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A POSITIVE ASSOCIATION FOUND BETWEEN AUTISM PREVALENCE AND CHILDHOOD VACCINATION UPTAKE ACROSS THE U.S. POPULATION

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The reason for the rapid rise of autism in the United States that began in the 1990s is a mystery. Although individuals probably have a genetic predisposition to develop autism, researchers suspect that one or more environmental triggers are also needed. One of those triggers might be the battery of vaccinations that young children receive. Using regression analysis and controlling for family income and ethnicity, the relationship between the proportion of children who received the recommended vaccines by age 2 years and the prevalence of autism (AUT) or speech or language impairment (SLI) in each U.S. state from 2001 and 2007 was determined. A positive and statistically significant relationship was found: The higher the proportion of children receiving recommended vaccinations, the higher was the prevalence of AUT or SLI. A 1% increase in vaccination was associated with an additional 680 children having AUT or SLI. Neither parental behavior nor access to care affected the results, since vaccination proportions were not significantly related (statistically) to any other disability or to the number of pediatricians in a U.S. state. The results suggest that although mercury has been removed from many vaccines, other culprits may link vaccines to autism. Further study into the relationship between vaccines and autism is warranted.

Autism is an urgent and growing public health problem in the United States. The illness impairs speech, language, social abilities, and behavior. In 1990, autism was considered a rare disease (Tebben 1990), but less than 2 decades later autism affected an estimated 1 in 91 U.S. children (Kogan et al. 2009). Although scientists generally agree that a genetic predisposition for autism exists (Rutter 2000), genes alone do not change quickly enough to create the current epidemic. The recent explosion in the prevalence of autism suggests the existence of one or more environmental triggers (Blaxill 2004). Could one of those triggers be the battery of vaccinations given to young children?

Chronic, negative reactions to vaccinations have been recognized in both humans and animals. In the late 19th Century, Burnett (1884/1960) described long-term negative effects such as eczema, diarrhea, and fatigue in some individuals who received a series of smallpox vaccinations. By the 1990s, veterinarians began to notice that some animals developed chronic ailments such as autoimmune disorders and seizures after being vaccinated (Smith 1995; Dodds 2001). In the early

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2000s, vaccines were shown to be linked to autoimmune disorders and, possibly, autism in humans (Shoenfeld and Aron-Maor 2000).

There are several reasons why vaccines may trigger autism. Certain vaccines contain thimerosal, a preservative that is almost half mercury (Hg) by weight, which was shown to be associated with adverse effects including autism. Nataf et al. (2006) found that children with autism have higher levels of precoproporphyrin, a biomarker for Hg toxicity, than neurotypical children. This finding was confirmed by Geier and Geier (2007) and Geier et al. (2009) in the United States, Austin and Shandley (2008) in Australia, and Youn et al. (2010) in Korea. Thimerosal-containing hepatitis B shots were associated with delayed acquisitions of vital reflexes in baby macaques (Hewitson et al. 2010). Although thimerosal was removed from many vaccines from 2000, it is still present in almost all influenza shots as well as eight other U.S. vaccines given to children (Centers for Disease Control and Prevention 2010). In addition, the CDC began in the early 2000s to encourage the inoculation of pregnant women and children aged 6 to 23 months against influenza (Centers for Disease Control and Prevention 2001; 2002). Given the increased use of influenza shots containing thimerosal, children's exposure to Hg via vaccines was likely increased in utero but not decreased after fetuses were born, even though thimerosal was removed from other vaccines.

There are other possible links between vaccines and autism besides Hg. Vaccines also contain the neurotoxin aluminum (Al) as well as live viruses. The Al in vaccines has been associated with disorders in the central nervous system (Authier et al. 2001) as well as with autism (Blaylock 2008). Combining Hg and Al magnifies the toxicity of each (Haley 2005). Both metals also are known to suppress the immune system (Havarinasab et al. 2005); thus, a susceptible person may not be able to mount an effective immunological response to the live viruses found in certain vaccines such as the measles–mumps–rubella shot. Measles-containing vaccines stimulate the production of cytokines that inflame and damage the brain, possibly contributing to autism (Ashwood et al. 2004; Vargas et al. 2005; Singh 2009).

Children with autism appear to have vulnerabilities that their neurotypical peers do not possess. Autistic children tend to exhibit higher levels of oxidative stress and poorer methylation, the process by which the body detoxifies itself (James et al. 2004). This difficulty in detoxifying could be associated with metals from vaccines being sequestered in the brain and causing neurological damage (Kern et al. 2007). Vaccines may also increase the oxidative stress of children with preexisting mitochondrial dysfunctions to such an extent that the children develop autism (Poling et al. 2006). In general, susceptibility to developing a neurological disability after exposure to an environmental insult such as a vaccine depends on factors such as a child's age at time of exposure, amount of exposure, genetic predisposition, and stress (Kern and Jones 2006).

