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Is the human sex odds at birth distorted in the vicinity of nuclear facilities (NF)? A preliminary geo-spatial-temporal approach

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Abstract

The trend in the human sex odds at birth in Europe was significantly distorted after the Chernobyl Nuclear Power Plant accident (ChNPP), and childhood cancers are significantly increased in the vicinity of German nuclear power plants (NPP). Therefore, the question arises whether the human sex odds at birth is also distorted in the vicinity of nuclear reactors and nuclear storage or processing facilities (NF). In this paper we investigate the feasibility of an ecological study based on official gender specific annual birth data of all municipalities of Belgium, Switzerland, and the following parts of Germany: Baden-Württemberg, Bavaria, Lower Saxony, North Rhine-Westphalia, and Rhineland-Palatinate. The analyses involve 316 360 municipality- or district-years, with 22 643 476 live births and an overall sex odds (SO = male live births/female live births) of 1.0546. During the operation time periods of the ascertained 28 NF in Germany and Switzerland, lagging for gestation period, and within 5 km distance from these sites, there is a non-significantly increased sex odds with a sex odds ratio (SOR) vs. the remainder of the study region and non-operational time periods of $SOR_{5km} = 1.0056$, p = 0.3615. However, within the distances of 15 km, 30 km, and 50 km, we may observe more precisely estimated elevated sex odds ratios: $SOR_{15km} = 1.0040$, p = 0.0463, $SOR_{30km} = 1.0035$, p = 0.0026, and $SOR_{50km} = 1.0017$, p = 0.0567. A significant Rayleigh function (p=0.0023) with mode at 14.4 km, 95%-CI = [10.9 km, 29.3 km], yields a $SOR_{peak} = 1.0051$. Moreover, there is a reciprocal distance association (1/r) of the sex odds beyond 10 km distance from NF, p = 0.0016. Therefore, evidence of a far-reaching genetic effect in the vicinity of 28 NF in Germany and in Switzerland is achieved. Further studies in this important area of environmental health research are recommended.

1. Introduction

Over the past decades, many animal experiments and epidemiological studies have revealed the vulnerability of living beings exposed to adverse chemical or physical environmental conditions. Environmental ionizing radiation is of interest as it can induce germ cell mutations and somatic cell mutations alike. Ever since the discovery of the mutagenic properties of ionizing radiation, the possibility of sex odds shifts in exposed human populations was considered. Children's development from conception through the embryonic and fetal periods to infancy is known to be especially radiosensitive. Recently, it has been shown that childhood cancers are significantly increased in the vicinity of German nuclear reactors (Spix et al. 2008; Nussbaum 2009). In this context, the Chernobyl accident is of interest and importance. Thyroid cancer in children occurred very early and in far too great a number of cases relative to previous (pretended) experience (Balter 1996). In fact, the World Health Organization and the International Atomic Energy Agency have failed to investigate and communicate the many easily accessible detrimental health effects attributable to the Chernobyl catastrophe (Tickell 2009; Scherb 2010; Scherb and Voigt 2010; Yablokov et al.

2010). A possible genetic effect of ionizing radiation — an impact on the human sex odds at birth (Schull and Neel 1958) — has not been investigated at all by national or international institutions nor by the scientific community despite the simplicity and exactness of this measure, not to speak of the important implications if this trait was significantly distorted after Chernobyl. Note, we prefer the term "sex odds" instead of "sex ratio" because odds is the appropriate notation of a probability divided by one minus this probability. Importantly, there will be no confusion when it comes to consider the "odds ratio", which then is the "sex odds ratio" and not the inconvenient "sex ratio ratio". We investigated trends in the sex odds before and after the Chernobyl accident (1982–1992) in several European countries and found a significant jump and a broken stick effect in the sex odds trends in 1987 immediately in the year following the Chernobyl accident (Figure 1) (Scherb and Voigt 2007; Scherb 2010).

