parental illnesses have been reviewed comprehensively (8), but the data are generally inconclusive. The well-documented rise in male births during periods of war has been suggested to be related to nutritional intake, psychosocial issues, or coital frequency patterns (3, 4), although these factors would not account for the continuing trends. Recently, one group proposed that mother-father age differences are responsible (5), but this conclusion has not been confirmed (9). Our study also failed to confirm the relation to parental age differences (data not presented). Other investigators have suggested that unknown environmental toxins may selectively affect Y chromosome–bearing spermatozoa (1, 2, 6, 7). In part, resolution of the role of different influences is difficult because very large sample sizes are required for examination of the admittedly small impacts observed in various studies.

We examined 1960–1994 birth records from Denmark and obtained information on 700,030 couples who gave birth to single infants. In these data, we observed a relation between sex ratio and family size, as reflected in the average birth order of the infants delivered. To explain this relation, we examined the sex of infants at birth and found a subtle but significant interaction with birth order, that is, birth of a male increased the likelihood that the next child would be male.

MATERIALS AND METHODS

As family size increases, the average birth order increases. For example, if every family had only a single child, the average birth order would be 1; if every family had exactly two children, the average birth order for completed families would be 1.5 (half first births and half second births). Hence, declining average birth order reflects a smaller average family size.

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Records of the sexes and birth orders of the infants were obtained from Statistics Denmark, the agency responsible for collecting demographic data. Since differences in sex ratios were minute, sex distribution data were grouped by decade (except for 1990–1994) to provide robust numbers. Before 1974, birth order information included stillbirths. Since 1974, it has included only liveborn children, but data on stillbirths are collected separately. Estimates for livebirths only from 1940 to 1973 were made by subtracting a constant fraction of stillbirths from each birth order on the basis of the findings in the 1974 data, the earliest year for which all parameters were available. Stillbirth rates were higher in earlier years, especially during the 1940s and 1950s, resulting in a progressive deviation from the estimates from livebirths only. For livebirths and stillbirths since 1974, we adjusted the average birth order by adding stillbirths, by birth order, to the livebirths. Since stillbirths represented only a tiny fraction of all births since 1974, this adjustment had little influence on the results.

Since 1968, the Civil Registration System in Denmark has assigned unique personal identifiers to all residents. By using these data, we linked parents to their liveborn children born after the mid-1950s (10). Data from these families were examined to identify mothers born from 1945 to 1967 who bore children from 1960 to 1994. For computational reasons, we included only families with single births in which all children had the same mother and father.

Differences in the probability of having a boy and then another child were evaluated by using chi-square and trend tests. Confidence intervals for proportions and relative risks were estimated by using log-linear binomial regression. Few families had more than five children, and those strata were excluded. Family linkage was retrospective between 1960 and 1967 and prospective from 1968 to 1994. The conclusions were unchanged when we analyzed only those data collected prospectively (data not presented).

RESULTS

Family size

Figure 1 illustrates the close correlation between the average birth order of livebirths and the sex ratio of newborns, especially in recent years. In the 1930s, the male:female ratio was relatively low compared with the high average birth order. However, taking into account the higher number of stillbirths in the early period helped to restore the parallel between birth order and sex ratio during these years and made the relation even stronger in later years. Between 1930 and 1980, the rate of stillbirths declined from 2.5 percent to about 0.5 percent and then stabilized. The male:female sex ratio of stillbirths was about 58 percent in the 1930s and fell steadily to about 52 percent by 1994. Since a higher proportion of concepti were born alive in more recent years and more of the additional sur-

