Rates and Characteristics of Un-Vaccinated Children in the United States: Reaching Parents Who Choose Not to Vaccinate Their Children

by

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Introduction

In recent years, there has been a resurgence of many childhood illnesses in the United States once nearly eradicated with the development of vaccinations. Pockets of vaccine-preventable disease (including measles, mumps, rubella, pertussis and varicella) have been recently reported with hundreds, sometimes thousands, of cases being contracted in localized outbreaks reminiscent of the more widespread epidemics of a century before. In the first seven months of 2008, the number of measles cases more than doubled (to 131) from an annual average of 63 seen between 2000 and 2007 (CDC, 2008a). And as recently as 2005, an epidemic of pertussis swept across the United States with more than 25,000 reported cases, including more than 7,000 cases among children under the age of seven years (CDC, 2009a; CDC, 2009b).

Epidemiological evidence suggests these outbreaks are likely caused by a combination of factors working together to create an opportunity for infection: vaccine failure (questionable vaccine effectiveness); a susceptibility to illness among people either too young or too old to have received routine vaccinations; and rates of un-vaccinated children that have risen to levels too high to fully protect a population from disease (Schaffzin et al, 2007 Parker et al, 2006).

Even more troubling are reports of parents who believe their children are better off not being vaccinated against disease. Research has found that parents of un-vaccinated children are more likely than others to express doubts about vaccine safety, either citing the controversial link between the measles-mumps-rubella (MMR) vaccine and cases of autism, voicing concern about combination vaccines, or fearing their child's own immune system might be weakened by

immunizations (Kutty, 2009). If parents who do not vaccinate their children believe there are risks associated with the vaccines themselves and the chance of contracting a disease is low, they may decide not to put their children at unnecessary risk by immunizing them (Steinhauer, 2008).

Unfortunately, little research has been done to determine whether there has been an increase in the proportion of children in the United States who are un-vaccinated and, if so, exactly which children are increasingly not being vaccinated.

Using nationally representative data from the National Immunization Survey (NIS) between 2002 and 2007, I examine whether the proportion of children in the United States who remain un-vaccinated has increased over these six years, and whether the characteristics of un-vaccinated children have changed significantly over this same period of time. Understanding both the recent trend in rates of un-vaccinated children and the components of any increase in rates of un-vaccinated children are first steps toward reducing the chance of returning to epidemics of the past by developing policies aimed at informing specific communities in this country about the importance of immunizations.

Background

Six vaccines make up the "431331" series of immunizations recommended by the Centers for Disease Control and Prevention for all children in the United States between birth and 18 months of age (CDC, 2006a). Table 1 lists these vaccines and the number of recommended doses that make up the "431331" series (so called for the recommended number of doses of each vaccine).

Table 1: Type of Vaccine and Number of Doses in the "431331" Vaccine Series

Type of Vaccine	Number of Doses Recommended
Diphtheria-Tetanus-acellular Pertussis (DTaP)	4
Inactivated Poliomyelitis "Polio" Virus (IPV)	3
Measles-Mumps-Rubella (MMR)	1
Haemophilus influenzae type b (Hib)	3
Hepatitis B (HepB)	3
Varicella "chicken pox" (VRC)	1

Table 2 identifies the recommended timing for the administration of the six vaccines that make up the "431331" series by vaccine type and age of child (CDC, 2006a).

Table 2: Recommended Childhood Immunization Schedule by Vaccine and Age, CDC 2006, Approved by the Advisory Committee on Immunization Practices (ACIP).

Vaccine	**Doses**	**Age of Child (in months)**							
		Birth	**1mo**	**2mos**	**4mos**	**6mos**	**12mos**	**15mos**	**18mos**
DTaP	**4**			DTaP	DTaP	DTaP		DTaP	
Polio	**3**			IPV	IPV	IPV			
MMR	**1**						MMR		
Hib	**3**			Hib	Hib		Hib		
Hep B	**3**	HepB	HepB			HepB			
Varicella	**1**						VRC		

Most existing research on childhood immunization patterns in the United States has focused on the need to fully-vaccinate children. This research distinguishes fully-vaccinated children (those who have received all the recommended vaccines) from under-vaccinated children (those who have not received all the recommended vaccines, who are less than fully-vaccinated) in order to address the need to increase the proportion of fully-vaccinated children. Recent studies have shown that a large majority of children in the United States are fully-vaccinated against these childhood diseases (with over three-quarters of U.S. children having received the six vaccines in the recommended "431331" series) and that the numbers have continued to increase over the past several years (from 65.5% in 2002 to 77.4% in 2007 (CDC, 2006b; CDC, 2008b).

Unfortunately, most studies do not differentiate between two very different groups of under-vaccinated children: those who are un-vaccinated altogether (who have received none of the recommended "431331" vaccines), and those who are at least partly-vaccinated (who have received some, but not all, of these vaccines). That is, most research does not consider the *degree* to which children are under-vaccinated. Consequently, little is known about communities in the United States who are not vaccinating their children at all.

Yet, there is reason to believe that the recent outbreaks of vaccine-preventable disease across the United States may be due, at least to some extent, to an increase in the number of completely un-vaccinated children (rather than to groups of children who are otherwise under-vaccinated). Outbreaks may be due partly to incomplete vaccine effectiveness, even in populations with high rates of immunization (Schaffzin, et al, 2007; Tugwell, et al, 2004), or to communities of people who are either too young or too old to be vaccinated, either having been born before the vaccines were developed or having not yet reached the age at which the vaccine is recommended (CDC, 1999). However, previous research has found that un-vaccinated children are many times more likely to contract a vaccine-preventable disease (such as measles or pertussis) than vaccinated children (Meissner, et al, 2004; Feikin, et al, 2000; Salmon, et al, 1999). At least some of the recent U.S. outbreaks have occurred among un-vaccinated children "whose parents had refused to have them vaccinated because of safety concerns about the vaccine" (Parker et al, 2006) and in communities where "personal beliefs" (Salathe & Bonhoeffer, 2008) and "personal belief exemptions" (Omer, et al, 2006) have resulted in vaccination coverage levels below those needed to prevent disease.

