Mass commuting and influenza vaccination prevalence in New York City: Protection in a mixing environment

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A B S T R A C T

Objective: Assess influenza vaccination among commuters using mass transit in New York City (NYC).

Methods: We used the 2006 NYC Community Health Survey (CHS) to analyze the prevalence of influenza immunization by commuting behaviors and to understand what socioeconomic and geographic factors may explain any differences found.

Results: Vaccination prevalence is significantly lower for New Yorkers who commute on public transportation compared to other New Yorkers. This difference is largely attenuated after adjusting for sociodemographic characteristics and neighborhood of residence.

Conclusions: The analysis identified a low prevalence of immunization among commuters, and given the transmissibility in that setting, targeting commuters for vaccination campaigns may impede influenza spread.

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Introduction

Influenza is an annual, major public health problem with an average of 36,000 deaths each year. (Thompson et al., 2003; CDC, 2005) In the 2007–2008 influenza season, the percentage of patient visits for influenza-like illness reached a weekly high of 6.0% of all visits, the hospitalization rate due to influenza for children aged less than 5 years was 4.03 per 10,000, and the percentage of all deaths that were attributed to pneumonia or influenza peaked at 9.1% for the week ending March 15, 2008. (CDC, 2008) Influenza is spread from person to person via three modes of transmission: droplet, contact (either direct skin-to-skin or indirect through fomites on surfaces), and aerosol. (Garner, 1996) The main route of infection is apparently via respiratory droplets of coughs and sneezes. (Salgado et al., 2002; Bridges et al., 2003; CDC, 2005) Large droplets do not remain suspended in the air for an extended period of time, especially when air-handling and ventilation systems help to condition the air. (DHHS, 2005b) Consequently, exposure in close proximity to infected individuals may be the biggest risk factor for infection.

Mathematical models of influenza spread have focused on a number of social settings in which individuals, known as “agents” in the models, are in close proximity to other, potentially infected, agents. These settings, known as mixing settings, typically include homes, schools, and workplaces (Longini et al., 2007; German et al., 2006; Ferguson et al., 2005, 2006; Halloran et al., 2008) and may also include some forms of mass transit (Epstein et al., 2007; Colizza et al., 2007; Grais et al., 2004; Hollingsworth et al., 2006; Brownstein et al., 2006), such as subways, trains, buses, and ferries.

A few studies have evaluated the potential impact of train or subway transportation on the spread of airborne infections. Ohkusa and Sugawara (2007) modeled an influenza outbreak in Tokyo, including the mass transportation for the metropolitan areas. Although they did not test the impact of closing the transportation system, they concluded that the transportation system had a substantial impact on the geographic spread of the infection, and voluntarily staying at home had a major role in stemming the spread. Yasuda et al. (2008) modeled the impact of closing trains and subways as an intervention method for Tokyo to stem the spread of influenza in the suburbs. They concluded that shutting down the trains was ineffective after the introduction of influenza into the commuter towns, but, if implemented early, it was somewhat effective in delaying the epidemic.

One major preventive measure recommended for influenza is the annual influenza vaccination. From 2006, the time the data analyzed was collected, to 2009 the Advisory Committee on Immunization Practice (ACIP) recommended influenza vaccinations for children; adults at high risk for influenza-related complications and severe disease; persons aged 50 years and older; and persons who live with or care for persons at high risk. (CDC, 2009). In 2010 the ACIP expanded its recommendations for influenza vaccination to all people age 6 months and older (CDC, 2010). The pre-2010 recommendations for vaccination exclude a majority of the adults younger than 50 years, and a substantial proportion of these adults are likely to commute in...
NYC and other cities. In contrast, the current recommendations include all commuters.