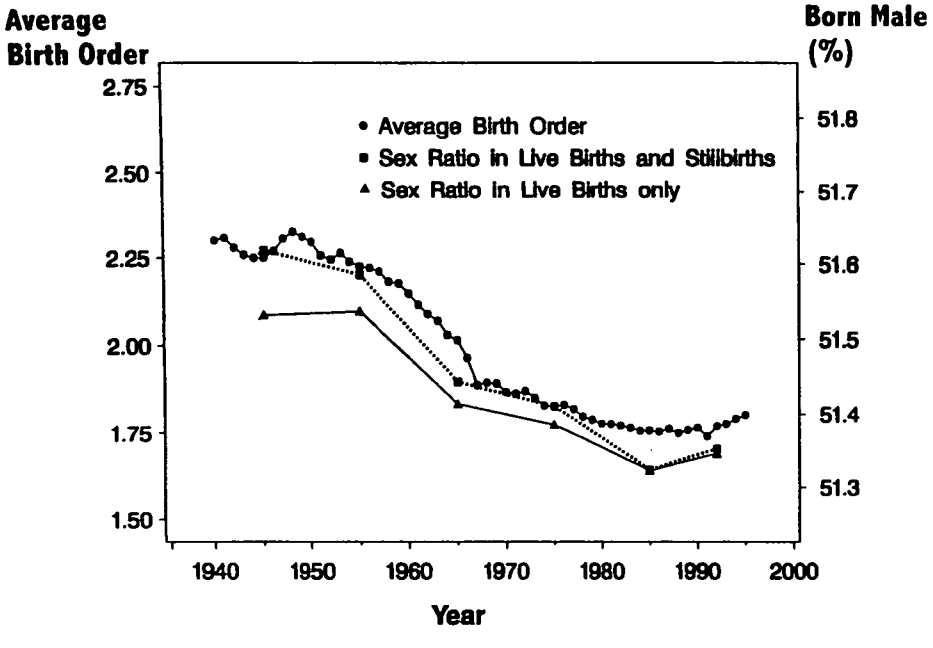

FIGURE 1. The average birth order of livebirths and of both stillbirths and livebirths (left axis) compared with the proportion born male (%) (right axis) during the same period. Data from Statistics Denmark, 1940–1994.

vivors were male, these trends should have contributed a higher proportion of liveborn male births during the later years of this study period. Despite this bias, the male:female ratio declined steadily.

Birth order

To understand how parity might affect the sex ratio, we examined the sex distribution of singleton livebirths in individual families by using data on 1,403,021 births to 700,030 Danish families between 1960 and 1994. Overall, each of these 700,030 women had at least one child, 510,902 had at least two children, 154,443 had at least three children, 31,595 had at least four children, and 6,046 had at least five children (table 1).

Table 2, derived from table 1, lists the proportion of males in each birth order stratum according to the sex of prior children in the family. Of first births, 51.2 percent were male (95 percent confidence interval: 51.1, 51.3). However, the probability of having another boy increased to 51.5, 51.6, 52.4, and 54.2 percent for families with one, two, three, or four prior boys, respectively (p for trend = 0.0007). The probability of having a boy as the next child was 54.2 percent for parents with four prior boys, but it was 47.8 percent for parents with four prior girls ($p = 0.049$). We consider this pattern to be due to biologic heterogeneity in the likelihood of having a boy, by which we mean that the probability of having boys or girls differs between couples.

To exclude an effect determined by families genetically restricted to having only male or female children,

TABLE 1. Numbers (and percentages*) of Danish families† having another child, given the sex of prior children, 1960–1994

Birth order‡			
First (n = 700,030)	Second (n = 510,902)	Third (n = 154,443)	Fourth (n = 31,595)
F:§ 341,522	248,641 (72.8%)		
	F: 121,801	38,184 (31.3%)	
		F: 18,770	4,169 (22.2%)
			F: 2,039
			M:§ 2,130
		M: 19,414	3,644 (18.8%)
			F: 1,741
			M: 1,903
	M: 126,840	35,373 (27.9%)	
		F: 16,814	3,498 (20.8%)
			F: 1,738
			M: 1,760
		M: 18,559	3,810 (20.5%)
			F: 1,839
			M: 1,971
M: 358,508	262,261 (73.2%)		
	F: 127,123	35,842 (28.2%)	
		F: 17,680	3,629 (20.5%)
			F: 1,826
			M: 1,803
		M: 18,162	3,693 (20.3%)
			F: 1,715
			M: 1,978
	M: 135,138	45,044 (33.3%)	
		F: 21,808	3,998 (18.3%)
			F: 2,010
			M: 1,988
		M: 23,236	5,154 (22.2%)
			F: 2,455
			M: 2,699

* Percentages are relative to the previous stratum.