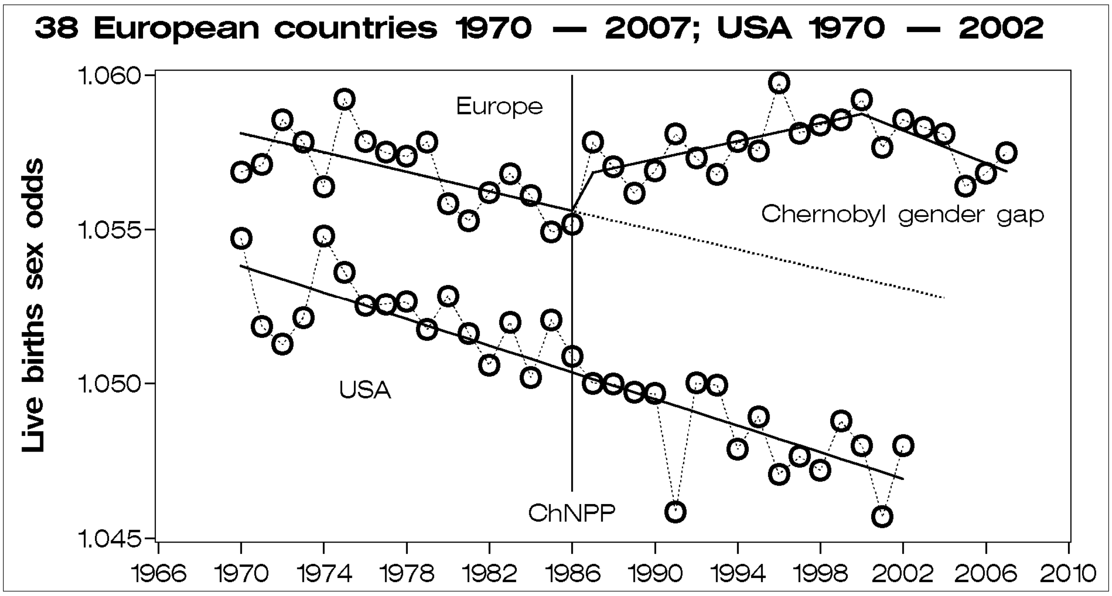

Figure 1: Trends of the annual live births sex odds (male/female) in the USA 1970 to 2002, and in Europe 1970 to 2007

In this paper, as an introductory and preliminary work, we will address the question whether the human sex odds at birth (secondary sex odds) is distorted in some way around NF, possibly similar to the increased childhood cancers near NPP (KiKK study). We are well aware of our municipality-based study's larger geographical non-differential misclassification error compared to the KIKK study where cases and controls were located up to approximately ± 25 meters. However, in the case of a far-reaching effect this may be of less concern. In an outlook, we conjecture possible associations of the sex odds with other sources of radiation as for example cosmic rays.

2. Data and Statistical Methods

This study is based on official (in German "amtlich"), gender specific annual live births statistics gathered and compiled from national or regional statistics offices in Belgium, Switzerland, and the following states of Germany: Baden-Württemberg, Bavaria, Lower Saxony, North Rhine-Westphalia, and Rhineland-Palatinate. For these countries or regions, the first author was able to compile the data from freely available internet data bases containing official demographic data, and through assistance by statistical authorities. In Table 1 we list the time periods available and the total live births by gender in those 7 countries and regions. All in all, 316 360 municipality- or district-years have been ascertained with 22.6 million live births and an overall sex odds of 1.0546. Table 2 lists the possibly relevant NF in or adjacent to the study regions by operational time periods and NF type.

2.1 Geo-spatial considerations

For the computation of distances in the German epidemiological study on childhood cancer in the vicinity of nuclear power plants (Spix et al. 2008), geographic coordinates given in the Gauss–Krüger coordinate system are used. The Gauss–Krüger coordinate system is a special transverse Mercator map projection used in Germany, Austria and Finland rather than the UTM-system but similar to this. The central meridians of the Gauss–Krüger zones are only 3° apart, as opposed to 6° in UTM. A transverse Mercator map projection approximates the reference ellipsoid by a cylinder sector, which perimeter smoothes the central meridian of the mapped zone some depth below the reference surface, so the elliptical cylinder intersects the ellipsoid. The transverse Mercator map projection provides a nearly conformal mapping of earth's surface in smaller regions, so distances can simply be computed by using the Euclidean distance from the numerical differences of the coordinate components with very small errors. The Helvetian Swisstopo uses a special oblique cylindrical Mercator projection with an inclined cylinder axis (also called "Swiss Grid"), based on a double projection starting from the 1841 Bessel ellipsoid and using a fundamental point in Berne. For distance computations over different systems it is necessary to transform coordinates into the same system. For the transformations, online calculators provided by the national geodetic authorities were used. For longer distances (more than some arc degrees) Euclidian distance from cylindrical coordinates causes increasing errors. Therefore, higher distances were computed using spherical trigonometry or, for higher precision, nautical programs. Figure 2 displays the study regions, the position of all municipalities, and the position of the possibly relevant NF, in or adjacent to the single regions, using uniform (H, R) coordinates.

Table 1: Available gender specific birth statistics by study region.