Medical research has provided evidence showing vaccines are beneficial not only to the children who receive them but also to the community at large. By building "herd immunity," the

resistance to infection within a group of people that is provided when a large enough proportion of the population is immune to disease (Haber, et al, 2007), even people who are not immune to the disease are protected from illness because their risk of exposure to disease is sufficiently reduced (Lewit & Mullahy, 1994; TFAH, 2004; Gordis, 2008). Fewer people contract the disease because fewer people are infected (and fewer people are susceptible to illness), so the likelihood of spreading and contracting the disease is lower overall. However, disease outbreaks may occur if vaccine coverage in the population falls below a "threshold of viral elimination," beyond which transmission of that disease can no longer be prevented (Hyde, et al, 2006).

Therefore, it is important to understand the rates and composition of un-vaccinated children (within the larger group of more frequently studied under-vaccinated children) to determine the threat to herd immunity and the likelihood of disease outbreak. Yet, despite conducting a wide-ranging literature review, I found only one article that specifically analyzed the number and characteristics of un-vaccinated children in the United States (as distinct from partly- and fully-vaccinated children). Smith, Chu & Barker (2004) used National Immunization Survey (NIS) data from 1995-2001 to look at un-vaccinated children between the ages of 19-35 months (children beyond the age at which the "431331" vaccine schedule should have been completed). Smith et al found not only an upward trend in the number of un-vaccinated children in the United States, but also that the characteristics of un-vaccinated children were "distinctly different" from those of partly-vaccinated children. They first found that "between 1995 and 2000, the estimated numbers [of un-vaccinated children] increased significantly, from 14,719 in 1995 to 24,073 in 2000 (P=0.05)." They also found that un-vaccinated children were more likely to be White and male, have a mother who was married with a college degree, live in a household with annual income exceeding $75,000, and live in states that allowed philosophical exemptions from

immunization. Significantly, they found as well that un-vaccinated children were "clustered geographically, increasing the risk of transmitting vaccine-preventable diseases" to both un-vaccinated and partly-vaccinated children (or even fully-vaccinated children for whom immunizations were less than fully effective). Finally, they found that the parents of un-vaccinated children also were more likely than others to express concern about vaccine safety. By comparison, under-vaccinated children as a whole (and therefore, partly-vaccinated children in particular, who make up the greatest portion of this group) more often were Black, had a younger, un-married mother who had not graduated from college and lived in a household near the poverty level.

Research Questions

Given both that studies have highlighted the relative importance of un-vaccinated children as a factor in the recent outbreaks of childhood diseases, and the dearth of research specifically examining populations of un-vaccinated children in the United States, this paper attempts to answer the following two questions:

First, did the proportion of children in the United States who are un-vaccinated change significantly between 2002 and 2007? And second, did the proportion of un-vaccinated children change in some populations (with certain characteristics) more than others over these six years?

Based on the findings by Smith et al, my own unpublished Master's Thesis research (2008), and the recent media focus on a possible link between vaccines and autism, I expect to find that the proportion of un-vaccinated children has increased significantly over the six year period. In addition, I expect that this increase will be visible in some populations more than others. Given the results of my own research and Smith et al's findings, I expect this increase will be particularly evident among White male children, whose mothers have higher levels of education,

who live in households with income above poverty, with four or more children, and in the western United States.

Data and Methods

Through the CDC, the NIS has collected vaccine data on children in the United States between the ages of 19-35 months every year since 1995 in order to monitor progress towards reaching national childhood immunization goals.

The NIS uses two phases of data collection to obtain vaccination information: (1) a Random Digit Dialing (RDD) telephone survey to obtain a child's vaccine history as well as demographic and socioeconomic characteristics of the child, mother and household; then, given informed consent from a parent to contact the child's vaccine provider(s) by mail, the NIS also collects data with (2) the Provider Record Check (PRC) Study, a provider-reported history of vaccination from the child's medical records (NIS Data User's Guide (DUG), 2007; Smith et al, 2001). Each year, about 70% of the children with completed RDD household surveys also have adequate PRC provider data. Together, RDD and PRC data from the NIS are available to the public via download from the CDC website in the form of annual Public-Use Data Files (U.S. Department of Health and Human Services, 2003-2008).

In annual samples from 2002 to 2007, the NIS collected data on over 120,000 children in the United States (un-weighted sample size, Table 3 below). Using sampling (probability) weights provided by the NIS, these data constituted a nationally representative sample each year of approximately 5.9 million children (weighted count) between the ages of 19 and 35 months. Over the six year period, the data that were collected represented more than 35 million children in the United States.

The smaller sample size in 2005 compared to 2004 was most likely due to a combination of several factors: a later than usual start to data collection; a change in study design (including sampling changes and a loss of respondent incentives) from the previous year; and the impact of Hurricane Katrina in August 2005. The key difference between un-weighted sample sizes in 2007 and previous years was likely a change in sampling areas.

Table 3. Un-Weighted Sample Size, Weighted Count and Percent of Total by Year, NIS 2002-2007.

	Un-Weighted		Weighted	
Year	Sample Size	Percent of Total	Count	Percent of Total
2002	21,410	17.79%	5,845,539.05	16.42%
2003	21,310	17.71%	5,899,319.14	16.58%
2004	21,998	18.28%	5,874,423.78	16.51%
2005	17,563	14.59%	5,935,946.53	16.68%
2006	21,044	17.49%	6,010,242.66	16.89%
2007	17,017	14.14%	6,025,081.72	16.93%
Total Pooled	120,342	100.00%	35,590,552.89	100.00%

Un-Weighted Sample Size = total number of children in NIS with "adequate provider data."
Weighted Count = number of estimated children that the NIS data represent (based on un-weighted sample size and yearly provider weights).