Compounding these biological issues is the fact that the number of vaccinations recommended for U.S. children by age 2 years has more than tripled, from 8 vaccinations in 1983 to 27 in 2010 (Centers for Disease Control and Prevention 1983; 2010). Although individual vaccines are tested for safety and efficacy, no study has ever examined the safety of the entire vaccination schedule recommended for U.S. children by the CDC. Neither the short-term nor chronic interactions among all the vaccines in a child's recommended schedule have ever been tested.

Examining the relationship between the proportion of children who receive vaccinations and the prevalence of autism may provide insights into whether autism is an adverse reaction to vaccinations. If an association between receiving vaccinations and developing autism is found to exist across geography and through time, further investigation into the hypothesis is warranted.

METHODS

In this study, the relationship between the proportion of U.S. children who received a series of vaccinations recommended by

the U.S. Centers for Disease Control and Prevention (CDC) by age 2 years and the prevalence of autism in each U.S. state over time was examined.

Measures

Prevalence of autism To determine autism prevalence by U.S. state, the number of 8-year-old students classified with either (1) autism or (2) speech or language impairments (speech disorders) was divided by the total number of 8-year-olds in the state. The number of children with disabilities came from the U.S. Department of Education, Office of Special Education Programs (2007) and the total number of students came from the U.S. Department of Education, National Center for Education Statistics. Although the diagnosis of autism is usually made when a child is 3 or 4 years old, some children are not diagnosed until they are older. Children who receive a diagnosis of autism usually do so by the time they are 8 years old. The category of speech or language impairments was included with autism, because these impairments are closely linked to autism (Conti-Ramsden et al. 2006; De Fosse et al. 2004; Herbert et al. 2007).

Exposure to a recommended vaccination series Since 1994, the CDC has commissioned an annual survey to estimate vaccination coverage in the United States for preschool children. Surveyors at the National Opinion Research Center (NORC) at the University of Chicago randomly call homes to find households with children aged 19 to 35 months. When such a household is found, the interviewer asks which vaccinations the child has received. If the parent or guardian agrees, NORC follows up the telephone interview with a written survey to the vaccination provider. The survey reaches approximately 30,000 households with children of the appropriate age. The proportion of children in each state that receives the various vaccines recommended by the CDC is reported. Starting in 1995, the CDC reports the percentage of young children who have received the 4:3:1:3:3 series of shots, which consists of at least four doses of the diphtheria, tetanus, and pertussis (or diphtheria, tetanus, and acellular pertussis) vaccine, three doses of poliovirus vaccine, one dose of any measles-containing vaccine, three doses of the Hib vaccine, and three doses of hepatitis B vaccine. The results of this survey as well as the follow-up verification from the vaccination provider are available to the public (Centers for Disease Control and Prevention, National Center for Health Statistics 2007). Since the possible magnification effect of the toxins in vaccines is of interest as well as the possible interactions between toxins and live viruses, the proportion of children who received the entire 4:3:1:3:3 series of vaccinations by the time they were 19 to 35 months old was examined in this study.

Children who are vaccinated at age 2 years may not develop autism until they are older. To determine the prevalence of autism for a specific cohort of children, the vaccination data from when the children were 2 years old is compared with autism prevalence when they are 8 years old. The relevant vaccination data for children who were 8 years old in 2001 are those from 1995, when the children were 2 years old. For children who turned 8 years old in 2002, the relevant vaccination data are from 1996, and so on. The earliest available data—vaccination data from 1995—were matched with autism prevalence up to 2007. Table 1 shows the vaccination and autism/speech disorder data by state for the various years in this study.