† Data from 700,030 families who had 1,403,021 children in birth order cohorts of up to five births per family; data for the fifth birth order cohort not presented because of vertical space limitations.

‡ Total percentage of children born in each birth order stratum after the first: second, 73.0%; third, 30.2%; fourth, 20.5%; fifth (not shown), 19.1% (n = 6,046).

§ F, female; M, male.

TABLE 2. Sex ratio changes (given as % male*), by birth order, among Danish families† with one to five single births, 1960–1994

Birth order				
First	Second	Third	Fourth	Fifth
51.2%	Prior F‡: 51.0%§ M	Prior FF: 50.3% M	Prior FFF: 51.1% M	Prior FFFF: 47.8% M
				Prior FFFM: 55.1% M
			Prior FFM: 52.2% M	Prior FFMF: 52.8% M
				Prior FFMM: 49.6% M
		Prior FM: 52.5% M	Prior FMF: 50.3% M	Prior FMFF: 52.1% M
				Prior FMFM: 60.3% M
			Prior FMM: 51.7% M	Prior FMMF: 53.2% M
				Prior FMMM: 55.2% M
	Prior M: 51.5% M	Prior MF: 50.7% M	Prior MFF: 49.7% M	Prior MFFF: 47.7% M
				Prior MFFM: 49.9% M
			Prior MFM: 53.6% M	Prior MFMF: 53.2% M
				Prior MFMM: 55.9% M
		Prior MM: 51.6% M	Prior MMF: 49.7% M	Prior MMFF: 50.8% M
				Prior MMFM: 50.0%M
			Prior MMM: 52.4% M	Prior MMMF: 47.6% M
				Prior MMMM: 54.2% M

* Percentage of male (M) children in each birth order stratum after the first: second, 51.3%; third, 51.4%; fourth, 51.4%; fifth, 52.2%.

† Prior children born to the same couple are shown in the order born.

‡ F, female.

§ The columns show the numbers of males and females born prior to the birth shown. Here, for example, of those families with one prior female, 51.0% of the next children born were male.

we further examined families that already included both boys and girls. The probability of a newborn being male was greater if the child born immediately before the newborn was also male rather than female ($p < 0.0001$). For example, of fourth children born to mixed-sex families with three children, 52.5 percent were boys when the third child was a boy compared with 49.9 percent when the third child was a girl (relative risk = 1.05, 95 percent confidence interval: 1.03, 1.07).

To understand the population impact of these findings, changes in family size over time need to be considered. If all deliveries were first-born infants only, then 51.21 percent of infants would be males, according to our data. If it is assumed that parents with the same biologic heterogeneity have another child according to the same pattern that occurs in Denmark, the proportions of all children born male would increase to 51.28 and 51.39 percent, respectively, for second- and third-born children. The net effect on all births (i.e., including a mix of birth-order strata) would be less apparent than in each separate stratum of birth order; clearly, however, as the average parity of mothers giving birth increases, the proportion of children born male will increase.

Parental sex preferences

To understand the population impact of family size on sex ratios at birth, the extent to which the sex of prior children affects reproductive decisions must also be evaluated. Parents with children of only one sex may be satisfied, or they may have another child in the hope of having one of the desired sex. In Denmark, parents were less likely to have another child once the family included both a boy and a girl (table 1; $p < 0.0001$), suggesting that they chose family size in part on the basis of the sex distribution of their children. However, parents whose first child was a boy had a second child 0.4 percent more frequently than those whose first child was a girl (table 1; $p < 0.001$). Similarly, couples with two boys first had a third child 2.0 percent more frequently than those who had two girls first ($p < 0.0001$).

For every age group of mothers, the proportion having a second child was consistently higher if the first child was a boy rather than a girl (data not shown). Similar results were observed for mothers of all ages regarding the decision to have a third child after having two boys rather than two girls. After we considered the waiting period to the next birth and adjusted for maternal age, differences in parental ages, parity, and calendar time period did not change these tendencies.

These reproductive decisions have an impact on the population's sex ratio at birth. When families with only boys have additional children more frequently than those with only girls, the proportion of children born male increases even more rapidly, because these families with boys are more likely to have another boy than are families with girls only. However, this effect is

small compared with the influence of the sex of previous children. Even together, both effects are small compared with the effect of family size.

