Early Human Development 91 (2015) 841–850

Contents lists available at ScienceDirect

Early Human Development

journal homepage: www.elsevier.com/locate/earlhumdev

Best practice guidelines

Ionizing radiation and the human gender proportion at birth—A concise review of the literature and complementary analyses of historical and recent data

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ARTICLE INFO

Keywords:
Atomic bomb testing
Chernobyl
Ecological study
Ionizing radiation
Medical X-rays
Nuclear facilities
Radiation induced genetic effects
Radioactive fallout
Time trend and distance trend analyses
Windscale/Sellafield

ABSTRACT

It has long been known that ionizing radiation causes genetic mutations and that nuclear bomb testing, nuclear accidents, and the regular and incidental emissions of nuclear facilities enhance environmental radioactivity. For this reason, the carcinogenic and genetic impact of ionizing radiation has been an escalating issue for environmental health and human health studies in the past decades. The Windscale fire (1957) and the Chernobyl accident (1986) caused alterations to the human birth sex ratio at national levels across Europe, and childhood cancer and childhood leukemia are consistently elevated near nuclear power plants. These findings are generalized and corroborated by the observation of increased sex ratios near nuclear facilities in Austria, France, Germany, Luxembourg, Switzerland, and The Netherlands. We present a concise review of the pertinent literature and we complement our review by spatiotemporal analyses of historical and most recent data. Evidence of genetic damage by elevated environmental radioactivity is provided.

Contents

1. Introduction

Boys and girls are not born in equal proportions. In his famous publication "An argument for Divine Providence, taken from the constant regularity observed in the births of both sexes (1710)", the Scottish physician and polymath John Arbuthnot documented for the first time ever that in the long run significantly more boys than girls are born: for every 104 to 106 baby boys 100 baby girls come into the world. The birth ratio of human males to females (sex ratio or sex odds) appears to be subject to many determinants including biological, medical, behavioral, psychological, economical, and environmental factors [1–5]. From the sex determining mechanism in man, involving the X and the Y chromosomes (XX = female, XY = male), it is obvious that the sex ratio must necessarily depend among others on three factors:

- ratio of X- and Y-bearing sperm
- selection of sperm within the female reproductive tract
- differential implantation and survival rates of embryos.

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http://dx.doi.org/10.1016/j.earlhumdev.2015.10.012

In animal experiments it has been found that ionizing radiation can cause mutations of the genetic material and may alter the sex ratio [6,7]. Moreover, animal experiments disclose the complexity of radiation induced genetic effects: irradiation of female mice with fission neutrons by Russel et al. has shown that the length of the period between irradiation and conception has a strong effect on the mutation frequencies seen in the offspring [8]. In conceptions seven weeks after irradiation, mutation frequencies turned out to be relatively high. Havenstein et al. have shown that radiation exposure of spermatogonia resulted in a change of the sex ratio in the rat [9]. Therefore, radiation induced sex ratio changes may also be expected in humans by analogy. However, the transfer of effect estimates obtained in animal experiments to humans is controversial [10].

A multitude of determinants of the human male to female ratio at birth has been suggested from historical times to date [11]. Based on the well-known asymmetric chromosomal sex determining mechanisms in living beings, the possibility of sex odds shifts in environmentally or occupationally exposed human populations was considered in the scientific community since the discovery of the mutagenic and carcinogenic properties of chemicals and ionizing radiation in animal experiments and in epidemiology [12]. Medical treatment with X-rays also raised concern whether it could impact the sex ratio in offspring of exposed parents or as a side-effect in the children of the exposed medical staff [13,14]. Initial positive evidence of radiation induced sex odds changes in humans was obtained after the atomic bombing of Japan [15].

In the aftermath of the Chernobyl accident, stillbirths, and congenital malformations increased across Europe [16–21]. This indication of detrimental genetic effects after Chernobyl prompted investigations whether the birth sex ratio at the district level or at the national level had also increased after Chernobyl with emphasis on the local or global variation of radioactive fallout. Initial pilot studies with positive findings were later extended to open more global national or even continental perspectives [22–24]. Evidence of causality results in those studies from temporality (effect after exposure) as well as from exposure–response relations at local or global ecological data levels: lower or higher exposed districts, states, countries, or continents show lower or higher sex ratios, respectively. To illustrate the corresponding data and the statistical methodology, a typical spatiotemporal exposure–response relation will be exemplified and visualized in this review by a synoptic analysis [22] of the annual gender specific birth data from Austria in the period 1973 to 2000, i.e. 14 years before and 14 years after the Chernobyl accident in April 1986.

