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# Proximity to point sources of environmental mercury release as a predictor of autism prevalence

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## Abstract

The objective of this study was to determine if proximity to sources of mercury pollution in 1998 were related to autism prevalence in 2002. Autism count data from the Texas Educational Agency and environmental mercury release data from the Environmental Protection Agency were used. We found that for every 1000 pounds of industrial release, there was a corresponding 2.6% increase in autism rates ( $p < .05$ ) and a 3.7% increase associated with power plant emissions ( $P < .05$ ). Distances to these sources were independent predictors after adjustment for relevant covariates. For every 10 miles from industrial or power plant sources, there was an associated decreased autism Incident Risk of 2.0% and 1.4%, respectively ( $p < .05$ ). While design limitations preclude interpretation of individual risk, further investigations of environmental risks to child development issues are warranted.

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**Keywords:** Mercury; Autism; Environment; Distance; Industry

## Introduction

Mercury is a heavy metal found naturally in trace amounts in the earth's atmosphere in differing forms—as elemental vapor, reactive gaseous compounds, or particulate matter. Studies show that background levels of environmental mercury deposition have steadily increased several fold since the pre-industrial era (Schuster et al., 2002), with the largest source of potentially adverse exposures coming primarily from coal-fired utility plants (33%), municipal/medical waste incinerators (29%) and commercial/industrial boilers (18%)—estimated to be responsible for 158 tons of environmental mercury released per year in the US (Environmental Protection Agency, Report to Congress, 1997). Other sources include hazardous waste sites, cement factories, and chlorine production plants. According to the Agency for Toxic Substances and Disease Registry (ATSDR), next to arsenic and lead,

mercury is the third most frequently found toxic substance in waste facilities in the United States (ATSDR, 2001).

Mercury is now widespread in the environment (EPA, 1997; ATSDR, 2001). The long-range atmospheric transport of mercury (Ebinghaus et al., 2001), and its conversion to organic forms through bio-accumulation in the aquatic food chain has been known for some time (MacGregor, 1975; Mahaffey, 1999). Notwithstanding, there are emerging concerns over the potential adverse effects of ambient levels of environmental mercury during early childhood development. There is sufficient evidence that children and other developing organisms are particularly susceptible to the adverse neurological effects of mercury (Landrigan and Garg, 2002; Grandjean et al., 1995; Ramirez et al., 2003; Rice and Barone, 2000).

Evidence from animal studies suggests that neonates lack the ability to efficiently excrete both methylmercury (Rowland et al., 1983) and inorganic mercury (Thomas and Smith, 1979), and that there is a higher lactational transfer of inorganic mercury than methylmercury (Sundberg et al., 1991a, b). Correspondingly, it has been shown that infants exposed via milk from mothers who were

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1 accidentally poisoned by methylmercury-contaminated  
 2 bread in Iraq accumulated higher mercury concentrations  
 3 in their blood than did their mothers (Amin-Zaki et al.,  
 4 1988) and the Faroe Island studies show that hair mercury  
 5 concentrations in infants increased with the duration of the  
 6 nursing period (Grandjean et al., 1994). It has also been  
 7 shown that maternal dental amalgams have been linked to  
 8 higher body burdens in infants (Oskarsson et al., 1996).

9 A 10-year longitudinal cohort monitoring study in  
 10 Finland demonstrated that median hair total mercury  
 11 concentrations increased in individuals who lived 2 km  
 12 from a mercury polluting power plant compared to  
 13 unexposed reference groups living further away (Kurtzio  
 14 et al., 1998). A study performed in China demonstrated  
 15 that higher mercury concentrations are present in soil  
 16 sediments and rice fields that are in close proximity to  
 17 mercury emitting industrial plants and mining operations  
 18 compared to areas that are more distant (Wang et al.,  
 19 2003). A variety of similar investigations involving human,  
 20 plant, and animal studies performed in different global  
 21 locations consistently demonstrate that mercury concen-  
 22 trations are inversely associated with distance to the  
 23 environmental source (Ordonez et al., 2003; Fernandez et  
 24 al., 2000; Hardaway et al., 2002; Navarro et al., 1993;  
 25 Kalac et al., 1991; Moore and Sutherland, 1981).