Dependent Variable

My dependent variable, vaccine status, is a dichotomous measure that identifies children as being either un-vaccinated or not un-vaccinated. In order to determine from NIS data which children were un-vaccinated, I first added up the total number of doses reported by the PRC for each of the six vaccines in the "431331" vaccine series (DTaP, Polio, MMR, Hib, HepB and Varicella) to calculate the total number of doses each child received. The result is a summary measure that ranges from 0 to 15, where sum = 0 if the child received no doses for any of the six vaccines and sum = 15 if the child received all recommended doses for all six vaccines (4+3+1+3+3+1 = 15 doses).

For the period 2002 to 2007, the NIS defined un-vaccinated children as those who either had RDD household data that indicated the child had not received any vaccinations (and therefore had "adequate provider data" although, since the child had not been vaccinated, no PRC provider data was available, so sum = missing), or had PRC data that indicated the child had not received any vaccinations (so sum = 0 because the child received none of the recommended doses). Based on this definition, I then grouped children into one of two categories: those who were un-vaccinated (sum = 0 or missing); and those who received any or all of the recommended vaccinations (sum = 1 to 15). This binary measure of vaccine status (1 = un-vaccinated, 0 = not un-vaccinated) serves as my dependent variable in the following analyses.

Independent Variables

These analyses included many of the same independent measures used by Smith et al to identify un-vaccinated children in the United States. These data, collected from parents in the RDD household survey, included the following categorical measures that were added to the models as a series of dummy variables:

- *Year of NIS Data:* for each year from 2002 through 2007;
- *Child characteristics:*
    - Race/Ethnicity: White, non-Hispanic (reference category); Hispanic; Black, non-Hispanic; and Other or Multiple Race/Ethnicity;
    - Gender: Male (ref); and Female;
    - Child's Age Group: 19-23 Months; 24-29 Months; and 30-35 Months (ref);
    - First-Born Status: No (ref); and Yes;
- *Mother characteristics:*
    - Level of Education: <12 Years; 12 Years; 13-15 Years; and >=16 Years (ref);
    - Mother's Age Group: Under 20 Years; 20-29 Years; and 30 Years or Older (ref);
    - Marital Status: Widowed/Divorced/Separated/Deceased ; Never Married; and Currently Married (ref);

- *Household characteristics:*
    - Income & Poverty Status: Below Poverty Level (ref); Income <= $50k but Above Poverty; and Income > $50k;
    - Number of Children Less Than 18 Years Old in the Household: One Child (ref); Two-Three Children; and Four or More Children;
    - U.S. Census Region of Residence: Northeast; Midwest; South; and West (ref);
    - Philosophical Exemption Status: No (ref); and Yes (whether or not the state of residence allowed an exemption from school immunization requirements for philosophical reasons, as distinguished from medical or religious reasons).

Table 4 (below) shows the weighted percent distribution of children across each independent measure for each of the six years of analysis and for the pooled sample (all six years combined). Asterisks indicate whether the distribution of that particular measure changed significantly across the six year period (as measured by a Pearson chi-square statistic).

Methods

I used Stata software to run all the statistical tests throughout this paper (StataCorp, 2008).

First, I ran a trend analysis to see if the proportions of un-vaccinated children changed significantly across the six year period. To measure the statistical significance of this change, I ran two-tailed t-tests to compare the proportion of un-vaccinated children in 2002 to the proportion in each subsequent year. So as not to overstate the significance of this association (that might have occurred if I had used weighted standard deviations with a weighted mean in my large sample of U.S. children), I used instead un-weighted standard deviations around weighted means to calculate these t-test statistics.

I also ran a bivariate analysis using Pearson chi-square statistics to look at whether children with different characteristics were more or less likely to be un-vaccinated in any given year.

Finally, I ran a multivariate analysis using binomial logistic regression models to look at vaccine status (1=un-vaccinated, 0=not un-vaccinated) on: year of NIS data; child, mother and household characteristics; and selected interaction terms. This analysis enabled me to determine

Table 4: Weighted Percent Distribution of Independent Measures, NIS Yearly and Pooled 2002-2007

Child Characteristics	2002	2003	2004	2005	2006	2007	Pooled
Race/Ethnicity ***							
Hispanic	24.36	26.25	27.10	26.81	28.98	27.51	26.85
White, non-Hispanic (ref)	53.75	52.00	51.20	51.65	50.07	51.25	51.64
Black, non-Hispanic	13.59	13.07	13.05	12.85	12.08	12.53	12.86
Other/multiple	8.30	8.69	8.65	8.69	8.87	8.72	8.65
Gender							
Male (ref)	51.50	51.10	51.15	51.18	51.17	51.19	51.21
Female	48.50	48.90	48.85	48.82	48.83	48.81	48.79
Child's Age							
19-23 months	29.89	29.69	29.91	29.78	29.97	30.07	29.89
24-29 months	35.50	34.51	35.14	34.16	34.30	34.27	34.64
30-35 months (ref)	34.61	35.81	34.95	36.07	35.73	35.65	35.47
First Born ***							
No (ref)	62.86	61.88	63.09	54.13	53.90	52.63	58.03
Yes	37.14	38.12	36.91	45.87	46.10	47.37	41.97
Mother Characteristics	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Pooled**
Education Level ***							
LT 12 years	17.39	22.30	21.99	17.02	19.09	20.50	19.72
12 years	35.31	31.52	31.35	35.57	33.27	30.51	32.92
13-15 years	15.55	21.24	21.42	12.84	17.39	20.13	18.09
GE 16 years (ref)	31.74	24.94	25.24	34.57	30.25	28.86	29.27
Mother's Age ***							
Under 20 years	3.34	3.11	2.94	2.69	3.05	3.09	3.04
20-29 years	44.81	46.43	46.03	42.88	41.52	39.87	43.57
30 years or older (ref)	51.85	50.46	51.03	54.42	55.42	57.04	53.39
Marital Status +							
Widow/div/sep/dead	7.67	8.76	8.82	7.88	7.95	7.59	8.11
Never married	21.71	22.62	23.07	22.09	22.38	22.55	22.40
Currently married (ref)	70.62	68.61	68.11	70.03	69.67	69.86	69.48
Household Characteristics	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Pooled**
Income & Poverty Status ***							
Below poverty level (ref)	24.15	27.99	28.72	27.33	27.38	29.57	27.55
Income <= $50k, abv poverty	39.30	38.47	35.73	32.24	30.99	27.98	33.99
Income > $50k	36.55	33.54	35.54	40.42	41.63	42.44	38.46
Number of Children in HH ***							
One (ref)	27.17	25.42	25.41	24.90	24.18	23.72	25.12
Two-three	59.70	60.51	60.51	60.63	60.50	60.99	60.48
Four or more	13.13	14.08	14.09	14.47	15.32	15.29	14.40
Census Region							
Northeast	17.02	16.91	16.81	16.85	16.67	16.33	16.76
Midwest	22.04	21.79	21.59	21.58	21.47	21.30	21.63
South	36.77	36.94	37.05	36.81	37.06	37.33	37.00
West (ref)	24.17	24.35	24.55	24.75	24.79	25.04	24.61
Philosophical Exemption							
No (ref)	57.17	56.87	56.71	56.74	56.90	56.80	56.87
Yes	42.83	43.13	43.29	43.26	43.10	43.20	43.13

