Latitude Gradients and Secular Trends in Sex Ratios at Birth: Europe and North America and a Global Overview

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ABSTRACT

Objective: In all continents, latitude gradients and secular trends have been found in the male-female ratio at birth (M/F: male births divided by total births), which is anticipated to approximate 0.515.

Methods: Annual national data for countries comprising Europe and North America for male and female live births were obtained from the World Health Organisation and analysed with contingency tables.

Results: This study analysed 397278548 live births. An overall decreasing trend in M/F was found ($p < 0.0001$). A latitude gradient was also noted, with more males being born in southern, warmer latitudes in Europe. The converse occurred in North America, with more males born in northern latitudes ($p < 0.0001$). There was an overall deficit of 2053687 male births based on an anticipated M/F of approximately 0.515. The declining M/F trend has reversed over 2000-9 in Mexico stabilised in the United States. M/F in the North American continent was unaffected following the Chernobyl event of 1986. There was a significant rise in M/F in Central Europe only in 1987 returning to the previous baseline over the following two years.

Conclusion: M/F is decreasing in Europe and North America, in contrast with the rising M/F previously found in Asia, South America and the post-Soviet states. The North American M/F latitude gradient is similar to that found in South America, with increasing M/F in higher and colder latitudes. Europe's latitude gradient is similar to that of Asia's, with more males born closer to the equator. No facile explanation/s for these findings are apparent.

Keywords: Birth rate/*trends, Europe, infant, newborn, North America, sex ratio

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INTRODUCTION

In humans, gender is determined at conception and male births occur slightly in excess (1, 2). The male to female ratio of live births is expressed (albeit technically incorrectly) as the ratio of male live births divided by total live births (M/F).This is expected to approximate 0.515 in humans, with 3% more liveborn boys than girls (1, 2). The reason/s for this discrepancy are uncertain but the factors that have been implicated as causing this imbalance and influencing it are legion (1, 2).

The maternal and paternal exposure to most toxins and stressors results in a male deficit (1, 2), and this is explained by the Trivers–Willard hypothesis which argues that females in poor condition are somewhat likelier to produce female offspring as these are more likely to survive into adulthood and reproduce, passing on their maternal genetic heritage (3). This is achieved through preferential, gender-selective spontaneous abortions in the context of stressful ambient conditions. This selects female over male offspring. Thus, such mothers are less likely to produce frail male offspring that may not survive to reproductive age, and who, if surviving to adulthood, would have to compete against other males. On the other hand, females in good condition are likelier to select for male offspring as under favourable conditions, males can sire large numbers of offspring. The only adverse environmental factor which consistently elevates M/F is radiation (4).

Secular variation in M/F

M/F is known to undergo secular variations (5), and several studies have shown that M/F is declining in the Europe and North America (6).

Latitude variation in M/F

M/F has also been shown to exhibit a latitude gradient. M/F increases with decreasing latitude in Europe and increases with increasing latitude in the North American continent (7, 8).

Chernobyl

Radiation is known to increase M/F and this has been broadly shown in Europe after the Chernobyl disaster of 1986 (9).

This study identifies secular trends and latitude gradients in M/F in Europe and North America, and compares these with trends recently described trends in other continents over the past 60 years. Any potential effects of the Chernobyl event are also sought.

METHODS

Data sources

All data analysed (and compared in the discussion) is derived from a World Health Organization (WHO) dataset. Some missing years were acquired from the Eurostat online database (10). Annual male and female live births were obtained directly from a WHO mortality database (WHO Statistical Information System - WHOSIS) for the period 1950-2009 (11).

Geographical division

Countries were allocated as per table 1. Missing data was acquired from the Eurostat online database. Residual missing years are indicated.

Mater Dei Hospital and the Malta Medical School do not have an Institutional Review Board (IRB), so approval could not be sought from said board. Ethical approval was not required as this study analysed a large and anonymous WHO database.

Statistics

Excel was used for data entry, overall analysis and charting. The quadratic equations of Fleiss were used for exact calculation of 95% confidence intervals (CI) for ratios (12). Chi tests and chi tests for trends for annual male and female births were applied by using the Bio-Med-Stat

Excel add-in. Excel's slope() function was used to determine direction of trends (increasing or decreasing M/F). The null hypothesis is that there were no significant geographical or secular differences in M/F. A p value ≤ 0.05 was taken to represent a statistically significant result.