26 A 2000 report by the National Academy of Sciences'  
 27 National Research Council estimates that approximately  
 28 60,000 children per year may be born in the US with  
 29 neurological problems due to in utero exposure to  
 30 methylmercury (NAS, 2000). The neurotoxicity of low-  
 31 level mercury exposure has only recently been documented  
 32 (NAS, 2000; EPA, 1997) and little is known about  
 33 persistent low-dose ambient exposures coming from  
 34 environmental sources or its influence on childhood  
 35 developmental disorders such as autism—a condition  
 36 affecting impairments in social, communicative, and  
 37 behavior development typically present before age 3 years  
 38 manifested by abnormalities in cognitive functioning,  
 39 learning, attention, and sensory processing (Yeargin-  
 40 Allsopp et al., 2003; CDC, 2007).

41 One hypothesis, which has been advanced to explain the  
 42 recently observed increases in autism in the US and  
 43 Europe, is that biological damage from neurotoxic  
 44 substances such as mercury may play a causal role  
 45 (Bernard et al., 2002). Holmes et al. (2003) found that  
 46 mercury levels in the hair of autistic children were  
 47 significantly lower than non-autistic controls indicating,  
 48 according to the authors, that autistic children retain  
 49 mercury in their body due to impairments in detoxification  
 50 pathways. After the administration of a heavy metal  
 51 chelating agent, Bradstreet et al. (2003) demonstrated that  
 52 autistic children, relative to controls excreted more  
 53 mercury in urine than non-autistic controls. Two recent  
 54 studies have shown that body burden of mercury, as  
 55 indicated by increased levels of urinary porphyrins specific  
 56 to mercury exposure, are significantly higher in autistic  
 57

children than in non-autistic children (Nataf et al., 2006;  
 Geier and Geier, 2006).

While the association between autism and thimerisol (a  
 mercury-based preservative formerly used in the childhood  
 vaccination schedule during the 1990s) has not been  
 scientifically established (Freed et al., 2002; Schechter and  
 Grether, 2008), two studies have demonstrated an associa-  
 tion with environmental sources of mercury and autism.  
 Windham et al. (2006) demonstrated that ambient air  
 mercury was associated with elevated autism risk in a  
 case-control study in California, and Palmer et al. (2006)  
 demonstrated that environmental mercury pollution was  
 associated with point prevalence estimates of autism using  
 EPA reported mercury release data from 254 counties in  
 Texas. A major limitation to this study was that the cross-  
 sectional design precluded any causal inferences. In  
 addition, exposure was inferred from total pounds of  
 environmentally released mercury aggregated at the county  
 level at a specific point in time. Using distance to potential  
 exposure sources may be a more reasonable proxy for  
 exposure than one defined by total amount contained  
 within artificial county boundaries. Given the literature on  
 the relevance of proximity to the source of mercury and  
 body burden, we suspect that distance to the source of  
 mercury exposure may actually explain, at least in part, the  
 association between increased autism rates and environ-  
 mental mercury pollution found in both the Palmer et al.  
 (2006) and Windham et al. (2006) studies.

The objective of the current study is to determine if  
 proximity to major sources of mercury pollution is related  
 to autism prevalence rates.

## Methods

### *Data source and sample*

Data for environmentally released mercury were ob-  
 tained from the *United State Environmental Protection  
 Agency Toxics Release Inventory* (TRI) (USEPA-TRI,  
 2006). TRI collects information about chemical releases  
 and waste management reported by major industrial  
 facilities in the US. The TRI database was established by  
 Section 313 of the Emergency Planning and Community  
 Right-To-Know Act of 1986 (EPCRA). Under EPCRA,  
 industrial facilities in specific sectors are required to report  
 their environmental releases and waste management  
 practices annually to the EPA. Facilities covered by this  
 act must disclose their releases to air, water, and land of  
 approximately 650 toxic chemicals, as well as the quantities  
 of chemicals they recycle, treat, burn, or otherwise dispose  
 of on-site and off-site. The current analysis used the 1998  
 county pollution report that industrial facilities provided to  
 TRI. Data for environmentally released mercury by coal-  
 fired power plants were obtained from TRI and from the  
 Texas Commission for Environmental Quality. In all, 39  
 coal-fired power plants and 56 industrial facilities in Texas  
 were used in the analysis.

