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Atomic bomb testing and its effects on global male to female ratios at birth

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Abstract.
AIMS: Fallout from atomic bomb testing may travel great distances before precipitating. Males are born in excess of females in a ratio that approximates 0.515 (M/T: male live births divided by total live births. Radiation increases M/T by causing lethal malformations that affect female more than male foetuses, decreasing total births. This study was carried out in order to ascertain whether the effects of increased background radiation levels from atomic weapon testing had any widespread effects on M/T and births in the Americas, Europe, Asia and Australasia in relation to the Partial Test Ban Treaty of 1963.
METHODS: Annual live births by gender were obtained from a World Health Organization dataset and annual number of atomic bomb tests were also obtained (historical data).
RESULTS: Overall, 94.5% of births studied showed a uniform reduction in M/T between the early 1950s to the late 1960s, followed by an increase to the mid-1970s, with a subsequent decline. A negative correlation of M/T with total births was found in 66% of births studied, and these were the regions which exhibited the rising M/T pattern in the 1970s. The birth deficit for countries with significant correlations of total births with M/T (North America, Europe and Asia) was estimated at 10090701.
CONCLUSIONS: A rising M/T was found in most regions in temporal association with atomic weapon testing. Most of these regions also had an associated decline in total births. Elevated levels of man-made ambient radiation may have reduced total births, affecting pregnancies carrying female pregnancies more than those carrying male pregnancies, thereby skewing M/T toward a higher male proportion.

Keywords: Birth Rate/*trends, radiation, ionizing, sex ratio, infant, newborn

1. Introduction

The atomic era was ushered in by the Trinity test explosion at Alamogordo in New Mexico in July 1945 [1]. The above-ground detonation of nuclear devices deposits substantial quantities of radioactive particles into the atmosphere to very high elevations. While larger and heavier particles tend to drop out close to the site of the explosion, smaller and lighter particles may remain aloft for decades and travel great distances before depositing out of the atmosphere spontaneously or via rainfall, as fallout, widely distributing radiation and increasing background radiation counts [2]. Fallout consists of hundreds of different radionuclides with variable half-lives ranging from minutes to many years. Exposure to fallout

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may occur from the deposition of radioactive particles on the skin or by internal contamination from particles that are ingested or inhaled.

Males are born in excess of females in a ratio that approximates 0.515 (M/T: male live births divided by total live births) [3]. A plethora of factors have been shown to affect M/T, with stress and toxins both decreasing M/T [3–5]. Radiation is one of the few toxins that increases M/T [6, 7]. This has been clearly shown in relation to the Chernobyl disaster of 1988 and the Windscale fire of 1957, which were both associated with an upward M/T shift and a decrease in total births in affected regions [6–10]. The phenomenon of increased M/T also been shown in births that occur in proximity to nuclear facilities [7, 8].

However, worldwide artificial increases in ambient radiation levels preceded the above events. This is because after the Second World War, widespread atmospheric atomic bomb testing continued up to 1963 when the United Kingdom, United States and the Soviet Union ratified the Limited Test Ban Treaty, pledging to refrain from testing nuclear weapons in the atmosphere, underwater, or in outer space. However, the Treaty permitted underground nuclear testing, and leaks from such tests into the atmosphere were not uncommon [11]. France continued atmospheric testing until 1974, and China continued until 1980, with a total of over 2000 devices tested [12].

The worldwide annual average population radiation exposure to natural sources is 2.4 mSv [13]. The increase in background radiation due to atomic tests alone peaked in 1962 and 1963 at about an additional 0.11 mSv per year worldwide (5% of the average background dose from all sources). After 1963, global background radiation levels fell progressively, down to 0.005 mSv per year by the year 2000 and exposure was mostly due to the isotopes ^{137}Cs, ^{90}Sr and ^{14}C [13].

In theory, increases in ambient radiation levels from atomic bomb testing could have led to a rise in M/T followed by a decline with a progressive reduction in atomic bomb testing and a waning of the effect of fallout, and these changes would be inversely correlated with total births. Indeed, several studies have indicated that this may have occurred [6, 7]. This study was carried out in order to ascertain whether the effects of increased background radiation levels had any widespread effects on M/T and births in the Americas, Europe, Asia and Australasia.