Figure 1 shows the relationship between the prevalence of 8-year-old children with autism or speech disorders by state in 2005 and vaccination proportions 6 years earlier. The darker the shading of the state, the higher is the proportion of children who received the 4:3:1:3:3 series of vaccinations by the time they were 2 years old; the larger the circle, the greater is the prevalence of autism or speech disorders. Groupings of data were determined using the Natural Breaks (Jenks) method in the Arc geographic information system (ArcGIS) software package (Environmental System Research Institute Inc. 2009). The map presents an ambiguous picture: Some states,

TABLE 1. Vaccination Rate (1995–2001) and AUT/SLI Prevalence (2001–2007) by U.S. State

U.S. state	Vax rate 1995	AUT/SLI 2001	Vax rate 1996	AUT/SLI 2002	Vax rate 1997	AUT/SLI 2003	Vax rate 1998	AUT/SLI 2004	Vax rate 1999	AUT/SLI 2005	Vax rate 2000	AUT/SLI 2006	Vax rate 2001	AUT/SLI 2007
Alabama	45.8	4.6	65.2	4.4	76.5	4.4	74.2	4.5	74.1	4.7	76.1	4.6	79.1	4.5
Alaska	54.3	5.8	67.2	5.1	68.8	5.5	74.1	6.0	74.5	4.8	70.6	5.0	71.2	4.8
Arizona	51.2	3.8	61.8	4.1	62.0	4.1	69.0	4.8	67.3	5.2	67.2	5.4	68.1	6.2
Arkansas	53.6	4.8	61.4	4.8	74.8	5.0	65.9	5.3	70.4	5.8	67.1	6.3	69.1	5.9
California	57.7	4.5	65.8	4.6	67.1	4.6	69.8	4.6	70.5	4.6	72.3	4.7	72.6	4.6
Colorado	51.4	3.1	66.3	3.5	64.4	3.6	67.9	3.6	69.6	3.9	71.6	4.0	71.5	4.1
Connecticut	63.9	3.6	80.6	3.9	76.0	3.7	81.5	3.9	82.3	3.9	81.6	4.2	78.4	4.1
Delaware	54.7	3.3	73.5	3.2	68.3	3.3	68.0	3.6	69.0	3.1	66.2	2.1	68.9	N/A
District of Coumbia	49.8	3.2	66.8	2.3	62.4	2.7	63.5	2.6	70.9	2.7	70.0	3.7	74.9	3.3
Florida	53.4	6.0	72.1	6.0	67.3	5.6	75.4	5.6	77.9	5.7	71.7	6.4	73.0	6.4
Georgia	61.7	5.2	76.9	5.5	72.9	5.7	75.7	5.9	77.9	5.9	77.7	5.9	78.5	5.7
Hawaii	66.2	2.0	74.4	1.8	73.2	1.7	73.0	1.4	79.2	1.3	72.8	1.4	70.8	1.0
Idaho	40.7	4.0	51.9	3.9	63.9	3.8	66.2	4.2	65.0	4.2	70.7	4.6	70.2	4.4
Illinois	57.2	5.6	64.9	5.6	67.4	5.6	73.7	5.5	72.0	5.5	71.2	5.7	72.7	5.6
Indiana	41.8	8.8	56.7	8.9	62.7	9.1	68.8	9.1	65.3	9.2	72.0	9.8	71.1	10.0
Iowa	47.7	1.6	70.3	2.5	71.0	2.1	78.1	2.2	78.9	2.2	82.5	2.1	78.6	2.0
Kansas	35.7	5.1	58.2	5.1	72.1	5.2	72.1	5.0	70.7	5.1	71.3	4.9	72.8	4.9
Kentucky	59.6	6.0	70.4	6.0	70.2	5.8	75.5	6.3	84.4	6.6	77.0	7.1	75.9	7.1
Louisiana	61.8	5.1	73.0	5.1	70.6	5.2	72.4	5.4	72.3	5.1	71.8	5.4	64.1	5.6
Maine	46.6	6.6	68.4	6.9	78.4	6.8	78.3	7.2	76.8	7.7	76.0	7.5	75.1	7.2
Maryland	59.2	4.5	64.9	4.7	73.7	4.8	72.3	4.6	72.7	4.5	75.4	4.7	73.4	4.6
Massachusetts	70.7	2.2	79.9	2.6	81.1	3.0	79.6	3.3	81.4	3.6	81.4	3.8	76.6	4.1
Michigan	46.7	5.1	66.2	5.5	69.3	5.5	73.9	5.7	70.9	5.9	73.7	6.2	70.0	6.2
Minnesota	41.2	4.0	63.2	4.3	63.7	4.4	73.1	4.5	78.5	4.8	82.4	4.8	76.3	5.1
Mississippi	38.1	6.2	68.1	6.4	70.8	6.6	79.5	6.2	79.0	6.2	75.9	6.7	80.2	6.8
Missouri	50.5	6.2	68.3	7.1	67.6	7.5	74.8	8.1	68.9	8.5	76.8	9.0	75.5	8.7
Montana	44.7	5.7	59.2	5.1	64.3	5.7	75.2	6.0	76.4	6.2	71.1	N/A	77.9	5.9
Nebraska	49.2	7.3	65.3	7.0	66.4	7.2	71.1	7.7	79.8	7.7	75.5	7.6	78.9	7.9
Nevade	55.9	4.0	61.9	4.0	65.5	4.2	70.4	3.9	68.5	4.3	69.1	5.0	68.1	5.1
New Hampshire	72.7	3.5	77.3	3.2	76.8	3.3	75.8	3.4	78.4	3.7	78.9	3.6	77.6	3.9
New Jersey	60.5	7.1	68.5	7.3	70.5	7.1	76.7	7.2	75.3	7.2	71.2	7.6	73.1	7.7
New Mexico	43.8	5.1	66.2	5.1	66.1	5.0	66.0	4.8	66.6	4.9	64.5	5.3	63.2	5.5