*Significant Change in Distribution Over Six Years: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

which independent characteristics were associated with being un-vaccinated, and whether the odds of being un-vaccinated changed between 2002 and 2007 in some populations (with some characteristics) more than others. In particular, the interaction analysis focused on differential changes in the proportions of un-vaccinated children over the six years within independent measures that were significantly associated with vaccine status.

Results

Proportions of Un-Vaccinated Children

I began by conducting a trend analysis to determine whether there had been a significant change in the weighted proportion of un-vaccinated children between 2002 and each subsequent year, as well as across the whole six year period (Table 5).

As expected, there was indeed a significant increase in the prevalence of un-vaccinated children over the period. This increase represents a significant rise in the number (count) and proportion (mean) of un-vaccinated children between 2002 and each subsequent year (but especially between 2002 and 2004, and between 2002 and 2007). Significance levels range from $p<0.05$ (comparing the proportion of un-vaccinated children in 2002 to the proportion in 2003) and $p<0.01$ (comparing 2002 to 2005 and 2006) to $p<0.001$ (comparing 2002 to 2004 and to 2007).

The proportion of children aged 19-35 months who were un-vaccinated for the "431331" vaccinations rose from 0.27% (about one-quarter of one percent) in 2002, representing about 16,000 U.S. children, to more than 0.80% (over three-quarters of a percent) in 2007, representing over 48,000 U.S. children. This finding means that three times as many children were un-vaccinated in 2007 as in 2002 (just five years earlier) with an average 10% increase in the proportion of un-vaccinated children each year across the period. This trend is consistent with

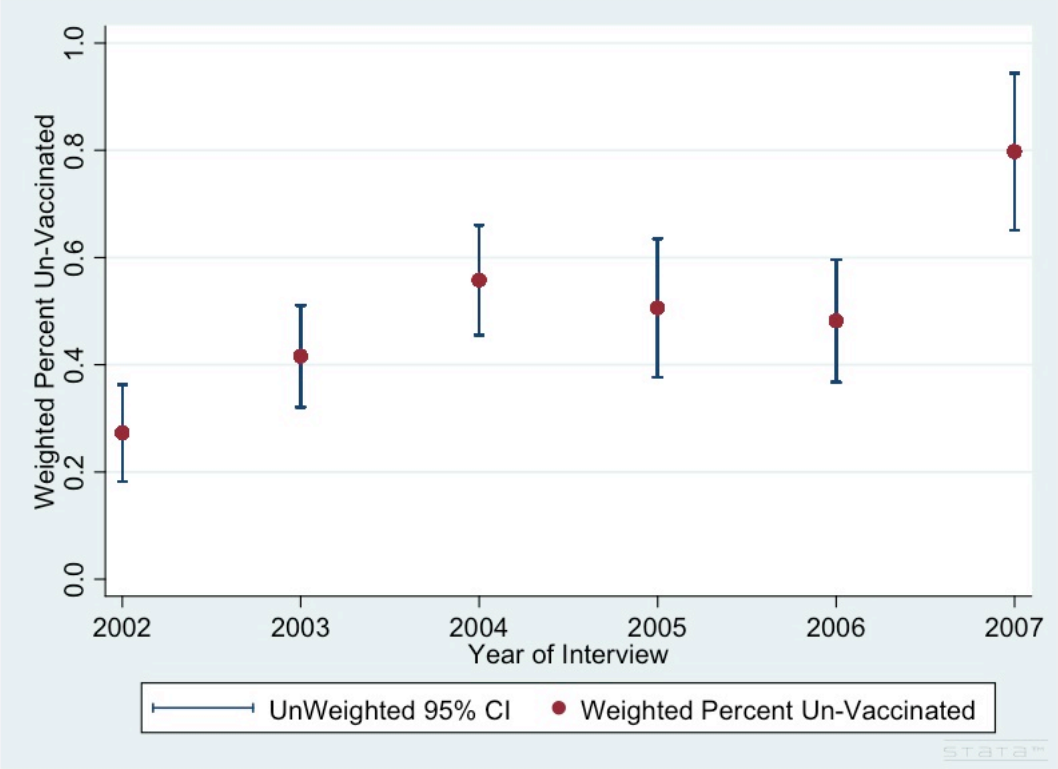
Table 5: T-test Comparison of Weighted Proportion of Un-Vaccinated Children In 2002 and 2003-07 (NIS 2002-2007)