RESULTS

Secular trends

This study analysed 397278548 live births. Five year total live births and sex ratios at births, in 5 year intervals, are shown in table 2. An overall decreasing trend in M/F was found in almost all regions (table 3).

Latitude gradients

A clear latitude gradient for M/F is seen in table 3 which is highly significant for both Europe (χ^2 for trend 27614, $p < 0.0001$) and for the North American Continent (χ^2 for trend 11533, $p < 0.0001$).

The gradients are in opposite directions. More males are born at southern, warmer latitudes in Europe while more males are born in colder, northerly latitudes in the North American continent (Figure 1). There was an overall deficit of 2053687 male births based on an anticipated M/F of approximately 0.515 (Table 3).

M/F trends have reversed in some regions over the last decade (2000-9), namely in the United States and in Mexico, although the former did not reach statistical significance (table 4).

Chernobyl

M/F in the North American continent was unaffected following the Chernobyl event of 1986. There was an upswing in M/F in Central Europe only in 1987 (figure 2), one year following the Chernobyl incident. This rise was significant (1986: males 2376490, females 2255616,

M/F 0.51350 (CI 0.51305-0.51259); 1987: males 2378456, females 2251222, M/F 0.51420 (CI 0.51374-0.51329); χ^2=4.5, p=0.035), returning to the previous baseline over the following two years.

DISCUSSION

Latitude variation in M/F

Latitude gradients in biological are not uncommon and not always explained. For example, it has been shown that the efficacy of the bacillus Calmette-Guérin vaccine in preventing tuberculosis varies by latitude (13).

M/F exhibits a variable latitude gradient. The gradient exhibited in the North American continent tallies with that of the South American continent (147773689 live births), where it has been shown that M/F increases with increasing distance from the equator (14). On the other hand, Asia (245938211 live births), which is a easterly continuation of the European landmass, exhibits a gradient direction that is similar to Europe's, with increasing M/F in warmer and more southerly latitudes (15).

The same dataset failed to show a latitude gradient within the Nordic countries (18250193 live births comparing Iceland, Norway, Sweden and Finland with the more southern Denmark) (16) and in the post-Soviet states (115167569 live births) (17). However, a latitude gradient following that of Europe was found within the ex-Yugoslavian states (22020729 live births), with more males born toward the southern parts of this region than to the north despite there being just 7 degrees of latitude spread in this region (18). Moreover, the European latitude gradient was reversed in the United Kingdom, with the M/F excess being greater in Scotland and Northern Ireland than in England, Wales and the Republic of Ireland (49263493 live births) (19).

Secular variation in M/F

M/F is declining in all regions studied in this paper except for Southern Europe, resulting is an overall male deficit of 2694268 births based on an anticipated M/F of 0.515. This trend is similar to that observed in Israel, Egypt and Kuwait (34644020 live births) (20). No such trends were observed in Australasia (17035325 live births) (21) while M/F is rising in Asia (15) and South America (14).

M/F increases in the setting of long periods of warfare (22) but decreases with short episodes of warfare (23) and in the presence of adverse environmental factors (24) including natural disasters such as smog and floods (25), earthquakes (26), collapsing economies (27) or even due to terrorist attacks such as the September 11 events (28).

An environment that exposes women to toxins and adverse events appears to encourage such women to spontaneously abort male fetuses in excess of female foetuses (3). This has been mooted as a potential explanation for the currently observed declining M/F in North America and Europe. It is for this reason that M/F has been proposed as a surrogate sentinel health indicator (29). However, studies dealing with M/F over the past 250 years indicate that the currently experienced decline in M/F commenced prior to industrialisation and its concomitant widespread industrial pollution (30).

Chernobyl

This paper confirms that M/F rose transiently in Central Europe after Chernobyl, highlighting the potential widespread effects of radiation on M/F.

CONCLUSION

This study further extends the understanding of latitude gradients and secular trends in M/F. But to date, no reasonable explanation/s have been posited for the observed latitude variations

in M/F, and the theory that associated the decline in M/F with increasing industrialisation and its ensuing pollution remains an untested hypothesis.