DISCUSSION

Our data show that as family size decreased in Denmark, the male:female ratio of newborns also decreased. Since the 1950s, family size has been declining throughout Europe (1–5). A substantial proportion of the decline in sex ratio appears to be a consequence of smaller family sizes in recent years.

In investigating this relation, we found that couples with boys had a higher likelihood of having additional boys. As the number of prior boys in the family increased, the likelihood of having another boy increased. We attribute this variability to biologic heterogeneity in the likelihood of having a boy. If there were no such heterogeneity (i.e., if each couple had a constant likelihood of having boys), then there would be no impact, regardless of family size or sex preference decisions. Our data show that this cannot be the case, since we found highly significant effects. Therefore, couples must be heterogeneous in their likelihood of having male children. This relation existed throughout the entire time period for which we had data and is probably a biologic phenomenon.

It is somewhat surprising that such a basic biologic observation has not been long known. However, the effect was very small, and determining that it was statistically significant required data from a very large number of families. Until recently, large sets of family-linked data have not been available. In a Norwegian study, family structure was computerized for births that occurred between 1950 and 1985 (11). Those data also show the influences of the sex of prior children on the proportion born male. At the fourth birth, for example, the probability of the next child being a boy was 52.7 percent for parents of four boys but only 49.6 percent for parents of four girls. Norwegians, like Danes, were also more likely to stop having children when they had mixed-sex families. However, families who had only boys were more common in Norway than in Denmark, suggesting a slight preference for boys in Norway during the years of that study. We are not aware of reports of other family-linked data from large populations.

Denmark and Norway are likely to be typical of other northern European populations, but other populations could be quite different. Even if they have the same biologic heterogeneity in having boys as Denmark does (which remains to be shown for other populations), differences in sex preferences will still affect the population sex ratio of newborns. Finally, the overall impact of biologic heterogeneity and sex preferences on sex ratio will be less pronounced in societies with small families than in those with large families.

We noted that the sex ratio was lower than expected during the early years of the study period, given the high average birth order. The birth order for 1930–1960 livebirths was derived as described in Materials and Methods, and the average birth order almost certainly was overestimated for the early years because we did not adequately adjust for the higher stillbirth rates during those years. Inclusion of recorded stillbirths considerably improved the relation, as shown in figure 1. We postulate that the higher rate of stillbirths during this era probably indicates a higher rate of fetal deaths even earlier in pregnancy. Abortions and miscarriages are much more common than stillbirths. Women who miscarry early in pregnancy typically do not realize that they were pregnant; thus, the sex of the lost conceptus is unknowable. Elective abortions that were based on the sex of the fetus theoretically could have influenced our results (12). However, determining sex in utero became routinely possible in the late 1970s, whereas the effect of the sex of prior children was present in the 1960s and earlier.

The impact of biologic heterogeneity depends not only on family size but also to a lesser extent on how preferences for having a child of a specific sex influence decisions to continue to have children. When couples with children nonrandomly continue to have children on the basis of the sex of their prior children, later births progressively oversample subgroups with different biologic heterogeneity. In Denmark, for example, the preference we found for girls means that families with boys, who are more likely to have additional boys, were oversampled in later birth order cohorts. However, in a model that adjusted the data by assuming no sex preference, according to the methods of Skjærven et al. (13), we found that sex preference did not explain the association between family size and sex ratio (data not presented).

Thus, declining family size in conjunction with biologic heterogeneity is most important in lowering the male:female sex ratio, and sex preference contributes to a lesser extent. On the basis of stillbirth data, we further postulate that improving maternal health, in which more concepti survive to become liveborn, also has an important impact. However, since the sex distribution of very early fetal losses is unknown, we had insufficient data to measure this contribution.

These results argue against hypotheses evoking Y chromosome toxins and other environmental influences to explain recent trends, since our findings explain the changes in sex ratio that raised such con-

cerns. Future investigations pursuing such hypotheses should examine trends in first births only to eliminate the family size, biologic heterogeneity, and sex preference influences we found. However, the increasing likelihood of having boys following the birth of prior boys remains an enigma.

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