2. Methods

2.1. Data

Atomic bomb testing data was obtained from a catolog of these events [12]. Annual live births by gender were obtained from a World Health Organization dataset (WHO HFA (Health for All database)).

The three North American countries (Canada, USA and Mexico) were analysed separately for the period 1950–2009 (data for Mexico missing for 1950–58 and 1984). The Australasian dataset only included Australia and New Zealand (1950–2009).

Europe was analysed in three separate regions in a method that has already been established [14]. Scandinavia (54°–71° N) included Iceland, Norway, Sweden, Finland and Denmark (1950–2009). One extreme outlier was removed (Finland, 1971, M/T = 0.571). Central Europe (40–55° N) included Austria, Belgium, Czechoslovakia (and the amalgamation of its continuation as the Czech Republic and Slovakia), France, Germany, Hungary, Luxembourg, Netherlands, Poland, Switzerland, UK & Eire and Yugoslavia (1950–2009). Southern Europe (35–40° N) included Bulgaria, Greece, Malta, Portugal, Italy and Spain (1950–2009 – Spain missing 1970, Italy missing 2005).

For the remaining regions, countries were only included if sufficiently large spans of identical years of data were available for analysis. Asia included Singapore, Thailand, Philippines and Japan (1950–1979). South America (1955–79) was analysed in two separate regions in a method that has already been established [15]. The equatorial region (10° N-20° S) included Nicaragua, Costa Rica, Columbia and Venezuela. The southern region (>20° S) comprised Uruguay, Chile and Argentina.

2.2. Birth deficit testing

Birth deficits were calculated by comparing observed births within affected years (periods wherein M/T rose) with expected births. The latter were calculated by taking the mean of the previous and following 5 years relative to affected years, and multiplying this mean by the number of affected years. These short periods were chosen as it is known that M/T exhibits spontaneous secular fluctuation [16]. This methodology has been previously utilized for the calculation of birth deficits after the Chernobyl accident [10].

2.3. 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 for ratios [17]. SPSS was used for the calculation of Pearson correlations. Chi-square tests for trend were used for annual male and female births. These were performed using the Bio-Med-Stat Excel add-in for contingency tables [18], which is based on the original work by Cochran and Armitage [19, 20]. A p value ≤ 0.05 was taken to represent a statistically significant result. The null hypothesis was that there were no significant changes in M/T before and after the ratification of the Limited Test Ban Treaty.

3. Results

3.1. M/T patterns and atomic bomb tests

This paper studied 1033775478 live births. M/T data in 5 year intervals is shown in Table 1. Several regions (Canada, USA, Mexico, Central and Southern Europe and South America 10° N-20° S) display similar trends: an initial decline in M/T from the early 1950 s, followed by a rise in the 1960 s/70 s, with a decline thereafter. This rise is superimposed over an overall declining trend in M/T with almost all of these changes occurring at highly statistically significant levels (Table 2).

Asia exhibited a trimodal M/T pattern (Fig. 1). M/T rose up to 1957 (chi = 560.0, $p < 0.0001$), fell over 1957–59 (chi = 541.5, $p < 0.0001$), rose again between 1959 and 1962 (chi = 441.1, $p < 0.0001$), fell between 1962 and 1965 (chi = 194.5, $p < 0.0001$), rose over 1965–70 (chi = 88.0, $p < 0.0001$), and declined between1970–79 (chi = 276.6, $p < 0.0001$). M/T loosely followed the pattern of annual number of atomic bomb tests carried out worldwide and correlated significantly with this variable ($r = 0.4$, $p = 0.02$).

There was a continually rising trend in M/T for South America >20° S (1955–79, chi = 80.1, $p < 0.0001$). There were no significant trends related to the abovementioned eras for Scandinavia and Australasia.

Overall, 94.5% of the data showed a uniform reduction in M/T between the early 1950 s to the late 1960 s, followed by an increase to the mid-1970 s, with a subsequent decline.