Region	**data available**	**male births**	**female births**	**sex odds**
Baden-Württemberg	1975 - 2008	1 795 839	1 702 372	1.0549
Bavaria	1972 - 2008	2 241 831	2 125 162	1.0549
Belgium	1989 - 2007	1 141 451	1 088 579	1.0486
Lower Saxonia	1971 - 2008	1 470 778	1 392 783	1.0560
North Rhine-Westphalia	1980 - 2008	2 584 664	2 449 001	1.0554
Rhineland-Palatinate	1970 - 2008	754 120	714 496	1.0555
Switzerland	1969 - 2008	1 633 929	1 548 471	1.0552
Combined		**11 622 612**	**11 020 864**	**1.0546**

Table 2: Nuclear facilities (NF) in the study region; gender specific births and sex odds ratio through operational periods within 35 km distance from the NF; Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR), Nuclear Storage Site (NSS), Nuclear Fuel Elements (NFE), and Uranium Mining (UM); * NF not considered because of low Belgium sex odds or low spatial-temporal coverage (s. Table 1).

No. (s. Fig. 2)	NF	Type	In operation since/to	Live births < 35 km during NF operation, lagged for gestation		Sex odds ratio vs. last row of this Table	p-value (Chi^2)	hold one NF out p-value (Chi^2), compare to **
				male	**female**			
1	Biblis	PWR	1975 -	223 648	211 753	1.0017	0.5804	0.0007
2	Obrigheim	PWR	1969 - 2005	164 321	155 447	1.0026	0.4733	0.0010
3	Neckarwestheim	PWR	1976 -	380 463	360 212	1.0017	0.4640	0.0005
4	Philipsburg	BWR/PWR	1980 -	333 967	314 761	1.0063	0.0133	0.0019
5	Grafenreihnfeld	PWR	1981 -	95 714	90 722	1.0006	0.8957	0.0007
6	Isar I und II	BWR/PWR	1977 -	67 059	63 341	1.0041	0.4627	0.0011
7	Gundremmingen	BWR	1966 -	142 702	135 276	1.0005	0.8986	0.0006
8	Fessenheim	PWR	1977 -	99 148	93 694	1.0036	0.4290	0.0012
9	Beznau I und II	PWR	1969 -	337 335	317 880	1.0065	0.0106	0.0031
10	Goesgen	PWR	1979 -	220 979	208 604	1.0047	0.1308	0.0005
11	Leibstadt	BWR	1984 -	143 467	135 293	1.0057	0.1354	0.0008
12	Muehleberg	BWR	1971 -	218 795	207 560	0.9998	0.9387	0.0004
13	Emsland	PWR	1988 -	55 502	52 301	1.0065	0.2915	0.0011
14	Grohnde	PWR	1984 -	84 739	80 308	1.0008	0.8791	0.0009
15	Wuergassen	BWR	1972 - 1994	34 453	32 643	1.0010	0.8960	0.0010
16	BR*	PWR	1962 - 1987	5 332	5 288	0.9563	-	-
17	Doel*	PWR	1974 -	392 512	375 500	0.9914	-	-
18	Tihange*	PWR	1975 -	122 594	117 476	0.9897	-	-
19	Dodewa*	BWR	1968 - 1997	5 926	5 710	0.9843	-	-
20	Brunsbuettel	BWR	1977 -	21 085	20 003	0.9997	0.9779	0.0010
21	Brokdorf	PWR	1986 -	15 505	14 769	0.9957	0.7073	0.0009
22	Kruemmel	BWR	1984 -	35 882	33 745	1.0085	0.2662	0.0012
23	Stade	PWR	1975-2003	43 456	40 771	1.0109	0.1174	0.0021
24	Unterweser	PWR	1979 -	86 010	81 341	1.0029	0.5608	0.0010
25	Lingen	BWR	1968 - 1977	19 372	18 400	0.9985	0.8862	0.0007
26	Karlsruhe	BWR	1966 - 1991	149 269	140 584	1.0070	0.0624	0.0007
27	Ahaus	NSS	2000 -	26 427	24 866	1.0080	0.3701	0.0009
28	Juelich	NSS	2000 -	75 735	71 688	1.0020	0.7076	0.0008
29	Ellweiler	UM	1969 -	31 361	29 450	1.0100	0.2225	0.0013
30	Menzenschwand	UM	1969 -	132 037	124 574	1.0052	0.1892	0.0012
31	Gorleben	NSS	2000 -	1 753	1 573	1.0570	0.1108	0.0010
32	Hanau/Kahl	NFE	1969 -	54 772	51 343	1.0118	0.0577	0.0021
	German states and Switzerland < 35 km from NF			**2 532 471**	**2 393 556**	**1.0035**	**** 0.0008**	
	German states and Switzerland > 35 km from NF			**7 948 690**	**7 538 729**	**1.0000**	**1.0000**	