New York	62.6	3.6	72.6	3.8	68.1	4.1	79.9	4.2	78.2	4.4	72.3	4.6	77.1	5.0
North Carolina	62.5	5.1	69.8	5.0	76.5	5.1	76.7	5.5	77.1	5.5	82.8	5.8	80.4	5.9
North Dakota	65.7	6.5	71.9	6.8	73.2	6.8	73.0	7.3	76.3	6.5	80.3	6.9	78.7	6.7
Ohio	47.7	4.3	69.5	4.4	63.9	4.3	71.0	4.4	73.0	4.5	68.9	4.7	71.2	4.6
Oklahoma	42.3	5.6	59.0	6.1	65.0	5.9	70.3	5.9	70.4	6.5	68.3	7.0	70.0	6.7
Oregon	56.6	6.1	62.4	6.1	62.0	6.1	67.4	6.4	63.8	6.6	74.7	6.8	68.5	6.9
Pennsylvania	62.2	4.4	70.1	4.7	70.9	4.7	75.7	4.9	80.8	5.0	77.8	5.3	78.8	5.4
Rhode Island	58.5	6.1	77.0	6.3	72.0	6.6	76.9	6.5	83.2	6.2	80.5	6.8	81.7	6.9
South Carolina	72.2	7.1	83.0	7.4	74.4	7.3	83.8	7.2	78.0	7.3	78.5	7.0	78.7	7.3
South Dakota	27.5	6.5	62.0	7.1	67.0	7.5	66.1	7.7	76.9	7.6	73.6	7.9	76.5	8.7
Tennessee	57.8	5.3	72.3	5.4	71.3	5.4	73.5	5.3	70.0	5.5	76.8	5.9	79.7	6.0
Texas	52.4	4.0	62.5	4.1	65.3	4.2	63.7	4.2	64.8	4.2	63.5	4.3	69.7	4.3
Utah	43.7	4.7	53.4	4.8	53.7	4.9	64.8	5.4	65.8	5.2	68.2	5.7	66.1	6.6
Vermont	55.8	3.4	76.8	3.0	78.0	2.3	80.7	2.9	85.2	2.5	77.0	2.8	80.3	N/A
Virginia	52.8	4.2	68.3	4.5	66.6	4.6	75.1	4.6	74.9	4.7	70.7	4.9	74.9	4.7
Washington	57.0	4.1	68.5	4.0	66.6	4.0	68.8	4.1	67.1	4.2	72.5	4.3	71.2	4.4
W Virginia	28.9	9.9	50.5	9.7	73.4	10.1	75.6	10.2	77.8	10.7	71.9	11.0	78.1	11.3
Wisconsin	53.1	4.2	67.1	4.4	70.9	4.7	70.6	4.9	78.6	5.1	74.2	5.7	79.5	6.0
Wyoming	18.9	6.9	48.0	6.8	69.2	7.6	75.4	8.1	81.5	8.2	78.2	8.7	74.3	10.0

Note. Vax rate = proportion of 2-year-olds (%) receiving 4:3:1:3:3 series of vaccinations 6 years earlier. AUT/SLI = prevalence of autism or speech/language impairment (%) in year indicated. N/A = not available.