Year	Wt'ed Count	Wt'ed Mean	Un-Wt'ed St Dev	Un-Wt'ed 95% CI	2-tailed T-test	p-value	Signif
2002	15,958	0.0027	0.0675	0.0018 - 0.0036	-	-	
2003	24,533	0.0042	0.0707	0.0032 - 0.0051	-2.1363	0.0327	*
2004	32,780	0.0056	0.0775	0.0046 - 0.0066	-4.0884	0.0000	***
2005	30,041	0.0051	0.0873	0.0038 - 0.0064	-2.8975	0.0038	**
2006	28,964	0.0048	0.0844	0.0037 - 0.0060	-2.8137	0.0049	**
2007	48,052	0.0080	0.0977	0.0065 - 0.0094	-5.9632	0.0000	***

*Significant Change in Weighted Mean between Years: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

both the increase in un-vaccinated children between 1995 and 2001 found by Smith et al, and the increased number of un-vaccinated children estimated by the CDC in its 2007 Data User's Guide (US-DHHS: NCHS, 2008). These results clearly confirm the expected increase in the proportion of un-vaccinated children between 2002 and 2007 and are reflected visually in Figure 1.

Figure 1: Weighted Proportion of Un-Vaccinated Children Each Year (NIS 2002-2007) with Un-Weighted 95% Confidence Intervals



Characteristics of Un-Vaccinated Children

Bivariate Analysis

This analysis looks at whether the crude (unadjusted) proportions of un-vaccinated children were higher among children with certain characteristics than others in order to begin the process of describing communities that were less likely to vaccinate their children.

Table 6 (below) shows the weighted percent of children who were un-vaccinated in each independent variable category for each year between 2002 and 2007 (and for all years pooled). The level of significance (indicating the magnitude of the p-value for a Pearson chi-square statistic) reflects the percent distribution of un-vaccinated children across the categories of each characteristic in each year. The measure is significant if the proportions of un-vaccinated children are sufficiently different across the categories of that characteristic in that year.

This analysis indicated that the proportion of un-vaccinated children was indeed higher among children with certain characteristics more than others (looking just at the pooled 2002-2007 data, in the right-hand column of Table 6). For example, children were significantly more likely to be un-vaccinated if they were White: on average across the six years, 0.64% of White children were un-vaccinated compared to only 0.35% of Hispanic children, 0.38% of Black children, and 0.40% of children of other or multiple races/ethnicities. Children also were significantly more likely to be un-vaccinated if: they were not the first born child in their family (0.57% of lower birth order siblings were un-vaccinated compared to only 0.42% of first born children); they had a mother who was widowed/divorced/separated/deceased (0.79%); they lived in a household with four or more children (1.11%); they lived in the western United States (0.68%); or they lived in a state that allowed a philosophical exemption from immunization (0.60%). Children also tended to be un-vaccinated (although not to a significant degree) if:

Table 6: Weighted Percent of Un-Vaccinated Children by Independent Measures and Significantly Different Percents, NIS Yearly and Pooled 2002-2007

Child Characteristics	2002	2003	2004	2005	2006	2007	Pooled
Race/Ethnicity				*		***	***
Hispanic	0.12	0.19	0.53	0.30	0.46	0.47	0.35
White, non-Hispanic (ref)	0.35	0.50	0.54	0.72	0.55	1.16	0.64
Black, non-Hispanic	0.30	0.58	0.48	0.15	0.42	0.36	0.38
Other/multiple	0.21	0.36	0.87	0.41	0.25	0.32	0.40
Gender						+	
Male (ref)	0.30	0.45	0.49	0.58	0.52	0.97	0.56
Female	0.24	0.38	0.63	0.42	0.44	0.61	0.46
Child's Age	+						
19-23 months	0.42	0.59	0.52	0.38	0.56	0.91	0.57
24-29 months	0.20	0.33	0.63	0.60	0.50	0.61	0.48
30-35 months (ref)	0.22	0.36	0.51	0.52	0.39	0.88	0.48
First Born					**		*
No (ref)	0.32	0.48	0.58	0.57	0.64	0.87	0.57
Yes	0.20	0.31	0.52	0.43	0.30	0.72	0.42
Mother Characteristics	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Pooled**
Education Level					**		
LT 12 years	0.25	0.44	0.75	0.40	0.95	0.95	0.64
12 years	0.25	0.48	0.52	0.57	0.24	0.98	0.50
13-15 years	0.27	0.40	0.43	0.26	0.47	0.62	0.42
GE 16 years (ref)	0.31	0.33	0.55	0.58	0.46	0.62	0.48
Mother's Age			+		+		
Under 20 years	0.04	0.09	0.02	0.08	1.43	0.44	0.36
20-29 years	0.29	0.39	0.68	0.57	0.55	0.81	0.54
30 years or older (ref)	0.27	0.46	0.48	0.48	0.38	0.80	0.48
Marital Status						+	*
Widow/div/sep/dead	0.38	0.79	0.91	0.43	0.62	1.63	0.79
Never married	0.19	0.38	0.59	0.23	0.40	0.36	0.36
Currently married (ref)	0.29	0.38	0.50	0.60	0.49	0.85	0.52
Household Characteristics	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**Pooled**
Income & Poverty Status	+					*	
Below poverty level (ref)	0.17	0.33	0.67	0.35	0.37	1.12	0.52
Income <= $50k, abv poverty	0.39	0.53	0.48	0.48	0.56	0.96	0.55
Income > $50k	0.21	0.43	0.55	0.56	0.45	0.49	0.45
Number of Children in HH	*	***	***	***	**	**	***
One (ref)	0.23	0.22	0.40	0.41	0.22	0.33	0.30
Two-three	0.23	0.36	0.35	0.37	0.46	0.90	0.45
Four or more	0.57	1.02	1.74	1.22	0.98	1.10	1.11
Census Region				+	***		**
Northeast	0.37	0.30	0.32	0.56	0.15	0.54	0.38
Midwest	0.27	0.49	0.53	0.79	0.34	0.75	0.53
South	0.19	0.37	0.53	0.31	0.44	0.79	0.44
West (ref)	0.32	0.50	0.78	0.52	0.89	1.02	0.68
Philosophical Exemption			*		*		**
No (ref)	0.27	0.37	0.41	0.47	0.37	0.71	0.43
Yes	0.28	0.48	0.75	0.55	0.63	0.91	0.60

*Significant Difference in Percent Un-Vaccinated: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

they were male (0.56% compared to 0.46% of females); they were among the younger ages between 19-23 months (0.57%); they had a mother who had not graduated from high school (0.64%); or they had a mother who was in her 20's (0.54%). There was no clear difference in the proportion of children who were un-vaccinated by income/poverty status, although a slightly higher proportion of children (0.55%) were un-vaccinated if they lived in a household with a moderate level of income (above poverty but below $50,000 per year).