Table 1
Regions and countries studied, in 5 year intervals

Canada (>50°N)							Scandinavia (>55°N)						
1950–54	1031319	974347	2005666	0.5142	0.5135	0.5149	1950–54	894174	842732	1736906	0.5148	0.5141	0.5156
1955–59	1187267	1123639	2310906	0.5138	0.5131	0.5144	1955–59	864619	815611	1680230	0.5146	0.5138	0.5153
1960–64	1202824	1139802	2342626	0.5135	0.5128	0.5141	1960–64	870554	822714	1693268	0.5141	0.5134	0.5149
1965–69	981174	929982	1911156	0.5134	0.5127	0.5141	1965–69	885565	835599	1721164	0.5145	0.5138	0.5153
1970–74	911350	859162	1770512	0.5147	0.5140	0.5155	1970–74	805951	755730	1561681	0.5161	0.5153	0.5169
1975–79	928272	876651	1804923	0.5143	0.5136	0.5150	1975–79	728664	690544	1419208	0.5134	0.5126	0.5143
1980–84	957515	906606	1864121	0.5137	0.5129	0.5144	1980–84	684980	649732	1334712	0.5132	0.5124	0.5141
1985–89	965920	920081	1886001	0.5122	0.5114	0.5129	1985–89	731274	693346	1424620	0.5133	0.5125	0.5141
1990–94	1017136	963026	1980162	0.5137	0.5130	0.5144	1990–94	813058	772708	1585766	0.5127	0.5119	0.5135
1995–99	909220	863172	1772392	0.5130	0.5123	0.5137	1995–99	729121	691903	1421024	0.5131	0.5123	0.5139
2000–04	853227	809474	1662701	0.5132	0.5124	0.5139	2000–04	714850	677261	1392111	0.5135	0.5127	0.5143
2005–09	935153	888253	1823406	0.5129	0.5121	0.5136	2005–09	656522	622981	1279503	0.5131	0.5122	0.5140
USA (30–50°N)							Central Europe (40-–55°N):						
1950–54	9778703	9292764	19071467	0.5127	0.5125	0.5130	1950–54	11891960	11184790	23076750	0.515322	0.5151	0.5155
1955–59	10713451	10200326	20913777	0.5123	0.5121	0.5125	1955–59	12022529	11329906	23352435	0.51483	0.5146	0.5150
1960–64	10660242	10158806	20819048	0.5120	0.5118	0.5123	1960–64	12372862	11691611	24064473	0.514155	0.5140	0.5144
1965–69	9204730	8755725	17960455	0.5125	0.5123	0.5127	1965–69	11948828	11301980	23250808	0.51391	0.5137	0.5141
1970–74	8638655	8204035	16842690	0.5129	0.5127	0.5131	1970–74	10825659	10226532	21052191	0.51423	0.5140	0.5144
1975–79	8444148	8022147	16466295	0.5128	0.5126	0.5131	1975–79	10003181	9452029	19455210	0.514165	0.5139	0.5144
1980–84	9321054	8884120	18205174	0.5120	0.5118	0.5122	1980–84	10174394	9648099	19822493	0.513275	0.5131	0.5135
1985–89	9875918	9401052	19276970	0.5123	0.5121	0.5125	1985–89	9971303	9466154	19437457	0.512994	0.5128	0.5132
1990–94	10384560	9902580	20287140	0.5119	0.5117	0.5121	1990–94	9554613	9066929	18621542	0.513095	0.5129	0.5133
1995–99	10015490	9557457	19572947	0.5117	0.5115	0.5119	1995–99	8820471	8362939	17183410	0.513313	0.5131	0.5135
2000–04	10391066	9917409	20308475	0.5117	0.5114	0.5119	2000–04	8497324	8065107	16562431	0.513048	0.5128	0.5133
2005–09	10798535	10299961	21098496	0.5118	0.5116	0.5120	2005–09	8685688	8255580	16941268	0.512694	0.5125	0.5129
							Southern European countries (35-–40°N):						
Mexico (<30°N)							1950–54	5056707	4767497	9824204	0.514719	0.5144	0.5150
1955–59	1559743	1477441	3037184	0.5135	0.5130	0.5141	1955–59	5204219	4926275	10130494	0.513718	0.5134	0.5140
1960–64	4407087	4159606	8566693	0.5144	0.5141	0.5148	1960–64	5464426	5162257	10626683	0.514217	0.5139	0.5145
1965–69	5107061	4863966	9971027	0.5122	0.5119	0.5125	1965–69	5433908	5139793	10573701	0.513908	0.5136	0.5142
1970–74	6049989	5869843	11919832	0.5076	0.5073	0.5078	1970–74	4866745	4589646	9456391	0.514651	0.5143	0.5150