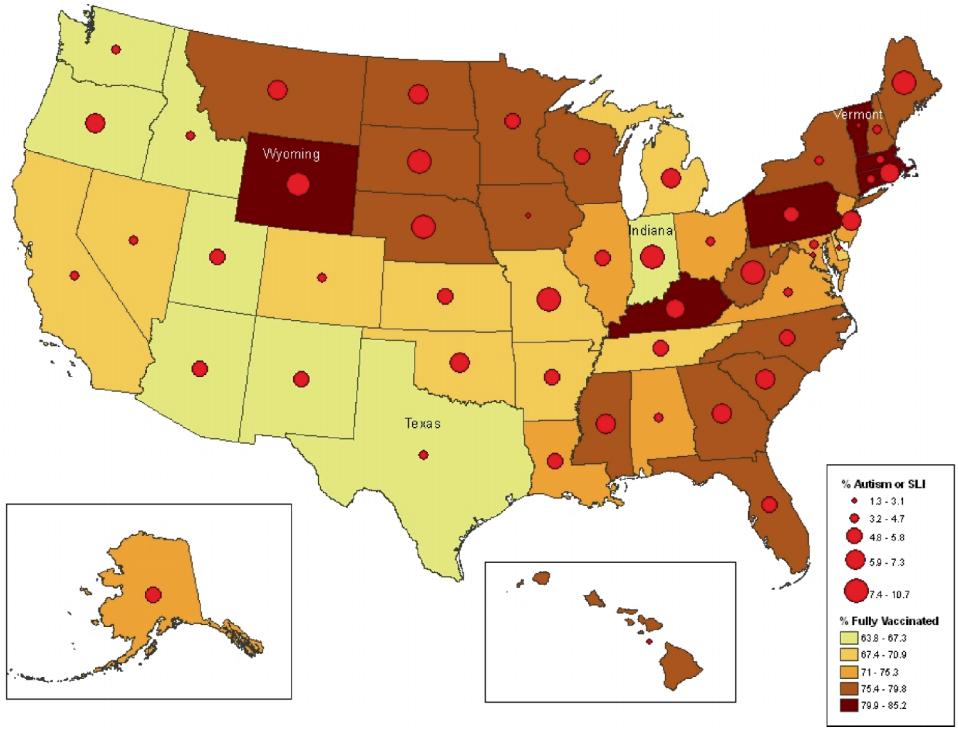

FIGURE 1. Vaccination (1999) and Autism or Speech Disorder (2005) by U.S. State (color figure available online).

such as Texas, have low vaccination rates and low prevalence of autism, while other states, such as Indiana, have low vaccination rates and a high prevalence of autism. Conversely, Wyoming has a high vaccination rate and high prevalence of autism, while Vermont has a high vaccination rate and low prevalence of autism. Additionally, Figure 1 merely presents a snapshot, based on prevalence data in 2005. More rigorous analysis is needed that includes several years of data, as well as variables to control for influences other than the vaccine series.

Controlling for family environment Family income and ethnicity may influence whether a child receives a diagnosis of autism. More affluent parents may be more prone to seek a diagnosis (McAdoo and DeMyer 1977). Ethnicity may be a factor in terms of the postulation that a deficiency in vitamin D is associated with autism: Dark-skinned people are known to require more vitamin D and therefore might be more prone to develop autism (Cannell 2008). For these reasons, variables that measure household income and ethnicity are included.

To measure income, the median income for a four-person family reported by the U.S. Census Bureau (2008) was used. The inflation-adjusted median income (using the year 2000 as the base) for the year the child was born was used. For example, the prevalence of autism or speech disorder for 8-year-olds in a particular U.S. state in 2001 was matched with the median income in that state from 1993. Ethnicity figures were derived directly from the CDC's National Immunization Survey. The survey reported whether the child was Hispanic, African American, white non-Hispanic, or other. For each state and year, the percentage of each ethnic group in the survey was determined.

Statistical Analysis

To understand whether vaccination might be linked to autism, data on the prevalence of autism or speech disorders between 2001

and 2007 were matched with vaccination rates between 1995 and 2001 for each U.S. state. Regression analysis determines how a 1% change in the vaccination rate influences the percent change in the prevalence of autism or speech disorders (Lewis-Beck 1990). The statistical model used took into consideration the unique characteristics of each state. For example, each state had a unique mixture of pollution, which may have affected the prevalence of autism (Palmer et al. 2006; 2009), yet such an effect was not included in this study. A fixed-effects, within-group panel regression (Hall and Cummins 2005) controlled for these unique yet undefined characteristics by deriving a different starting point (intercept) for each U.S. state. The 51 different intercepts—one for each U.S. state and the District of Columbia—reflected the base level of autism or speech disorders occurring in that state that were not explained by the other independent variables (vaccination rates, income, or ethnicity). The model then produced a single relationship between the independent variables and the prevalence of autism or speech disorders. Although each state started from a different prevalence rate of autism or speech disorder, the relationships between the dependent variable and independent variables was considered the same across state; a 1% change in vaccination rates was associated with the same percent change in prevalence of autism or speech disorder across states. Similarly, the model controlled for the year in which an observation took place. If autism awareness increased in a particular year, the prevalence might also rise (Liu et al. 2010). To control for reasons that occur in a particular year, time dummy variables for the year of observation were included: If an observation of prevalence occurred in the year 2002, then the variable 2002 took a value of 1 and the other year variables took a value of 0. Heteroskedastic-robust standard errors were calculated and used in determining *p* values (Hall and Cummins 2005). The statistical package TSP 4.5 was used for the analysis.