Multivariate Analysis

This multivariate analysis helps determine whether the proportion of un-vaccinated children increased in some populations more than others between 2002 and 2007 by adjusting for changes over time in the proportions of children with different characteristics. These binomial logistic models regress vaccine status (1 = un-vaccinated, 0 = not un-vaccinated) on NIS Year (0 = 2002 and 1 = 2007) first with Year alone, and then controlling for other independent measures.

Model 1 (M1) simply regressed Vaccine Status on Year of NIS interview. Model 2 (M2) then controls for the complete set of independent variables added as a series of dummy variables with a reference category (ref) identified for each characteristic. Table 7 (below) shows the results of these first two models.

Mirroring the previous bivariate analysis, Model 1 shows that the odds of being un-vaccinated increased dramatically for children in the United States between 2002 and 2007: on average, a child was almost three times more likely to be un-vaccinated in 2007 than in 2002 (OR=2.937, p=0.000).

By looking at Wald chi-square statistics for each set of dummy variables in Model 2 (one set for each child, mother and household characteristic), I determined that six characteristics were significantly associated with a child's odds of being un-vaccinated: child's race/ethnicity (Wald

Table 7: Binomial Logistic Regression Models of Vaccine Status on Year of Interview (2002 & 2007) with Year Alone (M1), and Controlling for All Child, Mother and Household Characteristics (M2): Odds Ratios, Significant P-values and Standard Errors (in parentheses) for NIS Data 2002 & 2007

	M1	M2
Year of Interview	2.937***	3.147***
	(0.586)	(0.659)
Child Characteristics		
Race/Ethnicity		
Hispanic	-	0.184***
		(0.070)
White, non-Hisp (ref)	-	1.000
		(-)
Black, non-Hisp	-	0.449*
		(0.156)
Other/multiple	-	0.309***
		(0.098)
Gender		
Male (ref)	-	1.000
		(-)
Female	-	0.690+
		(0.150)
Child's Age		
19-23 months	-	1.282
		(0.340)
24-29 months	-	0.715
		(0.183)
30-35 months (ref)	-	1.000
		(-)
First Born		
No (ref)	-	1.000
		(-)
Yes	-	1.292
		(0.373)

Mother Characteristics	M1	M2
Education Level		
LT 12 years	-	1.081
		(0.539)
12 years	-	0.992
		(0.351)
13-15 years	-	0.718
		(0.207)
GE 16 years (ref)	-	1.000
		(-)
Mother's Age		
Under 20 years	-	0.668
		(0.493)
20-29 years	-	0.865
		(0.256)
30 years or older (ref)	-	1.000
		(-)
Marital Status		
Widow/div/sep/dead	-	1.275
		(0.579)
Never married	-	0.381**
		(0.119)
Currently married (ref)	-	1.000
		(-)

Model Statistics	M1	M2
Number of Observations	38,427	35,559
Log Pseudolikelihood	-1263.000	-1109.499

Household Characteristics	M1	M2
Income & Poverty Status		
Below pov level (ref)	-	1.000
		(-)
Inc <= $50k, abv pov	-	0.688
		(0.228)
Inc > $50k	-	0.247***
		(0.102)
Number of Children in HH		
One (ref)	-	1.000
		(-)
Two-three	-	2.462**
		(0.745)
Four or more	-	3.094**
		(1.266)
Census Region		
Northeast	-	0.475*
		(0.178)
Midwest	-	0.553*
		(0.162)
South	-	0.645
		(0.181)
West (ref)	-	1.000
		(-)
Philosophical Exemption		
No (ref)	-	1.000
		(-)
Yes	-	1.217
		(0.283)

*Significance: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

chi2(df=3) = 25.67, p=0.0000); child's gender (Wald chi2(df=1) = 2.91, p=0.0880); child's age (Wald chi2(df=2) = 6.07, p=0.0482); mother's marital status (Wald chi2(df=2) = 10.75, p=0.0046); household income/poverty status (Wald chi2(df=2) = 15.37, p=0.0005); and number of children in the household (Wald chi2(df=2) = 9.73, p=0.0077).

Model 3 (M3) is a revised binomial logistic regression model that includes only Year and these six significant characteristics. Using this subset of six characteristics, I then created interaction terms by crossing each of these measures with NIS year (0=2002 and 1=2007). I added these interaction terms sequentially (one at a time) to create Models 4(a-f). Again using Wald tests, I determined that just two of these interaction terms were significant, indicating that the odds of being un-vaccinated changed significantly over time for children across these characteristics: race/ethnicity (Wald chi2(df=3) = 8.91, p=0.0306); and number of children in the household (Wald chi2(df=2) = 7.71, p=0.0212). I then included these two interaction terms (along with Year and the subset of six significant characteristics) in the final model for analysis, Model 5 (M5). Table 8 (below) shows results from these last three multivariate models (Model 3, Models 4(a-f) and Model 5) and includes odds ratios, robust standard errors (in parentheses) and p-value levels of significance (indicated by asterisks) for Year of NIS data, each of the six groups of significant (child, mother and household) characteristics, and the two significant interaction terms (race/ethnicity, and number of children in the household). .