In NYC, mass transit systems create mixing environments where the public is at increased risk of influenza transmission. In fact, the NYC Department of Health and Mental Hygiene has discussed telecommuting as one of a suite of possible approaches to controlling a pandemic. (Weisfuse, et al. 2006)

This study analyzes data from the 2006 annual NYC Community Health Survey of adults in NYC to characterize the commuting patterns of the population and evaluate the vaccination health behavior of the commuting population. We also examined the role that socio-demographic and geographic characteristics play in these vaccination patterns. These data will help jurisdictions around the country better assess effective prevention strategies and immunization campaigns.

Methods

To quantify the factors associated with flu vaccination probabilities and commuting behavior, we analyzed data from the 2006 NYC Community Health Survey (CHS-2006). (Details available at http://home2.nyc.gov/html/doh/html/survey/survey-2006.shtml [accessed June 22, 2009].) Developed by the NYC Department of Health and Mental Hygiene, the CHS provides robust data on the health of New Yorkers, including estimates of a broad range of chronic diseases and behavioral risk factors through a yearly telephone study. The cross-sectional 2006 CHS obtained data from 9,693 adults aged 18 and older from all five NYC boroughs – Manhattan, Brooklyn, Queens, Bronx, and Staten Island. The survey uses a computer-assisted telephone interviewing (CATI) system with interviews conducted in several languages, and all data collected are self-reported. This stratified random sample produces citywide, as well as neighborhood-specific, estimates. Strata were defined using the United Hospital Fund’s (UHF) neighborhood designations, which are comprised of aggregated ZIP codes that have been modified slightly for the addition of new ZIP codes. (Details available at: http://nyc.gov/html/doh/downloads/pdf/data/appb.pdf)

Data Description

The 2006 CHS questions pertaining to vaccination and mass transit were:

- **During the past 12 months, have you had a flu shot in your arm or a flu vaccine that was sprayed in your nose?**
- **Between 9 a.m. and 5 p.m. weekdays, where do you spend most of your time? How do you usually get there?** There were 10 potential responses: subway, city bus, express bus, bicycle, walking, car, taxi, commuter train, ferry, and some other way.

Data Analysis

In the CHS, final weights account for the initial unequal probabilities of selection, adjustments for household size and number of residential telephone lines, and post-stratification to population totals derived from census data. These weights are used in all the analyses. Missing values for the following variables were imputed: education category, age group, number of children in household, marital status, Hispanic ethnicity, and income category. Imputations were performed by fitting a logistic model to estimate the probability for each level of the missing value. Then the missing variable was randomly assigned the probability with probability proportional to the result from the logistic model.

We first described the demographic distribution of the population, and examined the prevalence of flu immunization and mixed commuting by demographic characteristics. We then fit three nested, weighted logistic models (SAS 9.2; Cary, NC) with the dichotomous dependent variable “received flu vaccine.” The first model included the “mixing commute” variable only. A mixing commute identifies commuting behavior where the commuter is in close proximity to other commuters, and consequently, has an increased risk of transmitting or becoming infected with influenza. We defined the dichotomous variable “mixing commute” as “1” if the person commuted by subway, city bus, express bus, or commuter train, and “0” if the person did not commute or commuted by bicycle, walking, car, taxi, ferry, or some other way. In the second weighted logistic model, we added gender, race, education, age group, marital status, number of children in the household, and income category. The final model also included UHF neighborhood in addition to the independent variables in the first and second models. Finally, we examined the relationship between poverty, immunization prevalence and mixing commute prevalence at the neighborhood level. For each UHF neighborhood we calculated the immunization prevalence, mixing commute prevalence and the percent of households below the poverty line. We then tested the association between neighborhood vaccination prevalence and neighborhood poverty and the association between neighborhood mixing commute prevalence and neighborhood poverty.