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Table 1: Countries available for analysis, geographical distribution and missing years

	Data from Eurostat	Missing years
Nordic and Baltic countries (>55°)		
Finland, Iceland, Norway, Sweden, Latvia		
Denmark	2007-9	
Estonia		1950-1980,1984
Lithuania		1950-1980,1984
Central Europe (40-55°):		
Germany, Austria, Hungary, Netherlands, Poland		
Czechoslovakia (and from 1993, Slovakia and the Czech Republic)		
Belgium	2008-9	
France	2009	
Luxembourg	2009	
Romania		1950-54
Switzerland	2008-9	
UK & Eire	2007-9	
Yugoslavia (and from 1991, Slovenia, Croatia, Serbia and Montenegro and Macedonia)	2007-9	Serbia and Montenegro: 1991, 2004-6
Southern countries (35-40°)		
Bulgaria, Greece, Malta, Portugal		
Italy		2005
Spain	2009	1970
North American Continent		
Canada (>50°), United States (30-50°)		
Mexico (<30°)		1950-57

Table 2: 5 year totals for available regions. Countries in European regions as per table 1 (CI: confidence intervals).

		1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	Total
Nordic	**M**	894174	864619	870554	885565	805951	728664	902092	1047870	1069732	911245	881206	937052	10798724
countries	**F**	842732	815611	822714	835599	755730	690544	856069	993021	1016616	863307	834606	889821	10216370
and	**Total**	1736906	1680230	1693268	1721164	1561681	1419208	1758161	2040891	2086348	1774552	1715812	1826873	21015094
Baltic	**UCI**	0.5156	0.5153	0.5149	0.5153	0.5169	0.5143	0.5138	0.5141	0.5134	0.5142	0.5143	0.5137	0.5141
States	**M/F**	0.5148	0.5146	0.5141	0.5145	0.5161	0.5134	0.5131	0.5134	0.5127	0.5135	0.5136	0.5129	0.5139
(>55°)	**LCI**	0.5141	0.5138	0.5134	0.5138	0.5153	0.5126	0.5123	0.5128	0.5121	0.5128	0.5128	0.5122	0.5136
Central	**M**	13142479	14212298	14246921	14027744	12835899	12071401	12069259	11848041	10849471	10024168	9469585	9568144	144365410
Europe	**F**	12352908	13390036	13455285	13257630	12116131	11395734	11431821	11236150	10284451	9490088	8977887	9086449	136474570
(40-55°)	**Total**	25495387	27602334	27702206	27285374	24952030	23467135	23501080	23084191	21133922	19514256	18447472	18654593	280839980
	UCI	0.5157	0.5151	0.5145	0.5143	0.5146	0.5146	0.5138	0.5135	0.5136	0.5139	0.5136	0.5131	0.5141
	M/F	0.5155	0.5149	0.5143	0.5141	0.5144	0.5144	0.5136	0.5133	0.5134	0.5137	0.5133	0.5129	0.5140
	LCI	0.5153	0.5147	0.5141	0.5139	0.5142	0.5142	0.5134	0.5130	0.5132	0.5135	0.5131	0.5127	0.5140
Southern	**M**	5056707	5204219	5464426	5433908	4866745	4848583	4015760	3500504	3252696	3047078	3236996	3196073	51123695
Europe	**F**	4767497	4926275	5162257	5139793	4589646	4553725	3764256	3285256	3057236	2864856	3043754	3007002	48161553
(35-40°)	**Total**	9824204	10130494	10626683	10573701	9456391	9402308	7780016	6785760	6309932	5911934	6280750	6203075	99285248
	UCI	0.5150	0.5140	0.5145	0.5142	0.5150	0.5160	0.5165	0.5162	0.5159	0.5158	0.5158	0.5156	0.5150
	M/F	0.5147	0.5137	0.5142	0.5139	0.5147	0.5157	0.5162	0.5159	0.5155	0.5154	0.5154	0.5152	0.5149
	LCI	0.5144	0.5134	0.5139	0.5136	0.5143	0.5154	0.5158	0.5155	0.5151	0.5150	0.5150	0.5148	0.5148
Canada	**M**	1031319	1187267	1202824	981174	911350	928272	957515	965920	1017136	909220	853227	935153	11880377
(>50°)	**F**	974347	1123639	1139802	929982	859162	876651	906606	920081	963026	863172	809474	888253	11254195
	Total	2005666	2310906	2342626	1911156	1770512	1804923	1864121	1886001	1980162	1772392	1662701	1823406	23134572
	UCI	0.5149	0.5144	0.5141	0.5141	0.5155	0.5150	0.5144	0.5129	0.5144	0.5137	0.5139	0.5136	0.5137
	M/F	0.5142	0.5138	0.5135	0.5134	0.5147	0.5143	0.5137	0.5122	0.5137	0.5130	0.5132	0.5129	0.5135
	LCI	0.5135	0.5131	0.5128	0.5127	0.5140	0.5136	0.5129	0.5114	0.5130	0.5123	0.5124	0.5121	0.5133
USA	**M**	9778703	10713451	10660242	9204730	8638655	8444148	9321054	9875918	10384560	10015490	10391066	10798535	118226552
(30-50°)	**F**	9292764	10200326	10158806	8755725	8204035	8022147	8884120	9401052	9902580	9557457	9917409	10299961	112596382
	Total	19071467	20913777	20819048	17960455	16842690	16466295	18205174	19276970	20287140	19572947	20308475	21098496	230822934
	UCI	0.5130	0.5125	0.5123	0.5127	0.5131	0.5131	0.5122	0.5125	0.5121	0.5119	0.5119	0.5120	0.5123
	M/F	0.5127	0.5123	0.5120	0.5125	0.5129	0.5128	0.5120	0.5123	0.5119	0.5117	0.5117	0.5118	0.5122
	LCI	0.5125	0.5121	0.5118	0.5123	0.5127	0.5126	0.5118	0.5121	0.5117	0.5115	0.5114	0.5116	0.5121
Mexico	**M**		1559743	4407087	5107061	6049989	5329441	4559016	6731112	7066522	6843640	6743938	6486241	60883790