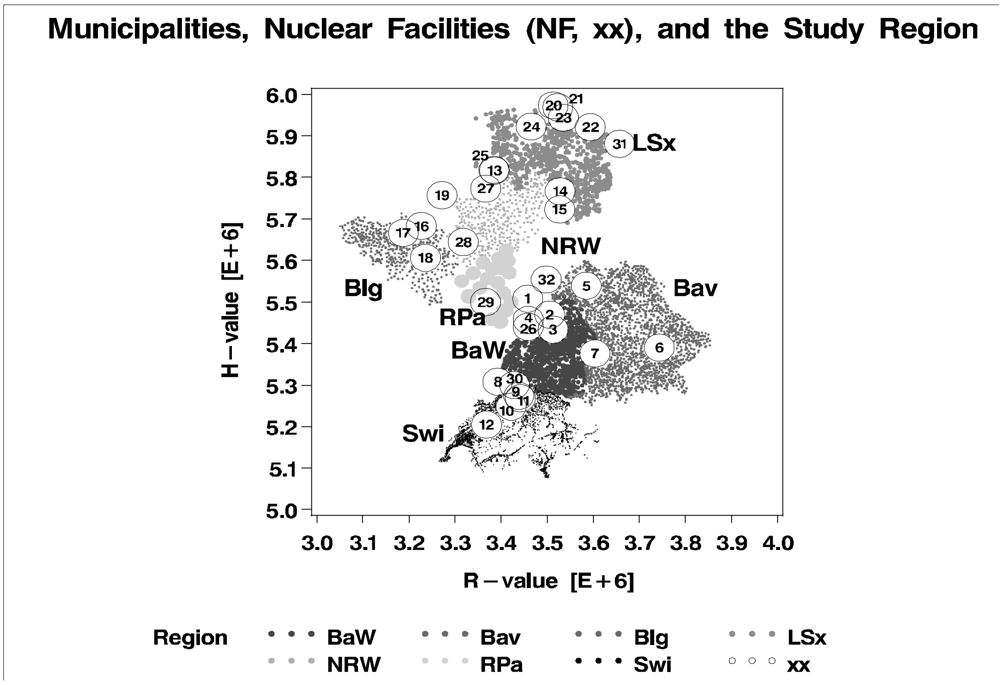

Figure 2: Belgium (Blg), Switzerland (Swi), Baden-Württemberg (BaW), Bavaria (Bav), Lower Saxony (LSx), North Rhine-Westphalia (NRW), and Rhineland-Palatinate (RPa), NF (xx) within surrounding 35 km circles, see Table 2.

2.2 Distributional assumptions and regression techniques

To investigate whether there are significant spatial trends depending on the distance from NF, we applied linear logistic regression (Scherb and Weigelt 2003). To allow for changing sex odds trends (slopes) with distance from NF, one may use various possible distance laws, the simplest one being a jump model for the 5 km disc around NF. We used dummy coding for distances and for time periods as well. For example, the dummy variable for the distance from NF below 5 km is defined as d5(x) = 1 for x < 5 km and d5(x) = 0 for x ≥ 5 km (x = distance [km]). The simple logistic model for a constant distance trend and a downward or upward jump beyond 5 km has the following form (LB: live birth, π_x : Binomial probability parameter at distance x):
$\text{Boys}_x \sim \text{Binomial}(\text{LB}_x, \pi_x)$

$$\log\ \text{odds}\left(\pi_x\right) = \text{intercept} + \alpha * \text{d5(x)}$$

The data in this study were processed with Microsoft Excel 2003. For statistical analyses, we used R 2.11.1, MATHEMATICA 5.0, and mostly SAS 9.1 (SAS Institute Inc: SAS/STAT User’s Guide, Version 9.1. Cary NC: SAS Institute Inc; 2003).

2.3 Statistical power considerations

Recently, it has been hypothesized that the overall background radiation may perhaps be responsible for approximately 20% of all childhood leukemia cases in Great Britain. (Little et al. 2009; Wakeford et al. 2009). Assuming a multiplicative risk model and an average level of the natural background radiation of approximately 1 mSv/a yields a doubling dose of approximately 4 mSv/a for childhood leukemia. Since childhood leukemia was doubled within 5 km of all German NPP (Kaatsch et al. 2008), this would mean, in reverse, that some kind of dose equivalent of 4 mSv/a was acting within 5 km of NPP. As Scherb and Voigt (2007) have shown, the sex odds ratio per mSv/a is in the order of magnitude of 1.015 per mSv/a. Thus, 4 mSv/a would yield a sex odds ratio of 1.06, and this in turn would distort the normal sex odds of 1.05 in central Europe to a sex odds in the vicinity of NF to 1.11. This means that a normal proportion male (p_{m0}) of H_0: $p_{m0} = 0.51$ would increase to H_1: $p_{m1} = 0.53$. As we have approximately 110 000 births within 5 km distance from NF in our study region, the power of the two-sample Binomial test for testing H_1 against H_0 would be close to 100% for this rather large effect. On the other hand, if the effect within 5 km of NF was in the range of an equivalent increase of 1 mSv/a, i.e. in the range of a doubling of the natural background radiation, then the power were 75%. Therefore, if the additional dose caused by NF within 5 km was in the range of 1 mSv/a, then the power of our data was nearly sufficient. The power were totally insufficient within 5 km distance if the effect was in the order of magnitude of some fraction of 1 mSv/a, say 0.2 mSv/a (power ≈ 8%), similar to the overall Chernobyl exposure in the average in all of Europe (Drozdovitch et al. 2007). On the other hand, as we have nearly 5 million live births within the 35 km circles of the NF, the power for such a 0.2 mSv/a equivalent within 35 km distance were 79%.