Table 1

<table>
<thead>
<tr>
<th>Socio-demographic characteristic</th>
<th>Population size (MOE)</th>
<th>Immunization % (MOE)</th>
<th>Mixing Commute % (MOE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6,068,009</td>
<td>26.4 (0.9)</td>
<td>33.4 (1.0)</td>
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<tr>
<td>Gender</td>
<td></td>
<td></td>
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<tr>
<td>Male</td>
<td>2,803,579</td>
<td>25.0 (1.4)</td>
<td>34.6 (1.6)</td>
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<td>Female</td>
<td>3,264,430</td>
<td>27.5 (1.1)</td>
<td>32.5 (1.2)</td>
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<td>Race/Ethnicity</td>
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<td></td>
<td></td>
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<td>White</td>
<td>2,351,798</td>
<td>31.5 (1.5)</td>
<td>25.9 (1.4)</td>
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<td>Black</td>
<td>1,371,764</td>
<td>21.7 (1.6)</td>
<td>38.2 (2.0)</td>
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<td>Hispanic</td>
<td>1,494,684</td>
<td>23.8 (1.7)</td>
<td>37.0 (2.0)</td>
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<td>Asian/Pacific Islander</td>
<td>642,275</td>
<td>25.0 (3.1)</td>
<td>42.4 (3.7)</td>
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<td>Other</td>
<td>207,487</td>
<td>22.0 (4.7)</td>
<td>33.7 (5.5)</td>
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<tr>
<td>Education</td>
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<td></td>
<td></td>
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<td>Less than high school</td>
<td>1,058,339</td>
<td>28.3 (2.1)</td>
<td>23.2 (2.0)</td>
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<td>High school graduate</td>
<td>1,467,464</td>
<td>26.9 (1.8)</td>
<td>29.6 (1.9)</td>
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<td>Some college/technical school</td>
<td>1,346,462</td>
<td>23.0 (1.8)</td>
<td>36.4 (2.1)</td>
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<tr>
<td>College graduate</td>
<td>2,195,744</td>
<td>27.2 (1.5)</td>
<td>39.0 (1.7)</td>
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<td>Age</td>
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<tr>
<td>18 - 24</td>
<td>770,967</td>
<td>16.0 (2.9)</td>
<td>46.6 (4.1)</td>
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<tr>
<td>25 - 44</td>
<td>2,647,875</td>
<td>17.4 (1.3)</td>
<td>40.4 (1.7)</td>
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<tr>
<td>45 - 64</td>
<td>1,707,802</td>
<td>28.1 (1.5)</td>
<td>30.7 (1.6)</td>
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<tr>
<td>65+</td>
<td>941,364</td>
<td>57.2 (2.0)</td>
<td>7.9 (1.1)</td>
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<td>Marital Status</td>
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<tr>
<td>Married</td>
<td>2,760,977</td>
<td>27.6 (1.4)</td>
<td>28.2 (1.5)</td>
</tr>
<tr>
<td>Divorced</td>
<td>512,547</td>
<td>27.9 (2.5)</td>
<td>34.1 (2.8)</td>
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<tr>
<td>Widowed</td>
<td>405,218</td>
<td>48.7 (2.9)</td>
<td>13.3 (2.0)</td>
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<tr>
<td>Separated</td>
<td>303,108</td>
<td>24.0 (3.3)</td>
<td>37.5 (3.8)</td>
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<tr>
<td>Never married</td>
<td>1,719,077</td>
<td>20.2 (1.6)</td>
<td>44.6 (2.0)</td>
</tr>
<tr>
<td>A member of an unmarried couple</td>
<td>367,082</td>
<td>21.1 (3.8)</td>
<td>38.5 (4.6)</td>
</tr>
<tr>
<td>Number of Children in household</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3,389,048</td>
<td>31.5 (1.2)</td>
<td>32.3 (1.2)</td>
</tr>
<tr>
<td>1</td>
<td>1,160,733</td>
<td>21.6 (2.0)</td>
<td>37.2 (2.4)</td>
</tr>
<tr>
<td>2</td>
<td>943,443</td>
<td>19.4 (2.2)</td>
<td>36.5 (2.7)</td>
</tr>
<tr>
<td>3</td>
<td>350,516</td>
<td>17.0 (3.4)</td>
<td>25.0 (4.2)</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>224,269</td>
<td>17.6 (4.4)</td>
<td>25.6 (5.2)</td>
</tr>
<tr>
<td>Household Income % of poverty line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;100%</td>
<td>1,323,682</td>
<td>27.2 (1.9)</td>
<td>27.5 (1.9)</td>
</tr>
<tr>
<td>100% - &lt;200%</td>
<td>1,160,779</td>
<td>24.0 (1.9)</td>
<td>31.3 (2.1)</td>
</tr>
<tr>
<td>200% - &lt;300%</td>
<td>497,185</td>
<td>22.5 (2.9)</td>
<td>36.2 (3.4)</td>
</tr>
<tr>
<td>300% - &lt;400%</td>
<td>561,223</td>
<td>25.5 (2.9)</td>
<td>37.3 (3.3)</td>
</tr>
<tr>
<td>400% - &lt;500%</td>
<td>596,366</td>
<td>25.3 (2.8)</td>
<td>34.5 (3.1)</td>
</tr>
<tr>
<td>500% - &lt;600%</td>
<td>512,821</td>
<td>24.1 (3.0)</td>
<td>37.2 (3.4)</td>
</tr>
<tr>
<td>600% or greater</td>
<td>1,415,751</td>
<td>30.6 (1.9)</td>
<td>36.4 (2.1)</td>
</tr>
</tbody>
</table>