I used Model 5 to estimate both main effects (the odds of being un-vaccinated among children with various characteristics) and interaction effects (the change in the odds of being un-vaccinated among children in populations for which the proportions of un-vaccinated children increased or decreased significantly between 2002 and 2007).

Table 8: Binomial Logistic Regression Models of Vaccine Status on Year of Interview (2002 & 2007) Controlling for Significant Child, Mother and Household Characteristics (M3), Selected Interaction Terms (M4a-f), and Final Model with all Significant Characteristics and Interaction Terms (M5): Odds Ratios, Significant P-values and Standard Errors (in parentheses) for NIS Data 2002 & 2007

	M3	M4a	M4b	M4c	M4d	M4e	M4f	M5
Year of Interview	3.214***	3.517***	3.472***	3.868***	2.933***	6.757***	1.221	1.315
	(0.647)	(0.873)	(0.969)	(1.484)	(0.651)	(3.522)	(0.516)	(0.570)
Child Characteristics								
Race/Ethnicity								
Hispanic	0.238***	0.104***	0.238***	0.236***	0.237***	0.236***	0.236***	0.102***
	(0.085)	(0.056)	(0.085)	(0.085)	(0.084)	(0.085)	(0.084)	(0.055)
White, non-Hisp (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Black, non-Hisp	0.413**	0.896	0.413**	0.412**	0.411**	0.414**	0.409**	0.860
	(0.129)	(0.360)	(0.129)	(0.129)	(0.129)	(0.130)	(0.128)	(0.349)
Other/multiple	0.367**	0.617	0.367**	0.365**	0.371**	0.368**	0.367**	0.600
	(0.109)	(0.327)	(0.109)	(0.108)	(0.110)	(0.110)	(0.109)	(0.317)
Gender								
Male (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Female	0.688+	0.688+	0.793	0.689+	0.690+	0.690+	0.687+	0.687+
	(0.148)	(0.148)	(0.235)	(0.148)	(0.148)	(0.148)	(0.148)	(0.148)
Child's Age								
19-23 months	1.270	1.276	1.270	1.749	1.277	1.273	1.270	1.275
	(0.341)	(0.344)	(0.341)	(0.631)	(0.342)	(0.342)	(0.341)	(0.343)
24-29 months	0.719	0.723	0.719	0.765	0.726	0.723	0.714	0.716
	(0.187)	(0.188)	(0.187)	(0.302)	(0.186)	(0.187)	(0.186)	(0.187)
30-35 months (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

*Significance Levels: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

Table 8, cont: Binomial Logistic Regression Models of Vaccine Status on Year of Interview (2002 & 2007) Controlling for Significant Child, Mother and Household Characteristics (M3), Selected Interaction Terms (M4a-f), and Final Model with all Significant Characteristics and Interaction Terms (M5): Odds Ratios, Significant P-values and Standard Errors (in parentheses) for NIS Data 2002 & 2007

Mother Characteristics	M3	M4a	M4b	M4c	M4d	M4e	M4f	M5
Marital Status								
Widow/div/sep/dead	1.237	1.222	1.234	1.234	0.444	1.248	1.223	1.210
	(0.586)	(0.579)	(0.585)	(0.582)	(0.259)	(0.592)	(0.581)	(0.575)
Never married	0.365**	0.359**	0.365**	0.365**	0.452	0.365**	0.364**	0.358**
	(0.110)	(0.108)	(0.110)	(0.110)	(0.221)	(0.110)	(0.109)	(0.108)
Currently married (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Household Characteristics								
Income & Poverty Status								
Below pov level (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Inc <= $50k, abv pov	0.665	0.662	0.665	0.665	0.664	1.433	0.656	0.655
	(0.186)	(0.185)	(0.186)	(0.186)	(0.186)	(0.717)	(0.184)	(0.183)
Inc > $50k	0.254***	0.251***	0.253***	0.253***	0.254***	0.613	0.250***	0.248***
	(0.075)	(0.075)	(0.075)	(0.075)	(0.075)	(0.329)	(0.075)	(0.074)
Number of Children in HH								
One (ref)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Two-three	2.086**	2.081**	2.086**	2.090**	2.085**	2.101**	0.843	0.844
	(0.534)	(0.535)	(0.534)	(0.537)	(0.534)	(0.537)	(0.315)	(0.315)
Four or more	2.571**	2.537**	2.568**	2.592**	2.590**	2.566**	1.845	1.747
	(0.770)	(0.758)	(0.779)	(0.775)	(0.777)	(0.771)	(0.797)	(0.761)

*Significance Levels: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

Table 8, cont: Binomial Logistic Regression Models of Vaccine Status on Year of Interview (2002 & 2007) Controlling for Significant Child, Mother and Household Characteristics (M3), Selected Interaction Terms (M4a-f), and Final Model with all Significant Characteristics and Interaction Terms (M5): Odds Ratios, Significant P-values and Standard Errors (in parentheses) for NIS Data 2002 & 2007

Interaction Terms	M3	M4a	M4b	M4c	M4d	M4e	M4f	M5
Year * Hispanic	-	2.542 (1.651)	-	-	-	-	-	2.573 (1.660)
Year * Black	-	0.314* (0.174)	-	-	-	-	-	0.327* (0.182)
Year * Other Race	-	0.477 (0.299)	-	-	-	-	-	0.495 (0.309)
Year * Female	-	-	0.829 (0.325)	-	-	-	-	-
Year * Cage19to23	-	-	-	0.656 (0.324)	-	-	-	-
Year * Cage24to29	-	-	-	0.926 (0.466)	-	-	-	-
Year * WidDivSep	-	-	-	-	3.398 (2.666)	-	-	-
Year * NeverMarr	-	-	-	-	0.759 (0.453)	-	-	-
Year * IncLE50k	-	-	-	-	-	0.388 (0.233)	-	-
Year * IncGT50k	-	-	-	-	-	0.344+ (0.210)	-	-
Year * 2-3children	-	-	-	-	-	-	3.818** (1.920)	3.800** (1.913)
Year * 4+children	-	-	-	-	-	-	1.815 (1.061)	1.914 (1.121)
Model Statistics	**M3**	**M4a**	**M4b**	**M4c**	**M4d**	**M4e**	**M4f**	**M5**
Number of Observations	35,559	35,559	35,559	35,559	35,559	35,559	35,559	35,559
Pseudo R2	0.0782	0.0815	0.0783	0.0788	0.0801	0.0807	0.0821	0.0852
Log Pseudolikelihood	-1120.960	-1117.012	-1120.810	-1120.308	-1118.681	-1117.991	-1116.289	-1112.519