### Measure of distance from mercury sources

The address location of coal-fired power plants and industrial facilities were entered into Arc-view V 9.0 Geographic Information Systems software along with polygonal shapes or boundaries of the school districts of Texas. GIS was then used to assign the *XY* location coordinates (latitude and longitude) of each plant and facility as well as to locate the centroid or *XY* geographical center of each school district. The amount of mercury emitted by each plant and by each facility was weighted on the *XY* coordinate of each plant's and facility's location. Using SPSS version 14 software, the distances between the *XY* coordinate of each source of emission and the *XY* coordinate of each school district centroid were calculated. As a result, each school district received a distance-in-miles measurement calculated separately for power plants and industrial facilities.

### School district data

Administrative data from the Texas Education Agency (TEA) were analyzed. In compliance with the Texas Education Code, the Public Education Information Management System (PEIMS) contains data necessary for the legislature and the TEA to perform their legally authorized functions in overseeing public education. The database consists of student demographic, personnel, financial, and organizational information. Data descriptions are available at the TEA website <http://www.tea.state.tx.us/data.html>. Autism counts per school district were obtained by special request from the TEA. Data were from 1040 school districts in 254 counties in Texas. Diagnoses of autistic disorder are abstracted from the school records and are made by qualified special education psychologists employed by the TEA or from psychologists or medical doctors outside the TEA system. While diagnoses were not standardized, there is considerable evidence that diagnoses of autistic disorder are made with good reliability and specificity in the field (Eisenmajer et al., 1996; Hill et al., 2001; Mahoney et al., 1998). Autism prevalence rates from 2002 were used as the outcome and 1997 rates were used as a covariate in multivariate regression models.

We have identified the key covariates from prior work (Palmer et al., 2005, 2006), which were used in this study to adjust for potential confounding. *Urbanicity* and *School District Resources* have been demonstrated to be important covariates as they relate to greater identification of autism spectrum disorders. We also include a measure of ethnicity (percent white in school district).

### Urbanicity

Eight separate demographically defined school district regions were used in the analysis as defined by the TEA: major urban districts and other central cities (1) major suburban districts and other central city suburbs (2) non-metropolitan and rural school districts (5).

In the current analysis, dummy variables were included in the analysis coding urban (dummy variable 1, and suburban (dummy variable 2), contrasted with non-metro and rural districts which were the referent group. Details and specific definitions of urbanicity categories can be obtained at the TEA website <http://www.tea.state.tx.us/data.html>.

*Racial composition* was accounted for by the proportion of White children enrolled in schools within each district.

*Total number of students* reflects all enrolled students in the districts 2002 school year and was used as the denominator in calculating autism rates.

*District population wealth* was calculated as the district's total taxable property value in 1998 as determined by the Comptroller's Property Tax Division (CPTD), divided by the total number of students in the district in 1998. Property value was determined by the CPTD as part of its annual study, which attempts to present uniformly appraised property valuations statewide. The CPTD value is calculated by applying ratios created from uniform independent appraisals to the district's assessed valuations.

### Statistical methods

District autism data in 2002 were treated as event counts and used as the outcome in a Poisson regression model predicted by pounds of environmental mercury release 1998, distance to sources of the release, and the relevant covariates. Total number of students enrolled in each district for 2002 defined the rates for each district. An over dispersion correction was applied due to the mean and variance not being equal. Due to the hierarchical structure of the data (e.g. districts nested within counties), the Poisson model was fit using MIWin multilevel modeling software (Rasbash et al., 1999) to obtain unbiased standard errors. Polynomials were added to the model to determine if a non-linear association was present between pounds of mercury, distance and autism rates. Regression coefficients of the models are reported as incident rate ratios by exponentiating the Poisson model coefficients.