Note: the margin of error (MOE) is calculated using a 95% confidence interval.
Results

The vaccination prevalence for NYC residents age 18 and above was 26.4%, and the prevalence of mixing commuters was 33.4%. As shown in Table 1, age plays a key role in immunization prevalence and mixing commute prevalence. New Yorkers age 65 years and older had double the immunization rate of those 45-64 and a rate more than 3 times as high as adults 18-24. Not surprisingly, older adults engaged in mixing commutes at a level less than one-third of those 45-64. As seen in Fig. 1, immunization rates by neighborhood ranged from 17.3% to 45.3%. As seen in Fig. 2, the mixing commute prevalence varied by more than 178 four-fold (10.2% to 48.1%). Some of the neighborhoods with the highest prevalence of mixing commuting, Brooklyn, West Queens and upper Manhattan, were also among those with the lowest prevalence of immunization.

Vaccination among commuters who engaged in a mixing commute was significantly lower than the prevalence for the rest of the population (20.2% versus 29.5%, p-value<0.0001). To determine whether the lower vaccination prevalence among mixing commuters could be explained by sociodemographic and neighborhood variables, we conducted a regression analysis. Table 2 presents the odds ratios from three separate logistic regression models. All of the regression models have vaccination as the dependent variable. Columns 2 through 4 show the odds ratios and the associated 95% confidence intervals for the three nested models.

Model 1 includes only mixing commute as an independent variable. In this model, mixing commute was highly significant (p<0.0001), with an odds ratio of 1.65 for non-mixing commuters. Model 2 contains the independent variable mixing commute as well as the sociodemographic independent variables: gender, race, educational attainment, age category, marital status, number of children in household and household income category. While the association between mixing commuting and vaccination was attenuated in this model (OR=1.12, p = 0.046), it was still statistically significant. The age of the individual was most strongly associated with immunization prevalence, followed by household income, race and mixing commute status. The odds of vaccination among individuals 65 years or older was 3 to 7 times greater than the other age groups. Individuals from households with the highest income (600% above the poverty line) had vaccination odds ratios significantly higher than those in other income categories. After adjusting for other demographic variables whites, Hispanics, and Asians had comparable odds ratios, while the black race group had an odds ratio of 0.82, which was significantly lower than for whites. Females were marginally more likely than males to be vaccinated (p = 0.064), whereas education, marital status, and number of children in household failed to achieve statistical significance.