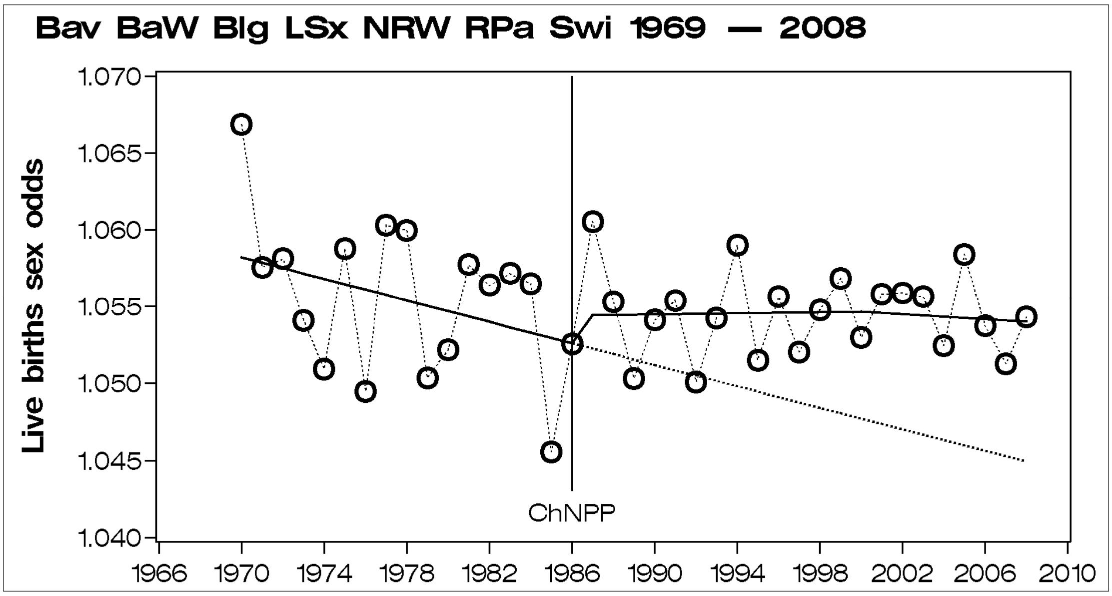

Figure 3: Trend of the live births sex odds (male/female) in Belgium (Blg), Switzerland (Swi), Baden-Württemberg (BaW), Bavaria (Bav), Lower Saxony (LSx), and North Rhine-Westphalia (NRW), and Rhineland-Palatinate (RPa) combined.

3. Results

As one of a number of elementary plausibility checks, we retrieved the annual sex odds trend from the compiled municipality-specific data set for the whole study region (n = 316 360). As the study region is situated in the central part of Europe, with less extreme low or less extreme high levels of Chernobyl fallout, one may expect a trend similar to the overall (average) European trend in Figure 1. The consistent and affirmative result is shown in Figure 3. However, whereas all the effects in Figure 1 (jump and broken stick effects) are highly significant (Scherb 2010), the corresponding effects in Figure 3 are not significant. One of the reasons for these non-significant effects ($p>0.1$) is the relatively small number of observations available here. In Europe (Figure 1), we have roughly 10 times more births than in our study region. From the non-significance of the temporal effects in Figure 3, we may conclude that for preliminary and orientating analyses of distance from NF sex odds trends there will be most likely no relevant temporal confounding. Consequently, in the following distance trend analyses, the only temporal components included will be the operational time periods of NF. Taking into account the secular downward trends of the sex odds and the Chernobyl effect is probably not relevant at this stage.

During the operation time periods of the ascertained total 28 NF in Germany and Switzerland, lagging for gestation period, and within 5 km distance from these sites, there is a non-significantly increased sex odds with a sex odds ratio vs. the remainder of the study region and non-operational time periods of SOR_{5km} = 1.0056, p = 0.3615. However, within the distances of 15 km, 30 km, and 50 km, with higher statistical power due to larger populations, we may observe more precisely estimated elevated sex odds ratios of SOR_{15km} = 1.0040, p = 0.0463, SOR_{30km} = 1.0035, p = 0.0026, and SOR_{50km} = 1.0017, p = 0.0567. Because there seems to be an optimum balance between effect strength and statistical power (population size) somewhere between 30 km and 40 km, we emphasize the distance 35 km in Table 2 and Figure 4. In Table 2 we list the 35 km SOR and p-values for single NF. Conversely, in the sense of a NF-specific sensitivity analysis, we also list p-values of the overall comparisons with the specific NF excluded (“hold one NF out”). No NF has a dominating influence on the overall effect. This is similar to the KiKK study.