The model that results from the 7 years of prevalence data (years 2001 to 2007) with control variables as well as time dummy variables is:

$$\begin{aligned}\text{Autism} = {} & a + b1*\text{Vaccination} + b2*\text{Log}(\text{Income}) + b3*\text{Hispanic} + b4*\text{African American} + b5*\text{Other} + b6*2002 + \\ & b7*2003 + b8*2004 + b9*2005 + b10*2006 + b11*2007\end{aligned}$$

If a combination of independent variables perfectly predicts another independent variable, the model is said to suffer from perfect multicollinearity and some coefficients will be undefined (Lewis-Beck 1990). In this model, if the percentage of the population in a U.S. state that was Hispanic, African American, and other is known, then the percentage of the population that was white, non-Hispanic might be determined with certainty. Similarly, if the year of the prevalence observation was not between 2002 and 2007, then the year of the observation was 2001 with certainty. Therefore, to obtain meaningful coefficients, the dummy variable for the year 2001 as well as the percentage of white, non-Hispanic children were removed from the model.

RESULTS

The results are reported in the first column of Table 2. The association between receiving the 4:3:1:3:3 series of vaccinations and the prevalence of autism or speech disorders is a positive and statistically significant 1.7%. This coefficient represents the average change in the prevalence of autism or speech disorders for a 1% change in vaccination rates, holding the other independent variables constant. This result holds both across geography and over time. The results suggest that if a given U.S. state has a 1% higher vaccination rate than another U.S. state, then the state with the higher vaccination rate might have, on average, a 1.7% higher prevalence of autism or speech disorders. Further, if a given U.S. state decreases its vaccination coverage by 1% from one year to the next, prevalence of autism or speech disorders may, on average, fall by 1.7%. If 100%

TABLE 2. Analysis of Learning Disabilities, United States, 2001–2007, Fixed Effects Model

	Autism or speech or language impairment	Emotional disturbance	Hearing impairment	Mental retardation	Orthopedic impairment	Other health impairment	Specifi clearning disability	Traumatic brain injury	Visual impairment
Proportion of children receiving 4:3:1:3:3 vaccination series	0.0166*** (0.00)	0.0010 (0.31)	0.0026 (0.70)	0.0008 (0.69)	–0.0008 (0.42)	0.0018 (0.32)	0.0064* (0.09)	0.0006 (0.17)	0.0003* (0.10)
Log(household Income)	–0.0029 (0.70)	0.0006 (0.72)	–0.0081 (0.31)	0.0008 (0.34)	–0.0014 (0.46)	–0.0011 (0.73)	0.0004 (0.95)	–0.0014*** (0.01)	–0.0001 (0.71)
Hispanic (%)	0.0213 (0.13)	0.0006 (0.83)	–0.0269* (0.06)	0.0117*** (0.00)	–0.0042 (0.20)	–0.0029 (0.56)	–0.0061 (0.72)	–0.0008 (0.41)	0.0005 (0.29)
African American, not Hispanic (%)	0.0216 (0.13)	0.0108 (0.15)	–0.0443 (0.12)	0.0053 (0.97)	–0.0073 (0.19)	0.0055 (0.29)	0.0231 (0.23)	–0.0001 (0.90)	0.0001 (0.79)
Other, not Hispanic (%)	–0.0208 (0.41)	–0.0124** (0.03)	–0.0074 (0.64)	0.0024 (0.69)	–0.0025 (0.60)	–0.0078 (0.26)	–0.0479*** (0.01)	–0.0009 (–0.77)	0.0013** (0.04)
Adjusted R^2	.9636	.9358	.1803	.9536	.7935	.9090	.9006	.9280	.5312
n	354	354	348	354	327	352	356	231	302

Note. Standard errors are heteroskedastic-robust using White's method. Time dummy variables included; *p* values are in parentheses. The maximum number of observations is 357. Not every state reports each disability for every year so the number of observations could be less than 357. Significance indicated as *** (**) (*) $p < .01$ (.05) (.10).

children received this series of vaccinations, the prevalence of autism or speech disorders would be 1.7% higher than the prevalence without vaccination. With more than 4×10^6 babies born in the United States each year, this finding translates into an additional 680 children (= number of children [4×10^6] $\times$ coefficient [0.017] $\times$ 1% [0.01]) exhibiting autism or speech disorders for every 1% rise in children receiving the 4:3:1:3:3 series of vaccinations by age 2 years.