Model 3 introduces neighborhood of residence as an independent variable. In this model, mixing commute was marginally significant (p = 0.09), with an odds ratio of 1.1 for non-mixing commuters. Age still the had most significant association with vaccination; the odds ratio for the age group 65 and older is triple the odds ratio for 45-65 year-olds and over 6 times the odds ratio for 18-24 and 25-44 year-olds. The neighborhood of residence was predictive of immunization propensity (p<0.0001), and odds ratios for immunization prevalence by neighborhood ranged from a low of 0.68 for Borough Park to 2.31 for the Upper East Side.

Fig. 1. Immunization rates UHF Neighborhoods.
Vaccination propensity and poverty rate was calculated for each of the 42 UHF neighborhoods. Neighborhood vaccination propensity and poverty rate had a correlation of -0.560 (p-value < 0.0001), indicating that neighborhoods with more poverty have lower vaccination prevalence. Mixing commute propensity and poverty rate was also calculated for each of the 42 UHF neighborhoods. Neighborhood mixing commute propensity and poverty rate had a correlation of 0.556 (p-value < 0.0001), indicating that neighborhoods with more poverty have higher commuting rates.

Discussion

Our analysis suggests that commuters have significantly lower levels of vaccination than do non-commuters; this lower vaccination prevalence may be a public health concern because of the close contact with a great number of people in the NYC public transportation system (Weisfuse et al. 2006). This difference is largely attenuated after adjusting for socioeconomic factors and neighborhood of residence, suggesting that increased immunization among young, low income and black individuals might help stop the spread of disease among commuters.

The pre-2010 ACIP recommendations on influenza vaccination focused on protecting individuals at highest risk for the most adverse health outcomes. While this strategy is understandable, the population that ACIP recommended for vaccination has substantially different demographic characteristics from the population of NYC residents who use public transportation. Most importantly, the NYC commuter population is younger. Our finding a lower immunization rate among NYC residents who use public transportation compared to those who do not is therefore unsurprising. As our analysis indicates, this difference is largely explained by age, neighborhood of residence, income, and race. Given the close proximity of commuters, promoting vaccination among commuters may reduce the transmission of disease, thus protecting the most vulnerable among both commuters and non-commuters, and may deter the exacerbation of an epidemic (Weisfuse et al., 2006).

The current ACIP recommendations include influenza vaccination for all people over 6-months. Non-compliance of these new standards will likely be high for commuters. Consequently, we recommend public outreach efforts to facilitate a change in vaccination behavior in the commutating population. One simple and cost effective approach would be advertising the recommendations on public transportation. An advertising campaign geared to the general public could include messages on subway lines, buses and ferries.

Another approach is to target specific neighborhoods for an outreach program. The percent of households below the poverty line is negatively correlated with NYC neighborhood vaccination propensities and positively correlated with NYC neighborhood mixing commute propensity. If similar correlations hold for other communities with extensive mass transit systems, then targeting high poverty neighborhoods for vaccination programs would target populations with low vaccination propensity and high mixing commute propensity. This could therefore be a cost effective method to raise the immunization prevalence among a vulnerable group with high transmission risk. For NYC we can use the CHS data to identify the neighborhoods with a high proportion of commuters but low