### Modeling strategy

*Pounds of mercury* release were first entered into the model followed by polynomial functions to access non-linear associations with autism rates. Next, *distance* was entered into the model to determine if it decreased the effect of *pounds*. Finally all covariates were entered: baseline *autism rates in 1997*, *urbanicity*, *racial composition*, *proportion of economically disadvantaged students*, and *district population wealth*. Note that mercury release data from 1998 are used to predict autism rates in 2002; it is plausible to postulate that releases during 1998 would have exposure potential for a cohort who was in utero in 1997. If an effect was present, this would be reflected in the 2002 school district records—the age (5 years old) this cohort would be entering the system.

**Results**

Table 1 shows the descriptive statistics of the study variables. Note that there is considerable variation in each variable. Table 2 shows the Poisson regression coefficients and the corresponding Incident Risk Ratio (IRR) for the models exploring the linear and non-linear association between 1998 mercury release from industrial sources, distance, and 2002 autism rates. Model 1a shows that environmentally released mercury in 1998 is significantly associated with autism rates in 2002. We multiplied the coefficient by 1000 to reflect increases in autism rates per 1000 pounds. The coefficient yields an IRR of 1.026,

indicating that for every 1000 pounds of release in 1998, there is a corresponding 2.6% increase in 2002 autism rates. In model 1b, the squared term for pounds was entered into the model. Note that the linear coefficient is no longer significant and the polynomial term is. This indicates that the association between industrial sources of mercury release is non-linear—e.g. for every 1000 pounds there is an associated 1.1% accelerated risk. Adding distance to the equation in model 1c shows that for every 10 miles away from the source there is a decreased autism Incident Risk of 1.4%. Adding non-linear terms for distance (distance squared and the square root of distance) (not depicted) was not significant and therefore not utilized

Table 1  
Descriptive statistics of study variables

	Mean or percent	Standard deviation	Range
<i>Predictor variables</i>			
Total number pounds of mercury per year for power plants	1225lb	946	8–2516
Total number pounds of mercury per year for industrial facilities	1526lb	1909	3–6685
Minimum distance to industrial facilities	39.7 miles	29.3	0.34–170.4
Minimum distance to power plants	71.7 miles	53.2	0.74–305.8
<i>Relevant demographic covariates</i>			
Value of taxable property	\$265,148	\$328,631	0–\$3,481,369
Percent urban	4%	–	–
Percent suburban	15%	–	–
Percent White	61.5%	–	0–100%
Proportion autism 1997 (rate per 1000)	0.85	2.1	0–26.3
<i>Outcome variable</i>			
Proportion autism 2002 (rate per 1000)	2.0	3.2	0–39.5

Table 2  
2002 Autism rates as a function of industrial release of mercury

Model	Amount of Hg (per 1000 lb)	Amount of Hg (per 1000 lb) <sup>2</sup>	Distance to industrial sources per 10 miles	1997 autism rates	District Wealth (per \$100,000)	Urban vs. rural	Suburban vs. rural	Percent White
<i>Model 1a</i>								
Regression coefficient (standard error)	<b>.026(.010)*</b>	–	–	–	–	–	–	–
Incident Risk Ratio	<b>1.026</b>	–	–	–	–	–	–	–
<i>Model 1b</i>								
Regression coefficient (standard error)	–.007 (.014) <sup>ns</sup>	<b>.018(.006)**</b>	–	–	–	–	–	–
Incident Risk Ratio	–	<b>1.018</b>	–	–	–	–	–	–
<i>Model 1c</i>								
Regression coefficient (standard error)	.021 (.015) <sup>ns</sup>	<b>.02(.006)**</b>	<b>–.014 (.006)*</b>	–	–	–	–	–
Incident Risk Ratio	–	<b>1.020</b>	<b>0.986</b>	–	–	–	–	–
<i>Model 1d</i>								
Regression coefficient (standard error)	.003 (.011) <sup>ns</sup>	<b>.018 (.005)**</b>	<b>–.02 (.008)*</b>	<b>.16 (.01)***</b>	<b>.047 (.01)**</b>	<b>.29 (.04)***</b>	<b>.33 (.04)***</b>	<b>.004 (.001)**</b>
Incident Risk Ratio	–	<b>1.018</b>	<b>.980</b>	<b>1.170</b>	<b>1.048</b>	<b>1.33</b>	<b>1.39</b>	<b>1.004</b>

Note: Second column reflects the amount of mercury squared, the non-linear polynomial term.