(<30°)	**F**	1477441	4159606	4863966	5869843	5159892	4418639	6509517	6963152	6748949	6796424	6453351	59420780
	Total	3037184	8566693	9971027	11919832	10489333	8977655	13240629	14029674	13592589	13540362	12939592	120304570
	UCI	0.5141	0.5148	0.5125	0.5078	0.5084	0.5081	0.5086	0.5039	0.5037	0.4983	0.5015	0.5062
	M/F	0.5135	0.5144	0.5122	0.5076	0.5081	0.5078	0.5084	0.5037	0.5035	0.4981	0.5013	0.5061
	LCI	0.5130	0.5141	0.5119	0.5073	0.5078	0.5075	0.5081	0.5034	0.5032	0.4978	0.5010	0.5060

Table 3: Secular trends in M/F. Countries in European regions as per table 1 (CI: confidence intervals)

	χ^2	p	Slope	Trend	Total males	Total females	Total	Male deficit	Expected males	LCI	MF	UCI
Nordic countries and Baltic States (>55°):	34.2	<0.0001	-3.7E-05	Decreasing	10798724	10216370	21015094	24049	10822773	0.5136	0.5139	0.5141
Central Europe (40-55°):	483.6	<0.0001	-3.8E-05	Decreasing	144365410	136474570	280839980	267180	144632590	0.5140	0.5140	0.5141
Southern Europe (35-40°):	106.6	<0.0001	2.81E-05	Increasing	51123695	48161553	99285248	8208	51131903	0.5148	0.5149	0.5150
All Europe	232.9	<0.0001	-2.3E-05	Decreasing	206287829	194852493	401140322	299437	206587266	0.5142	0.5143	0.5143
Canada (>50°)	11.7	0.000623	-2.1E-05	Decreasing	11880377	11254195	23134572	33928	11914305	0.5133	0.5135	0.5137
USA (30-50°)	76.4	<0.0001	-1.7E-05	Decreasing	118226552	112596382	230822934	647259	118873811	0.5121	0.5122	0.5123
Mexico (<30°)	9204.2	<0.0001	-0.0003	Decreasing	60883790	59420780	120304570	1073064	61956854	0.5060	0.5061	0.5062
All North America	5402.6	<0.0001	-0.00011	Decreasing	190990719	183271357	374262076	1754250	192744969	0.5103	0.5103	0.5104

Table 4: Secular trends in M/F for 2000-9. Countries in European regions as per table 1 (CI: confidence intervals)