Fig. 2. Mixing Commute rates for UHF Neighborhoods.
Socio-demographic Characteristic | Model with commuting variable only OR (95% CI) | Model with commuting and Sociodemographic variables OR (95% CI) | Model with commuting, Sociodemographic, and UHIF OR (95% CI)
--- | --- | --- | ---
Mixing Commute | 1.65* (1.49, 1.83) | 1.12* (1.00, 1.26) | 1.11 (0.99, 1.24)
Yes (Ref) | 1.00 | 1.00 | 1.00
Gender | Male N/A | 0.91 (0.82, 1.01) | 0.93 (0.84, 1.03)
Female (Ref) | 1.00 | 1.00 | 1.00
Race/Ethnicity | Black N/A | 0.82* (0.71, 0.95) | 0.85 (0.71, 1.01)
Hispanic N/A | 1.06 (0.92, 1.23) | 1.05 (0.89, 1.24)
Asian/Pacific Islander N/A | 1.12 (0.94, 1.34) | 1.18 (0.98, 1.41)
Other N/A | 0.92 (0.69, 1.24) | 0.98 (0.72, 1.32)
White (Ref) | 1.00 | 1.00 | 1.00
Education | Less than high school N/A | 1.00 (0.84, 1.18) | 1.06 (0.89, 1.26)
High school graduate N/A | 1.05 (0.92, 1.21) | 1.13 (0.98, 1.31)
Some college/technical school N/A | 0.91 (0.79, 1.05) | 0.98 (0.84, 1.13)
College graduate (Ref) | 1.00 | 1.00 | 1.00
Age | 18 – 24 N/A | 0.15* (0.12, 0.19) | 0.15* (0.12, 0.20)
25 – 44 N/A | 0.16* (0.14, 0.19) | 0.16* (0.13, 0.18)
45 – 64 N/A | 0.29* (0.25, 0.34) | 0.29* (0.25, 0.34)
65+ (Ref) | 1.00 | 1.00 | 1.00
Marital Status | Married N/A | 1.00 (0.80, 1.25) | 1.03 (0.82, 1.29)
Divorced N/A | 0.89 (0.68, 1.17) | 0.90 (0.69, 1.19)
Widowed N/A | 1.03 (0.77, 1.37) | 1.05 (0.78, 1.40)
Separated N/A | 0.88 (0.65, 1.12) | 0.88 (0.64, 1.20)
Never married N/A | 0.95 (0.76, 1.20) | 0.93 (0.73, 1.17)
A member of unmarried couple (Ref) | 1.00 | 1.00 | 1.00
Number of Children in household | 0 N/A | 1.15 (0.85, 1.57) | 1.09 (0.79, 1.49)
1 N/A | 1.11 (0.81, 1.53) | 1.03 (0.75, 1.43)
2 N/A | 1.07 (0.77, 1.47) | 1.02 (0.74, 1.41)
3 N/A | 0.91 (0.63, 1.32) | 0.87 (0.60, 1.27)
> 3 (Ref) N/A | 1.00 | 1.00 | 1.00
Household Income % of poverty line | <100% N/A | 0.68* (0.58, 0.81) | 0.78* (0.66, 0.93)
100% – <300% N/A | 0.61* (0.52, 0.71) | 0.68* (0.58, 0.80)
300% – <600% N/A | 0.72* (0.63, 0.83) | 0.80* (0.69, 0.92)
600% or greater (Ref) | 1.00 | 1.00 | 1.00
Neighborhood** | N/A N/A | p < 0.0001
Note: OR = odds ratio; CI = confidence interval. *P < 0.05 level, 2-sided. **Only significance for the variable is shown on this table. Results are based on three separate logistic models.

The genesis of the analysis presented in this paper came from creating an agent based model for influenza transmission. Specifically, to initialize agents (in the agent based model) to vaccination and commuting status we needed to quantify the relationship between demographic characteristics and neighborhood of residence with vaccination and commuting status. We choose to use the 2006 NYC Community Health Survey because it was a probability sample with a large sample size that contained the information we needed. However, if we designed a study specifically to analyze the relationship between community and vaccination rates we could have improved the questionnaire to include information such as the number of commuting events per week, distance traveled and time of commute. Also, we could have conducted the survey during winter so the recall period for influenza vaccination would only be 4–5 months.

Conclusions

Commuting on the New York City mass transit system might be a setting with high influenza transmission. However, the population that commutes has less vaccination coverage than other subgroups, in part because pre-2010 ACIP recommendations do not include most commuters. Now that these recommendations have been revisited public outreach programs can be targeted to groups most at risk to be non-compliant with the current standards.

Acknowledgments

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