More recently, a number of further studies with positive findings were carried out concerning accidental, professional, and environmental exposure in or by the nuclear or medical industries: the Windscale/Sellafield complex [25,26], exposure by nuclear testing (Kazakhstan) [27], living near nuclear facilities (Germany, France, and Switzerland) [28,29], and radiation exposure in medical professions [14]. Moreover, it has been suggested and evidenced that the seasonality of the sex ratio [30], and the well-known sex ratios' dependency on rain [31], might actually be due to elevated environmental radioactivity due to rainfall, which leads to precipitation of atmospheric radionuclides [32].

Overwhelming evidence has accumulated that low-dose ionizing radiation raises the birth sex ratio in man in a more or less linearly dose dependent manner. Spermatogenesis and early human embryogenesis are vulnerable and error prone processes, which are sensitive to low-dose ionizing radiation before and around fertilization affecting epigenetic reprogramming including dysfunction of the paternal X. This may be the mechanism for the observed increases in the sex ratio.

Table 1
Live birth in Japan 1930–1960 (total and male); CBS_MHLW: Cabinet Bureau of Statistics. Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labour and Welfare, Japan; Neel Schull 1956: The effect of exposure to the atomic bomb on pregnancy termination in Hiroshima and Nagasaki. Washington, D. C.: National Academy of Sciences National Research Council, Publ. No. 461, Table 7.4, p. 94.

Year	CBS_MLHW		Neel Schull 1956		Combined	
	Total	Male	Total	Male	Total	Male
1930	2,085,101	1,069,551			2,085,101	1,069,551
1931	2,102,784	1,073,385			2,102,784	1,073,385
1932	2,182,742	1,117,954			2,182,742	1,117,954
1933	2,121,253	1,087,688			2,121,253	1,087,688
1934	2,043,783	1,042,736			2,043,783	1,042,736
1935	2,190,704	1,122,867	2,190,704	1,122,867	2,190,704	1,122,867
1936	2,101,969	1,076,197	2,101,969	1,076,197	2,101,969	1,076,197
1937	2,180,734	1,116,154	2,180,734	1,116,154	2,180,734	1,116,154
1938	1,928,321	990,888	1,928,321	990,888	1,928,321	990,888
1939	1,901,573	973,744	1,901,573	973,744	1,901,573	973,744
1940	2,115,867	1,084,282	2,115,867	1,084,282	2,115,867	1,084,282
1941	2,277,283	1,165,437	2,277,283	1,165,437	2,277,283	1,165,437
1942	2,233,660	1,145,068	2,233,660	1,145,068	2,233,660	1,145,068
1943	2,253,535	1,155,983	2,267,292	1,163,000	2,253,535	1,155,983
1944			2,171,621	1,112,778	2,171,621	1,112,778
1945			1,677,620		1,677,620	
1946			1,922,383	993,515	1,922,383	993,515
1947	2,678,792	1,376,986	2,678,792	1,376,986	2,678,792	1,376,986
1948	2,681,624	1,378,564	2,681,624	1,378,564	2,681,624	1,378,564
1949	2,696,638	1,380,008	2,696,638	1,380,008	2,696,638	1,380,008
1950	2,337,507	1,203,111	2,337,507	1,203,111	2,337,507	1,203,111
1951	2,137,689	1,094,641	2,137,689	1,094,641	2,137,689	1,094,641
1952	2,005,162	1,028,061	2,002,254	1,026,611	2,005,162	1,028,061
1953	1,868,040	957,524			1,868,040	957,524
1954	1,769,580	911,212			1,769,580	911,212
1955	1,730,692	889,670			1,730,692	889,670
1956	1,665,278	856,084			1,665,278	856,084
1957	1,566,713	805,220			1,566,713	805,220
1958	1,653,469	848,733			1,653,469	848,733
1959	1,626,088	835,822			1,626,088	835,822
1960	1,606,041	824,761			1,606,041	824,761
Total	57,742,622	29,612,331	39,503,531	19,403,851	63,514,246	31,718,624