Figure 4 to Figure 7 show the sex odds within 1-km-distance rings vs. the distance from the nearest NF in Switzerland and in the German states combined. The 35 km jump model and the Rayleigh model are significant: p = 0.0006 and p = 0.0023 (F-test). The simple reciprocal distance trend model reaches only one-sided borderline significance (p = 0.1240, F-test), but may be mis-specified in case the presumable dose response association was nonlinear or exposure was non-monotonic in the near vicinity of the NF. The reciprocal distance model restricted to the data above 10 km distance fits the data somewhat better (p = 0.0016, F-test).

4. Discussion

An important task of environmental health research is the investigation of a possible causal relationship between exposure and the frequency of a biological trait. Changes in the sex odds of officially recorded population-based statistics, e.g., live births, stillbirths, or cancer incidence, may be sentinel indicators for detrimental health effects of more or less concealed changes in the environment. Since sex odds shifts have been observed after the Chernobyl accident, and an increased childhood cancer incidence was seen in the vicinity of NPP, the question arises whether the human sex odds at birth is also distorted in the vicinity of NF. Because childhood leukemia was approximately doubled within 5 km distance from German reactors (Kaatsch et al. 2008), we looked at the secondary sex odds in the vicinity and within operation time periods of NF in Belgium, Switzerland, and the following parts of Germany: Baden-Württemberg, Bavaria, Lower Saxony, North Rhine-Westphalia, and Rhineland-Palatinate (geo-spatial temporal approach).

As Belgium reveals a relatively low overall sex odds, has only 3 NF, and has a restricted observation period beginning in 1989 only, Belgium was excluded for the purpose of the present paper. In the German and Swiss data, there is a non-significant increase of the sex odds below 5km from NF. However, within greater distances of 15 km, 30 km, or 50 km we observe significant or borderline significant increases of the sex odds. Because an impartial Rayleigh function is also significant, this could mean that exposure to emitted radio nuclides is non-monotonically distributed and/or that dose response relations are non-linear, yielding an (apparent) maximum risk at about 15 km distance. Consequently, this pilot investigation yields some evidence of a relatively far-reaching genetic effect in the vicinity of 28 NF in Germany and in Switzerland. Further studies in this important area of environmental health research are recommended.

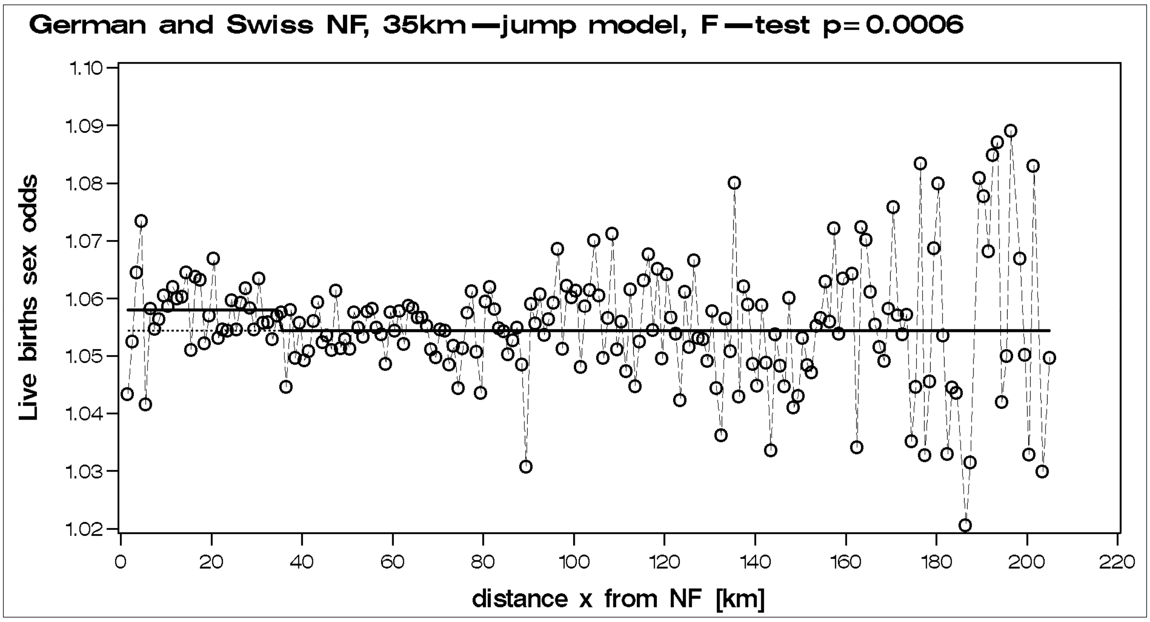

Figure 4: Distance trend model: ln(sex odds) = a + b*d_{35km}(x); a = 0.0530, 95%-CI = [0.0520, 0.0540]; b = 0.0035, 95%-CI = [0.0014, 0.0055]; SOR_{jump} = 1.0035.