1975–79	5329441	5159892	10489333	0.5081	0.5078	0.5084	1975–79	4848583	4553725	9402308	0.51568	0.5154	0.5160
1980–84	4559016	4418639	8977655	0.5078	0.5075	0.5081	1980–84	4015760	3764256	7780016	0.516163	0.5158	0.5165
1985–89	6731112	6509517	13240629	0.5084	0.5081	0.5086	1985–89	3500504	3285256	6785760	0.51586	0.5155	0.5162
1990–94	7066522	6963152	14029674	0.5037	0.5034	0.5039	1990–94	3252696	3057236	6309932	0.515488	0.5151	0.5159
1995–99	6843640	6748949	13592589	0.5035	0.5032	0.5037	1995–99	3047078	2864856	5911934	0.515411	0.5150	0.5158
2000–04	6743938	6796424	13540362	0.4981	0.4978	0.4983	2000–04	3236996	3043754	6280750	0.515384	0.5150	0.5158
2005–09	6486241	6453351	12939592	0.5013	0.5010	0.5015	2005–09	3196073	3007002	6203075	0.51524	0.5148	0.5156
Australasia							Asia						
1950–54	640046	607289	1247335	0.5131	0.5123	0.5140	1950–54	9778703	9292764	19071467	0.5127	0.5125	0.5130
1955–59	710029	672876	1382905	0.5134	0.5126	0.5143	1955–59	10713451	10200326	20913777	0.5123	0.5121	0.5125
1960–64	767396	725420	1492816	0.5141	0.5133	0.5149	1960–64	10660242	10158806	20819048	0.5120	0.5118	0.5123
1965–69	755638	716603	1472241	0.5133	0.5124	0.5141	1965–69	9204730	8755725	17960455	0.5125	0.5123	0.5127
1970–74	821175	780464	1601639	0.5127	0.5119	0.5135	1970–74	8638655	8204035	16842690	0.5129	0.5127	0.5131
1975–79	722200	683632	1405832	0.5137	0.5129	0.5145	1975–79	8444148	8022147	16466295	0.5128	0.5126	0.5131
1980–84	734879	696381	1431260	0.5134	0.5126	0.5143	1980–84	9321054	8884120	18205174	0.5120	0.5118	0.5122
1985–89	773750	734854	1508604	0.5129	0.5121	0.5137	1985–89	9875918	9401052	19276970	0.5123	0.5121	0.5125
1990–94	813294	769668	1582962	0.5138	0.5130	0.5146	1990–94	10384560	9902580	20287140	0.5119	0.5117	0.5121
1995–99	791803	750853	1542656	0.5133	0.5125	0.5141	1995–99	10015490	9557457	19572947	0.5117	0.5115	0.5119
2000–04	786535	746518	1533053	0.5131	0.5123	0.5138	2000–04	10391066	9917409	20308475	0.5117	0.5114	0.5119
2005–06	329547	312651	642198	0.5132	0.5119	0.5144	2005–09	10798535	10299961	21098496	0.5118	0.5116	0.5120
South America (10°N-20°S)							South America (>20°S)						
1955–59	2450260	2351287	4801547	0.5103	0.5099	0.5108	1955–59	2029194	1955716	3984910	0.5092	0.5087	0.5097
1960–64	2848154	2747856	5596010	0.5090	0.5085	0.5094	1960–64	2154030	2069928	4223958	0.5100	0.5095	0.5104
1965–69	3047898	2944481	5992379	0.5086	0.5082	0.5090	1965–69	2138211	2047280	4185491	0.5109	0.5104	0.5113
1970–74	3275831	3159163	6434994	0.5091	0.5087	0.5095	1970–74	2273019	2180379	4453398	0.5104	0.5099	0.5109
1975–79	3554924	3429134	6984058	0.5090	0.5086	0.5094	1975–79	2476848	2357465	4834313	0.5123	0.5119	0.5128