\*p < .05.  
\*\*p < .01.  
\*\*\*p < .001.

Table 3  
2002 Autism rates as a function of power plant release of mercury

Model 2: 2002 autism rates as function of 1998 pounds of mercury emission from power plant sources	Pounds of Hg per 1000	Non-linear term (Pounds of Hg per 1000) <sup>2</sup>	Distance to industrial sources per 10 miles	1997 autism rates	District Wealth (per \$100,000)	Urban vs. rural	Suburban vs. rural	Percent White
<i>Model 2a</i>								
Regression coefficient (standard error)	.037 (.018)*	—	—	—	—	—	—	—
Incident Risk Ratio	1.037	—	—	—	—	—	—	—
<i>Model 2b</i>								
Regression coefficient (standard error)	.044 (.020)*	.050(.030) <sup>ns</sup>	—	—	—	—	—	—
Incident Risk Ratio	1.044	—	—	—	—	—	—	—
<i>Model 2c</i>								
Regression coefficient (standard error)	.017 (.022) <sup>ns</sup>	—	.011 (.040)*	—	—	—	—	—
Incident Risk Ratio	—	—	.989	—	—	—	—	—
<i>Model 2d</i>								
Regression coefficient (standard error)	.003 (.011) <sup>ns</sup>	—	.014 (.045)*	.161 (.01)**	.045 (.01)**	.290 (.04)**	.330 (.04)**	.005 (.001)**
Incident Risk Ratio	—	—	.986	1.170	1.056	1.33	1.39	1.005

Note: Second column reflects the amount of mercury squared, the non-linear polynomial term.

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

in other models. Model 1d is the fully adjusted model depicting that the positive non-linear term for pounds, and the inverse association for distance, remain independently associated with 2002 autism rates after adjustment for 1997 autism rates, urbanicity, racial composition, and district wealth. Urbanicity and 1997 autism rates demonstrate to be the strongest predictors of 2002 autism rates in the final model.

Table 3 shows the Poisson regression coefficients and the corresponding IRR for the models exploring the linear and non-linear association between 1998 mercury release from power plant sources, distance to these sources, and 2002 autism rates.

Model 2a shows that environmentally released mercury from power plants in 1998 is significantly associated with autism rates in 2002. For every 1000 pounds of release there is a corresponding 3.7% increase in autism rates. In model 2b, the squared term for pounds was entered into the model and was not significant and therefore, not used in the subsequent models. Adding distance to the equation in model 2c shows that for every 10 miles away from the source, there is a significant 1% decrease in the autism Incident Risk. A 20-mile distance would yield a 2.2% decreased risk. Adding non-linear distance terms (distance squared and the square root of distance) (not depicted) was not significant and therefore not utilized in the next model. Most importantly however, in model 2c, the coefficient for pounds is no longer significant. This suggests that the direct effect between pounds of release in 1998 and 2002 autism rates are fully explained by distance to the source of release. The fully adjusted model 2d shows that this effect remains independent after adjustment for the covariates.

## Discussion

These results build upon two prior studies demonstrating an association between environmental mercury release and autism rates (Palmer et al., 2006; Windham et al., 2006). The current study shows that environmental mercury in 1998 is associated with autism rates in 2002 after adjusting for other relevant sociodemographic covariates including autism rates in 1997. This is consistent with the prior reports. The novel findings in this study are that distance to the sources of mercury release was independently related to autism rates. In the separate analysis of power plant emissions, distance to the source fully explained the association between total pounds of mercury release and autism rates.