	χ^2	p	Slope	Trend
Nordic countries and Baltic States (>55°):	0.8	ns	-0.00009	Decreasing
Central Europe (40-55°):	5.8	0.016	-0.00007	Decreasing
Southern Europe (35-40°):	1	ns	-0.00005	Decreasing
All Europe	6.7	<0.0001	-0.00006	Decreasing
Canada (>50°)	0.3	ns	-0.00005	Decreasing
USA (30-50°)	0.7	ns	0.00002	Increasing
Mexico (<30°)	102.3	<0.0001	0.00036	Increasing
All North America	78.6	<0.0001	0.00018	Increasing

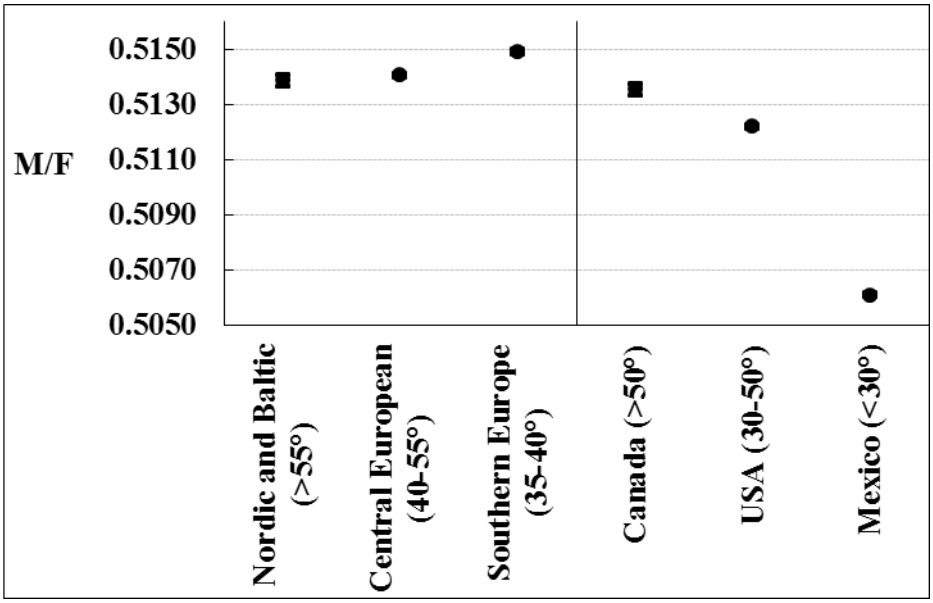

Fig. 1: M/F by latitude for Europe and North America.

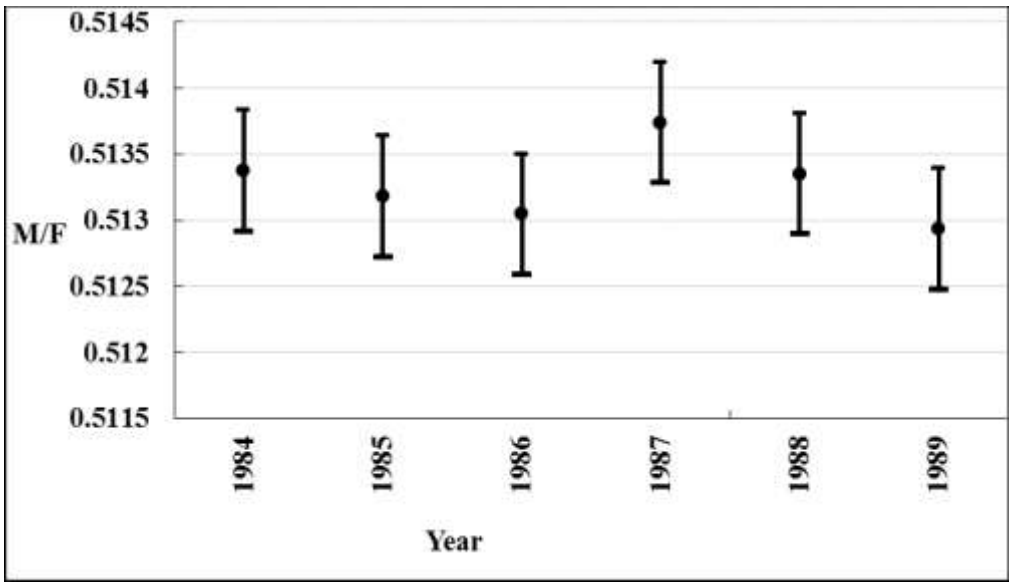

Fig. 2: M/F in Central Europe (countries as per table 1) for the period around the Chernobyl incident (1986).