Table 2
M/T changes during different eras

	Overall decline			Initial decline			Rise			Final decline		
	Era	chi	*p*	Era	chi	P	Era	chi	*p*	Era	chi	*p*
Canada	1950–2009	11.7	0.0006	1950–67	6.2	0.01	1967–71	7.1	0.008	1971–2009	13.4	0.0002
USA	1950–2009	76.4	<0.0001	1950–64	21.2	<0.0001	1964–74	23.8	<0.0001	1974–2009	65.2	<0.0001
Mexico	1958–2009	9204.2	<0.0001	1958–70	375.1	<0.0001	1970–88	32.3	<0.0001	1988–2009	1155.1	<0.0001
Scandinavia	1950–2009	32.2	<0.0001	None present			None present			None present		
Central Europe	1950–2009	512	<0.0001	1950–63	66.6	<0.0001	1963–79	4.1	0.044	1979–2009	13.2	0.0002
Southern Europe	1950–2009	106.6	<0.0001	1950–74	0.18	ns	1974–84	27	<0.0001	1984–2009	12	0.0005
S. America 10° N-20° S	1955–79	10.0	0.001	1955–68	46.8	<0.0001	1968–79	0.3	ns	Data unavailable		
South America >20° S	1955–79	Overall increase, chi = 80.6, $p < 0.0001$								Data unavailable		
Australasia	1950–2009	None present		None present			None present			None present		

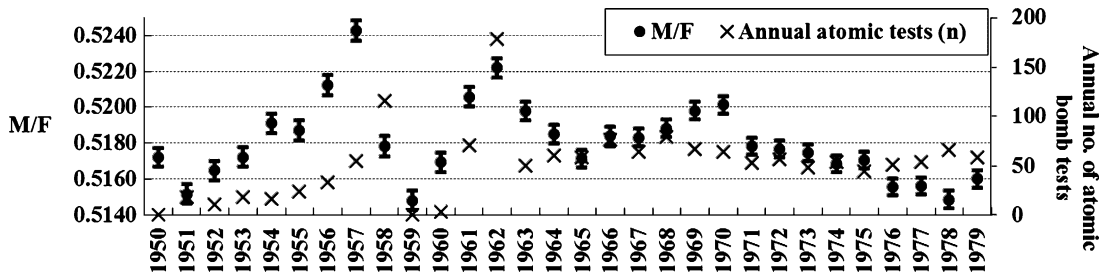

Fig. 1. Annual M/T vs. annual number of atmospheric atomic bomb tests for Asia, 1950–79.

Table 3
Correlations for M/T with live births for time periods as per second column in Table 2 (Asia 1950–2009)

	r	*p*
Canada	0.05	ns
USA	−0.51	<0.0001
Mexico	−0.75	<0.0001
Scandinavia	0.28	0.03
Central Europe	0.74	<0.0001
Southern Europe	−0.63	<0.0001
S. America 10° N-20° S	−0.34	ns
S. America >20° S	0.46	0.02
Asia	−0.39	0.03
Australasia	−0.2	ns

3.2. M/T and births

Annual M/T was correlated with annual births for each of the abovementioned regions (Table 3). Overall, 66% of the data showed a negative correlation of M/T with total births, and these were the regions which exhibited the abovementioned pattern, with rise in M/T in the 1970 s. A positive correlation was found in 27% of the data while 7% showed no correlation.

3.3. Birth deficits

South America was not included in birth deficit calculations as the rise in M/T continued to the end of the dataset. The birth deficit for the other countries in Table 3 with significant correlations of total births with M/T (North America, Europe and Asia) was estimated at 10090701 (Table 4).

4. Discussion

After the bombing of Hiroshima and Nagasaki in 1945, studies exhibited only partial evidence for an influence on M/T by radiation [21, 22]. However, it was shown that perinatal and infant mortality were more robustly associated with radiation exposure [23, 24].