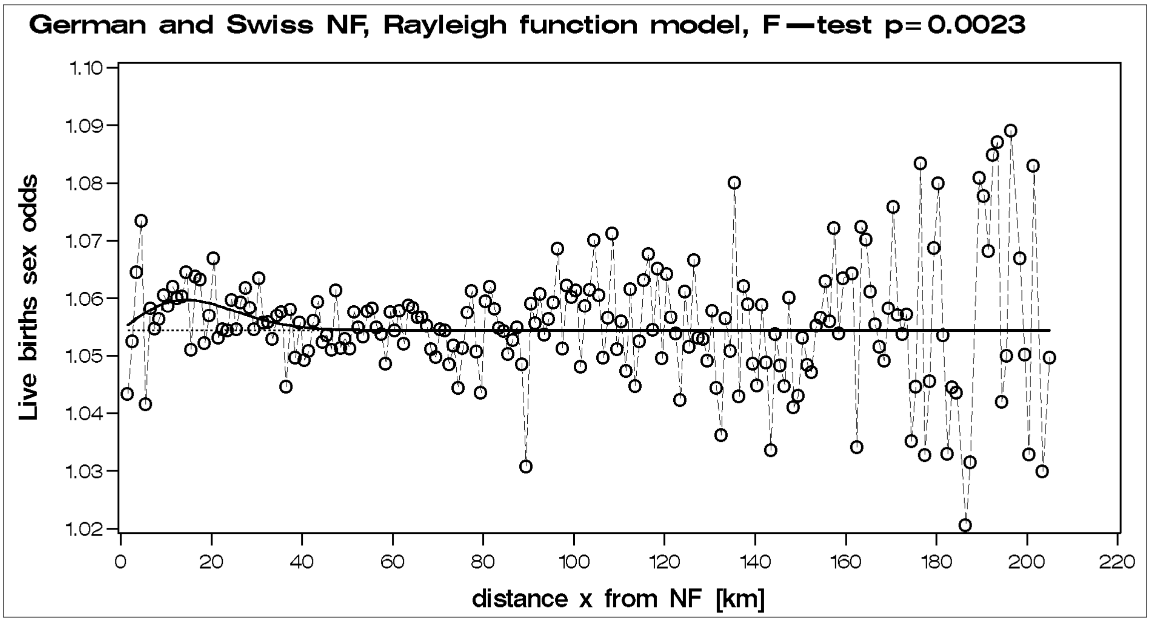

Figure 5: Distance trend model: ln(sex odds) = a+b∗x∗exp(-c∗x^2); a = 0.0529, 95%-CI = [0.0519, 0.0540]; b = 0.00058, 95%-CI = [0.00010, 0.00106]; c = 0.00240, 95%-CI = [0.00058, 0.00422]; peak at 14.4 km, SORpeak = 1.0051.