We also found that the association between releases from industrial rather than power plant sources was non-linear—e.g. increases in pounds from industrial sites were associated with an accelerated risk function. This difference in the shapes of the exposure-response curve for industrial release (exponential increase) versus release from power plants (linear) might be explained by the fact that pollution from industrial sources are relatively more localized and not as far spreading as pollution from power plants. It is

1 reasonably to suspect that greater local release could cause  
2 exponential effects as compared to more widely distributed  
3 releases.

4 On the other hand, the non-linear functions for distance  
5 were not significantly related to the outcome. It is plausible  
6 to suspect that exposure mediated by distance from the  
7 source depends more on other factors such as character-  
8 istics of the physical environment and predominant wind  
9 or rain patterns rather than simply distance alone.  
10 Exposure from power plants can potentially span thou-  
11 sands of miles and modeling the kinds of factors that affect  
12 exposure over time would require data that are not readily  
13 available. Notwithstanding, the results demonstrate an  
14 overall inverse association between distance to the source  
15 of release and subsequent autism rates. While these effects  
16 are relatively small, they are significant and demonstrate  
17 potential public health risks.

18 Although a major limitation to this study is that we  
19 cannot verify exposure at the individual level, a host of  
20 other plant, animal and human studies have demonstrated  
21 that distance to sources of environmental mercury expo-  
22 sure are related to increased body burdens of mercury  
23 (Ordonez et al., 2003; Fernandez et al., 2000; Hardaway  
24 et al., 2002; Navarro et al., 1993; Kalac et al., 1991; Moore  
25 and Sutherland, 1981). However, the effects of duration  
26 and dose amounts of environmental exposures are not  
27 currently known—and we do not know that body burden  
28 of mercury is in fact related to the potential exposure  
29 measures used in these analyses.

30 Mercury is a known immune modulator (Moszczynski,  
31 1997). These effects include the production of autoanti-  
32 bodies to myelin basic protein (El-Fawal et al., 1999) and  
33 effects on the ratio of Th1/Th2 immunity factors (Kroemer  
34 et al., 1996). This is consistent with the literature  
35 demonstrating similar types of altered immune function  
36 in autistic children (Singh et al., 1997; Singh and Rivas,  
37 2004; Krause et al., 2002; Cohly and Panja, 2005; Vojdani  
38 et al., 2003). However, unlike the specific vector known  
39 about exposure through fish consumption, very little is  
40 known about exposure routes from seemingly randomly  
41 distributed ambient exposures in the environment—parti-  
42 cularly in air.

43 Even if ambient air, ground exposure routes, and low-  
44 level toxic thresholds can be identified by researchers,  
45 differential genetic susceptibilities in the ability to meta-  
46 bolize heavy metals and other pollutants would still need to  
47 be considered in future research (Herbert et al., 2006).  
48 While inconclusive to date, the existing studies warrant the  
49 need for further investigation on environmental mercury  
50 pollution and the developmental health of children.

51 There are some important limitations to this manuscript  
52 that should be addressed. First, these data do not reflect  
53 the true community prevalence rates of autism, largely  
54 because children who are not of school age are not counted  
55 in the TEA data system. This is reflected in the  $\frac{1}{500}$  autism  
56 rates for 2002 present in Table 1—which are lower than the  
57 current CDC reports of  $\frac{1}{150}$  (CDC, 2007).

Further, individual risk cannot be inferred from  
population-based ecological studies such as this. Further,  
conclusions about exposure are limited, because distance  
was not calculated from individual homes to the pollution  
source, but from school district centroids of varying sizes.  
Rural school districts are usually larger in size than urban  
school districts and are one good reason to include  
urbanicity as covariates in these models.

This study should be viewed as hypothesis generating—a  
first step in examining the potential role of environmental  
mercury and childhood developmental disorders. Nothing  
is known about specific exposure routes, dosage, timing,  
and individual susceptibility. We suspect that persistent  
low-dose exposures to various environmental toxicants,  
including mercury, that occur during critical windows of  
neural development among genetically susceptible children  
(with a diminished capacity for metabolizing accumulated  
toxicants) may increase the risk for developmental  
disorders such as autism. Successfully identifying the  
specific combination of environmental exposures and  
genetic susceptibilities can inform the development of  
targeted prevention intervention strategies.

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