Table 4
Calculation of birth deficit for countries with negative correlation of M/T with total births

	Affected yrs	Minus 5 yrs	Tot. births	Plus 5 yrs	Tot. births	Mean −5	Mean +5	Est. midpoint	Affected yrs (n)	Expected	Observed	Difference
Canada	1967–71	1962–66	2194680	1972–76	1754945	438936	350989	394963	5	1974813	1839026	135787
USA	1964–74	1959–63	21036354	1975–79	16466295	4207271	3293259	3750265	11	41252914	38830635	2422279
Mexico	1970–88	1965–69	9971027	1989–93	13746111	1994205	2749222	2371714	19	45062562	42007187	3055375
Central Europe	1963–79	1958–62	23658208	1980–84	19822493	4731642	3964499	4348070	17	73917192	73558405	358787
Southern Europe	1974–84	1969–73	9499499	1985–89	6785760	1899900	1357152	1628526	11	17913785	19222585	−1308800
Asia	1955–70	1950–54	16607961	1971–75	21727912	3321592	4345582	3833587	16	61337397	55910123	5427274 10090701

Affected yrs: Years when M/T rose as per table 3. Minus and plus 5 years: 5 years preceding and following affected yrs. Mean −5/+5: Mean of above. Est. midpoint: Mean of −5/+5. Affected yrs (n): No. of affected years (when M/T rose). Expected: Expected births=Est. midpoint × affected yrs. Observed: Actual births during affected births.

94.5% of the data in this paper appears to adhere to trends more recently described and attributed to a delayed increase in ambient radiation from fallout released and dispersed by atmospheric atomic weapons testing prior to the Partial Test Ban Treaty in 1963. The pattern consists of a uniform reduction in M/T between the early 1950 s to the late 1960 s, followed by an increase to the mid-1970 s, with a subsequent decline [7].

A report by the European Committee on Radiation Risk on infant mortality concluded that there was as a 2–3% increase in infant mortality per mSv of parental exposure (equivalent to a relative risk of 1.1 to 1.2/mSv per year) based on data for the period 1959–1963 [25]. Further evidence for radiation effects on stillbirths and certain birth defects from another study tallied with doses in the same ranges (1.3– 2.3/mSv per year) [26]. Indeed, this study has shown that in most regions, annual M/T correlated negatively with annual births. Moreover, this study has conservatively calculated a deficit of over 10 million births that may be attributed to ambient radiation effects from atomic weapon testing. The estimate was conservative as only eras wherein the M/T slope was positive where included, and the years immediately following these periods where the trend reversed were not included.

This study's findings indicate that elevated levels of man-made ambient radiation may have reduced total global births, affecting pregnancies carrying female foetuses more than those carrying male foetuses and thereby skewing M/T toward a higher male proportion. This is because ionising radiation is a unique toxin as maternal exposure produces the opposite effect to paternal exposure. Prospective fathers who are irradiated sire an excess of males [27], while prospective irradiated mothers give birth to an excess of females [21]. Radiation is also unique in that it appears to be the only toxin that elevates M/T when both genders are equally exposed [6].

It has been hypothesised that a radiation-induced X-linked recessive lethal gene in a mother's germ cell line would have no effect on a heterozygous daughter but would be lethal if passed on to a male zygote. Furthermore, X-linked recessive lethal mutations in mothers would shift M/T to favour female offspring. Moreover, X-linked dominant lethal mutations in mothers would be equally lethal to both genders [22]. X-linked dominant mutations induced in fathers would only inhibit female offspring. Recessive X-linked lethal mutations in fathers would not influence M/T as sons do not receive the paternal X-chromosome and daughters inherit a protective second X-chromosome from their mother [22].

M/T is therefore distorted by radiation through increased foetal mortality that affects female more than male conceptuses. It is speculated that the skew toward higher female mortality may be due to the fact that the X chromosome contains more genetic material and is larger, and hence, may be physically more easily hit by ionising radiation. Another possibility is that ova and sperm somehow afford their genetic material different levels of protection [6].

Earlier studies estimated approximately 8000 lost births from the Windscale fire of 1957 [9] and over two million births lost from the Chernobyl incident of 1986 [10]. It appears that mankind has also significantly altered M/T through atomic weapon testing. Living close to nuclear power plants has also been shown to increase M/T [7]. Furthermore, and unrelated to radiation effects, selective female foetal abortion in Asian cultures wherein males are preferred has led to an estimated 100 to 200 million missing women worldwide [28, 29]. Mankind's actions have therefore significantly depressed the species' female live-birth proportion.

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