*Significance Levels: + p<0.1, * p<0.05, ** p < 0.01, *** p<0.001.*

In this context, an odds ratio for a main effect characteristic is the ratio of the odds that a child with that characteristic was un-vaccinated within the whole six year period to the odds that a child with the reference level characteristic for that measure was un-vaccinated (who by definition had an odds of being un-vaccinated of 1.0). An odds ratio for a interaction effect is the ratio of the change in the odds that a child with that characteristic was un-vaccinated between 2002 and 2007 relative to the change in the odds that a child with the reference level characteristic for that measure was un-vaccinated.

Looking first at the main effects in Model 5 (the first two pages of Table 8), the odds of being un-vaccinated were significantly higher among only four groups of children:

- Child's race/ethnicity: White Children who were almost ten times more likely to be un-vaccinated than children who were Hispanic (OR=1.000/0.102=9.8, p=0.000);
- Child's Gender: Boys were 46% more likely to be un-vaccinated than girls (OR=1.000/0.687=1.46, p=0.081) although this difference was only marginally significant;
- Mother's Marital Status: Children of currently married mothers were almost three times more likely to be un-vaccinated than children whose mothers had never been married (OR=1.000/0.358=2.8, p=0.001) probably reflecting different rates of un-vaccinated children among Whites and Black non-Hispanics. In turn, children with previously married mothers (widowed/divorced/separated/deceased) had even higher odds of being un-vaccinated than children whose mothers were currently or had never been married; and
- Household Income & Poverty Status: Children who lived in households with incomes below the poverty level were four times more likely to be un-vaccinated than children in

households with incomes above $50,000 per year (OR=1.000/0.248=4.0, p=0.000). This last finding is particularly interesting because it is markedly different from Smith et al findings regarding higher SES children.

While Model 2 indicated that children who lived in households with two-three (and four or more) children were significantly more likely to be un-vaccinated than only children, and children who lived in the western United States had been significantly more likely to be un-vaccinated than children who lived in either the Northeast or the Midwest, these main effects were no longer significantly associated with a child's odds of being un-vaccinated once the number of characteristics was reduced and the models controlled for interactions.

Finally, looking at the interaction terms in Model 5 (the third page of Table 8), the odds of being un-vaccinated changed among some groups of children over the six years between 2002 and 2007. Specifically:

- the odds of being un-vaccinated decreased significantly among Black children (compared with White children): the odds that a Black child was un-vaccinated in 2007 was only about one third as great as their odds of being un-vaccinated in 2002 (OR=0.327, p=0.044); and
- the odds of being un-vaccinated increased significantly among children who lived in households with 2-3 children (compared with children who lived in one child households): the odds of being un-vaccinated was 3.8 times higher in 2007 among children in households with 2-3 children than it had been in 2002 (OR=3.8, p=0.008). The odds that a child in a household with four or more children was un-vaccinated also increased (1.9 times) between 2002 and 2007, but this change was not significant (p=0.268).

Discussion

Compared with the findings of Smith, Chu and Barker (2004), the results of this analysis appear to suggest that un-vaccinated children may now be found in more heterogeneous populations than was the case during the 1995-2001 time frame. While children with certain characteristics (Whites, boys, children with currently married mothers, and those in larger families) were still more likely to be un-vaccinated than others (Hispanics, girls, children with never married mothers, and only children), the odds of being un-vaccinated are clearly higher than they once were among children with an increasingly varied set of characteristics.

In contrast to the previous analysis by Smith et al (in which un-vaccinated children were more likely to be found in households with higher incomes), this analysis found that children living in households with incomes below poverty had significantly higher odds of being un-vaccinated. Also, children were more likely to be un-vaccinated if their mother was previously married than if they were currently or (especially) never married. At the same time, children who lived in households with 2-3 children were increasingly more likely to be un-vaccinated in 2007 than they had been six years earlier. Finally, although Smith et al found more un-vaccinated children living in the western United States, this analysis found that geographic region was no longer a significant factor in the odds of being un-vaccinated (indicating perhaps that un-vaccinated children are more widely distributed geographically across the country than they had been in the past).

Conclusion

Overall, these results suggest a shift may be taking place towards children not being vaccinated within increasingly diverse, less homogeneous communities across the United States. While White boys in large families with currently married mothers are still more likely to be

un-vaccinated than other children in 2007, this study provides some evidence that an increasing proportion of un-vaccinated children can be found in smaller families with previously married mothers in households with lower (even below poverty) income. This suggests that the concept and practice of not vaccinating one's children may be spreading across the United States to some extent beyond the highly specific (and high SES) characteristics described by previous research.

This finding could be consistent with the appearance of heightened publicity in the past few years about parents deciding not to vaccinate their children. Perhaps more parents are learning about the controversy surrounding vaccine safety and choosing, in turn, not to vaccinate their own children. To the degree that parents make medical decisions for their children based on information gathered from a wide range of sources (including medical professionals, fellow parents, news and print media, and internet websites), there are many opportunities for parents to collect data and develop opinions about childhood vaccinations.

There may be other reasons as well for the shift in characteristics associated with increased odds of un-vaccinated children, but understanding the characteristics of these children and their parents is still an important next step in reducing the incidence of preventable childhood disease. Different policy recommendations may be needed to reach parents who are making a deliberate choice not to vaccinate their children in contrast to parents who have no choice but to forgo vaccinations due to a lack of access to medical services.

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