Robustness Tests

The association between receiving vaccinations and developing autism or a speech disorder might be driven by parental behavior or access to medical care. A parent or guardian who obtains timely vaccinations for a child may also be more prone to seek medical diagnoses such as autism for the child. Similarly, parents who live in areas with greater access to medical care such as cities may be better able to obtain both vaccinations as well as autism diagnoses for their children.

To test whether the association between autism and vaccination is spurious, two methods were used. The first was to analyze diagnoses of other disabilities. If the autism results are driven by parental behavior or access to medical care, one should also see prevalence rates of other disabilities—especially those that require parental action—are positively associated with receiving the vaccination series. Tests were conducted to examine the association between the proportion of children receiving the 4:3:1:3:3 series of vaccinations and the prevalence of other disabilities. The same model that was used to analyze autism was also used to determine other disabilities. The source of the data for the number of children receiving services from schools for particular disabilities was the U.S. Department of Education, Office of Special Education Programs (2007), the same as the source for the number of children receiving services for autism. The other disabilities were emotional disturbance, hearing impairment, mental retardation, orthopedic impairment, other health impairment, specific learning disability, traumatic brain injury, and visual impairment.

In columns 2 through 9 of Table 2, the relationships between the proportions of children receiving the 4:3:1:3:3 series of vaccinations and the prevalence of 8 other disabilities are reported. None of the relationships is significant at the 5% level. The prevalence rates of two classifications—specific learning disability and vision impairment—are marginally positively related to the proportion of children receiving the 4:3:1:3:3 series of vaccinations ($p = .09$ and .10, respectively). A specific learning disability is defined as "a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, that may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or to do mathematical calculations" (U.S. Department of Education, Office of Special Education Programs 2007). Since the disability relates to language or speech impairments, certain school systems might classify children with specific learning disabilities, while other schools classify children with similar impairments with speech or language impairments. The positive relationship between visual impairment and vaccination may be the result in autistic children of the influence on the retina of the pertussis toxin (found in the DTP vaccine), which produces visual impairments (Megson 2000).

To further test whether access to medical care influenced the positive relationship between vaccination proportions and the prevalence of autism, the relationship between the number of pediatricians in a state and the prevalence of autism was examined. If autism diagnoses are driven by access to medical care, the greater the number of pediatricians per U.S. state, the higher should be the prevalence of autism. However, the relationship between autism prevalence and number of pediatricians per 1000 children by state (Freed et al. 2004), as measured by the correlation coefficient between the two sets of numbers, is –0.29. The result is not statistically significant, suggesting there is no significant relationship

between the number of pediatricians per 1000 children and the prevalence of autism.

The results from examining the number of pediatricians by state and the analysis of other disabilities suggest that the association between the proportion of 2-year-olds receiving the 4:3:1:3:3 series of vaccinations and the prevalence of autism is driven neither by parental behavior nor by access to medical care.

Limitations

This study examined aggregate data, which introduced at least four limitations. (1) Since the dependent variable was a percentage, the regression analysis showed association, not causation. If individual children had been examined, the dependent variable might have been 1 if the child developed autism or speech disorder and 0 otherwise. The results of such a regression could have been used to predict health outcomes for children not in the study. However, such analysis is beyond the scope of this study. (2) The data in this study were not exact. Learning disability classifications were assigned by individual school districts, which may have implemented classifications differently; vaccination proportions were based on limited surveys, not entire populations. (3) Aggregation bias assumes each individual in a given group acts according to the average of the group, but that is rarely the case. In this study, children in each U.S. state were divided into two groups, fully vaccinated and not fully vaccinated. However, the variation among the not fully vaccinated children was not known. Even if a child missed only one shot in the series, that child was classified as not fully vaccinated. A child who missed only one shot was different from a child who was completely unvaccinated, yet in this study both children were classified as not fully vaccinated. (4) Confounding factors were also an issue. Factors such as prenatal exposure to toxins (Austin 2008) and toxin exposure from sources other than vaccines (Palmer et al. 2006; 2009) were not considered yet might influence whether a child develops autism. Although the study found that, on average, children who were not fully vaccinated were less likely to develop autism or speech disorders, any given child—especially a child who was almost fully vaccinated or was exposed to toxins in utero—may have developed the disabilities. As a result of "ecological fallacy"—applying results from the study of aggregate populations to individuals—epidemiological studies such as this one are better for creating hypotheses than for establishing causation (Washio et al. 2008).