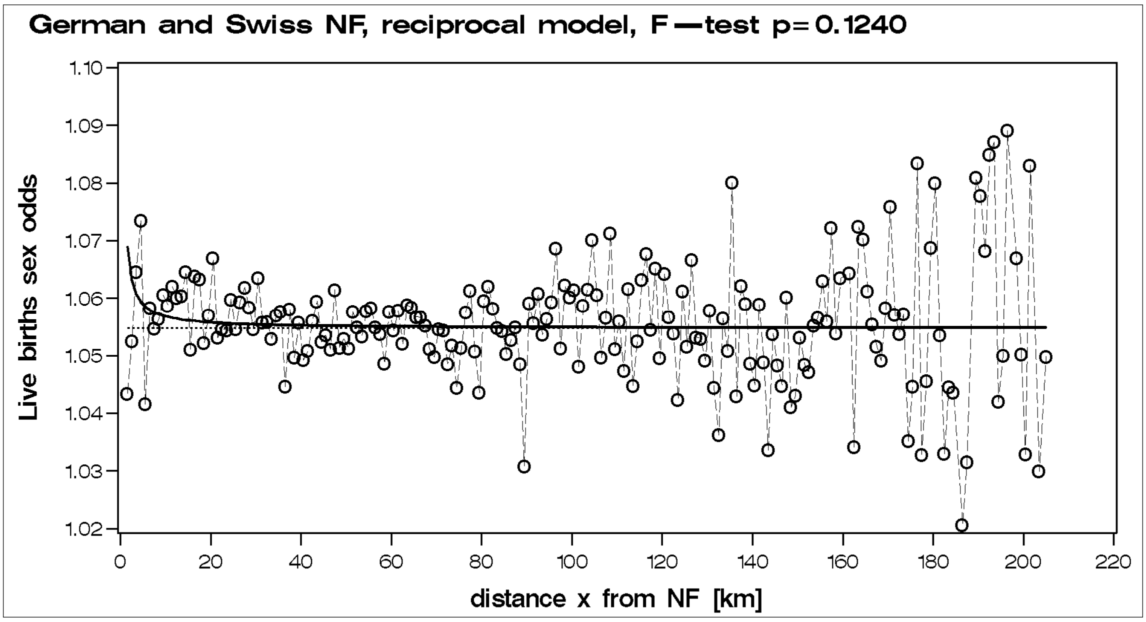

Figure 6: Distance trend model: ln(sex odds) = a + b/x; a = 0.0533, 95%-CI = [0.0522, 0.0543]; b = 0.0199, 95%-CI = [- 0.0053, 0.0451].

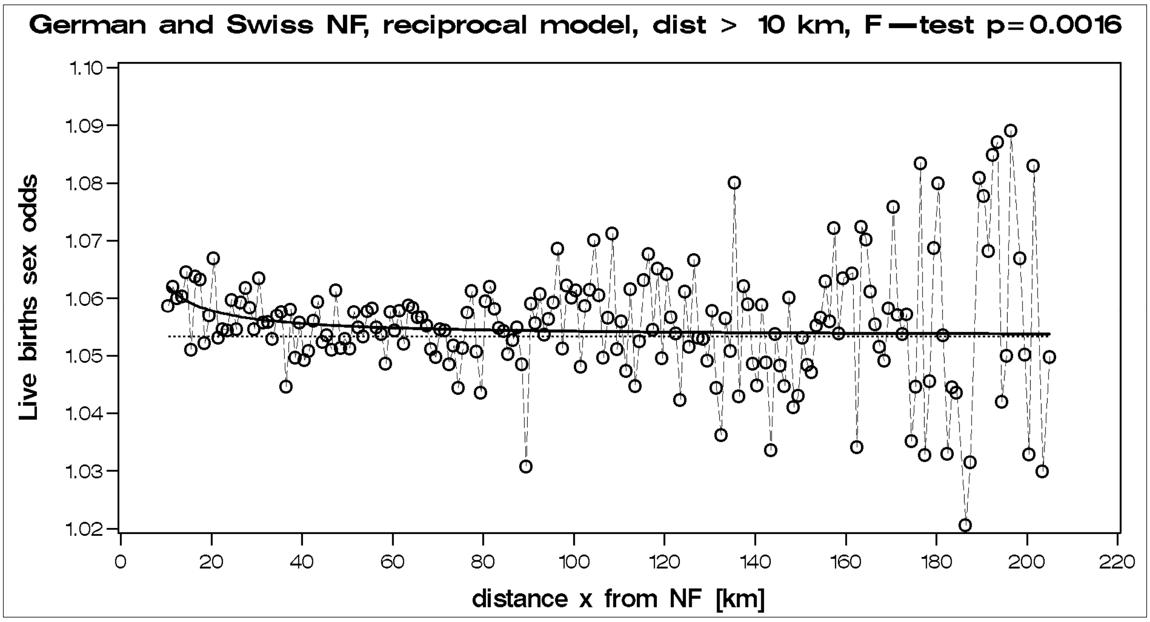

Figure 7: Distance trend model restricted to distances > 10 km: ln(sex odds) = a + b/x; a = 0.0519, 95%-CI = [0.0505, 0.0533]; b = 0.0855, 95%-CI = [0.0332, 0.1377].

5. Outlook

Extended investigations are required to support or refute the findings of this paper. We will enhance the scope of our research efforts with data on further German states (Bundesländer), more complete time periods, and additional European countries. Other sources of ionizing radiation could be considered as well. One example is cosmic rays (CR). Direct measuring of cosmic ray intensity is possible since the 1950s. The examination of the live births sex odds from alpine high-altitude municipalities comparing recent CR-data from cosmic ray observatories is another possibility one may think of.

In the literature it has been argued (perhaps naively) that a falling sex odds would indicate “missing boys”. If we assume that the observed increased sex odds near NF in our data was due to “missing girls” only, then it is straightforward arithmetic to quantify the apparent “gender gap” to approximately 8400 missing girls, e.g. according to the Rayleigh model in Figure 5. As a specification of the sex odds among the presumable missing children completely determines this calculation, a sex odds of 3:10 that we assumed in previous publications would entail approximately 15 200 missing children in our data. A solution to this problem remains open as long as very little is known about radiation induced genetic effects in man.

6. Literature

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