DISCUSSION

The results of this study add support to the hypothesized link between vaccines and autism, yet many studies conclude that a link between vaccines and autism cannot be established. How can this study be reconciled with the studies that find no link? Recall that this study asked whether a series of vaccinations could be associated with autism. It used a constant definition of the prevalence of autism and speech disorders—school children receiving services for autism or speech disorders as a % of all school children—as well as a constant age of 8 years old for diagnosis. By using a special type of regression analysis (fixed effects, within-group panel regression) along with dummy variables for time, this study also controlled for confounding factors introduced since the study looked at different U.S. states over time. Most studies that were not able to establish a link focused on a single vaccination or vaccine ingredient and did not consider the interaction among vaccinations. Questions about the methodology or databases used have also been raised. Madsen et al. (2002) investigated a possible link between the measles–mumps–rubella (MMR) vaccine and autism. Data showed the prevalence of autism among children who received the MMR was the same as the prevalence among children who did not, and the study concluded that a link between the MMR vaccine and autism was not established. However, many children in the study were too young to have been diagnosed with autism even if they had received the MMR vaccination (Goldman

and Yazbak 2004). If Madsen et al. (2002) had examined only older children, the results might have been different. A series of articles appeared in 2003 and 2004 that used a Danish database to show that the number of autism cases increased even though thimerosal was removed from vaccines. However, the definition and catchment area of autism cases used in the database expanded during the time of the studies. Had the narrow definition of autism that was used in the beginning of the studies been maintained, the results might have been different (Geier and Geier 2004). In another study, Verstraeten et al. (2003) found a link between exposure to thimerosal and autism, but were not able to confirm the result with further study. However, the U.S. National Institute of Environmental Health Sciences (2006) and the Centers for Disease Control and Prevention (2008) acknowledged that the database used in the study was inadequate for studying a possible link between thimerosal and autism. Concerns included the fact that the study examined different medical facilities over time but provided no controls for differing definitions of autism across institution and over time. Had the studies controlled for these issues, the results might have been different.

One study did examine the entire vaccination schedule. Smith and Woods (2010) evaluated the long-term effects of the timing of vaccinations and found that children who were vaccinated on-time had fewer neurological issues than children who were vaccinated late, which was defined as a child receiving at least 1 vaccination more than 30 days after the recommended date. However, almost all the children in the study were exposed to vaccines, so the study did not address the question of whether exposure to vaccines was associated with negative neurological outcomes. Moreover, by dividing children into 2 groups—those who received vaccinations on time and those who did not—the study aggregated what may be a disparate group of late vaccinators. A child who received all but 1 vaccination on time might be different from a child who received no vaccinations, yet both were in the group of children who did not receive timely vaccinations. Had the researchers examined fully vaccinated versus completely unvaccinated children, the results might have been different.

Future Directions for Research

Comparing the prevalence of autism among children who are fully vaccinated and those who are not vaccinated at all would be enlightening. In their study "Children Who Received No Vaccines: Who Are They and Where Do They Live?" Smith et al. (2004) used data from the U.S. National Immunization Survey to determine the location of unvaccinated children. A follow-up study could investigate the prevalence of autism among unvaccinated children. Other children who typically are not vaccinated could be surveyed. These groups include the Amish and children served by Homefirst, a health clinic near Chicago (Eisenstein, 2009), as well as some homeschooled children or younger siblings of children with autism whose parents decided not to vaccinate. Incremental analysis could also determine the increase or decrease of the prevalence of autism or speech disorders as the number or type of vaccinations increased. A study of vaccinated versus unvaccinated children is useful and feasible.

CONCLUSIONS

Evidence presented in this paper suggests a possible link between susceptible children receiving a battery of vaccinations and developing autism or speech disorders. Although Hg has been removed from many childhood vaccines, other ingredients could link vaccines to autism. Aluminum, which is found in at least 20 U.S. childhood vaccines (Centers for Disease Control and Prevention, 2010), is not only a neurotoxin, but also an immunosuppressant that may allow measles-containing vaccines to create cytokines that damage the brain. Enhanced exposure to aluminum via vaccines may be associated with an increase in the prevalence of neurological disorders such as

autism, especially if an aluminum-containing vaccine is administered along with a measles-containing vaccine. Reducing thimerosal and observing an increase in autism exonerates neither thimerosal nor vaccines from being potential links to autism. Further research into the relationship between vaccines and autism is warranted.

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