Patterns of influenza vaccination coverage in the United States from 2009 to 2015

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A R T I C L E   I N F O

A B S T R A C T

Background: Globally, influenza is a major cause of morbidity, hospitalization and mortality. Influenza vaccination has shown substantial protective effectiveness in the United States.
Methods: We investigated state-level patterns of coverage rates of seasonal and pandemic influenza vaccination, among the overall population (six months or older) in the U.S. and specifically among children (aged between 6 months and 17 years) and the elderly (aged 65 years or older), from 2009/10 to 2014/15, and associations with ecological factors. We obtained state-level influenza vaccination rates from national surveys, and state-level socio-demographic and health data from a variety of sources. We employed a retrospective ecological study design, and used both linear models and linear mixed-effect models to determine the levels of ecological association of the state-level vaccinations rates with these factors, both with and without region as a factor for the three populations.
Results and Conclusions: Health-care access has a robust, positive association with state-level vaccination rates across all populations and models. This highlights a potential population-level advantage of expanding health-care access. We also found that prevalence of asthma in adults is negatively associated with mean influenza vaccination rates in the elderly populations.
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Introduction

Globally, influenza is the cause of three to five million cases of severe illness and 250,000 to 500,000 deaths annually (World Health Organization, 2016). Influenza vaccine coverage rates in the United States are the highest among the Americas (Palache et al., 2014). The US Healthy People 2020 initiative set a target of 70% vaccination coverage of both children and adults by 2020 (National Vaccine Advisory Committee, 2013). Vaccine effectiveness against seasonal influenza A and B virus infection and pandemic influenza (A(H1N1)pdm09) has demonstrated moderate effectiveness (Flannery et al., 2014).

Previous studies have investigated individual-level correlates of seasonal and pandemic influenza vaccination rates in the US. It was found that younger age (Linn et al., 2010; Galarce et al., 2011; Takayama et al., 2012), lower levels of education (Linn et al., 2010; Takayama et al., 2012), lower household income (Linn et al., 2010; Fox et al., 2014), urbanicity (Galarce et al., 2011), having a history of chronic conditions or poor physical health (Linn et al., 2010; Takayama et al., 2012), lack of health insurance (Takayama et al., 2012; Fox et al., 2014), and smoking (Takayama et al., 2012) were factors associated with lower coverage. In addition, non-Hispanic Black race was associated with lower rates of pandemic influenza vaccination (Uscher-Pines et al., 2011). However, whether these factors could explain state-level variations has not been investigated. Also, regional variations in vaccination rates have not been considered.

In the US, the Center for Diseases Control and Prevention (CDC) recommended seasonal influenza vaccination to all persons aged 6 months or older in 2010/11 following the 2009 influenza A (H1N1) pandemic (Centers for Disease Control and Prevention, 2013). In this study, our aim is to identify how socio-demographic and health-related factors are ecologically associated with the mean state-level rates of influenza vaccination coverage among the overall population (i.e. persons aged six months or above) from 2009/10 to 2014/15. Our secondary aim is to compare the association of these factors in the presence or absence of region

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as a factor. In addition to our main analysis in the whole population, we studied these associations separately in the elderly (aged 65 or above) and children (aged 6 months to 18 years) sub-populations.

Methods

Study population and setting

Our study population ("overall population") consisted of all persons aged six months or older from 50 states and the District of Columbia in the U.S. from 2009/10 to 2014/15 who were eligible for influenza vaccination. We also studied the elderly and children sub-populations within the overall population. All data were obtained from publicly available sources.

Study design

We adopted a retrospective ecological study design to assess the overall socio-demographic, health-related and regional correlates with the mean state-level vaccination rates across the time period. This study design does not permit the analyses of individual-level associations. However, it is appropriate for studying the state-level vaccination rates and their potential associations with these factors.

Influenza vaccination coverage data

We used published data from Behavioral Risk Factor Surveillance System (BRFSS) (Xu et al., 2014) and National Immunization Survey (NIS) (Center for Disease Control and Prevention (CDC), 2015). These sources give influenza coverage rates for the 50 states plus the District of Columbia for each influenza seasonal year (from June through May) for the period from 2009/10 to 2014/15. BRFSS's study population included adults aged 18 years or above whereas the NIS study population covered children aged 6 months to 17 years old. For 2009/10, due to the H1N1 pandemic, they report coverage for: seasonal vaccination, pandemic H1N1 vaccination, or at least one influenza vaccination. We used the last value. These vaccination rates ranged from 30% to 60%. We also computed the mean rates based on their annual rates from 2009/10 to 2014/15. These mean state-level rates are then used for further analyses.

Region

We aggregated the 50 states and the District of Columbia into ten regions according to the US Human and Health Services (HHS) classification (US Department of Health and Human Services, 2015).

Socio-demographic and health-related data

To investigate factors associated with vaccination rates, we searched publicly available sources for socio-demographic and health-related data. Specifically, we collected secondary data for the following state-level variables in which their data definitions and data sources are described in more detail below. We chose socio-demographic and health variables considered relevant based on previous literature (Linn et al., 2010; Galarce et al., 2011; Takayama et al., 2012; Fox et al., 2014; Uscher-Pines et al., 2011).

Health care access

We obtained estimates from the CDC's Behavioral Risk Factor Surveillance System (BRFSS) Surveys in 2013. Health care access is defined as having any kind of health insurance, prepaid plans, government plans or Indian Health Service (Centers for Disease Control and Prevention, 2013a).

Population proportion of children and elderly

We obtained population estimates from the US Census Bureau in 2013 to determine the proportion of children and elderly in each state (U.S. Census Bureau, 2013a).

Per capita personal income level

We also obtained the per capita income level in 2013 from the US Bureau of Economic Analysis in each state (U.S. Bureau of Economic Analysis, 2013b).

Educational attainment

Data about educational attainment is obtained from the US Census Bureau in 2013. It is defined as the proportion of population who had attained college degree or above (U.S. Census Bureau, 2013b).

Racial or ethnic origin

We defined race and ethnic origin into two variables: Hispanic and Black. We classified persons into Hispanic or non-Hispanic origin. We also defined persons as Black or non-Black (i.e. White, Asian American, Native American or others, including persons who are multi-racial).

Prevalence of asthma

We estimated prevalence of asthma among the adult population using responded from the 2013 BRFSS survey (Asthma Centers for Disease Control and Prevention (CDC), 2015).

Missing data

There are missing data in the 2013/14 influenza vaccination coverage for two states. Since vaccination levels are relatively constant from year to year, we simply calculate mean coverage for those two states using the remaining years. We filled the "N/A" entry of "Black" for Wyoming using 1 minus the proportions of White, Hispanic, Others, and yield 0.009845.

Statistical analyses

We fit linear models to test the effects of socio-demographic and health variables for the overall, children and elderly populations (thus fitting a total of three models). We then added region as a random factor to each of these models, to control for spatial and cultural patterns at that scale (thus fitting three additional linear mixed-effect models). We standardised all variables to mean zero and unit standard deviation before performing analyses. We conducted all statistical analyses using R (version 3.2.2).

Results

Figure 1 shows patterns of influenza vaccination coverage across the US. Vaccination is lower in the Northwestern and Western regions, and higher in the Mid-Western and Northeastern regions. There were also large state-level variations within the Mid-western region. We show estimates from our regression models in Figures 2–4, and Supplementary Tables 1-3.
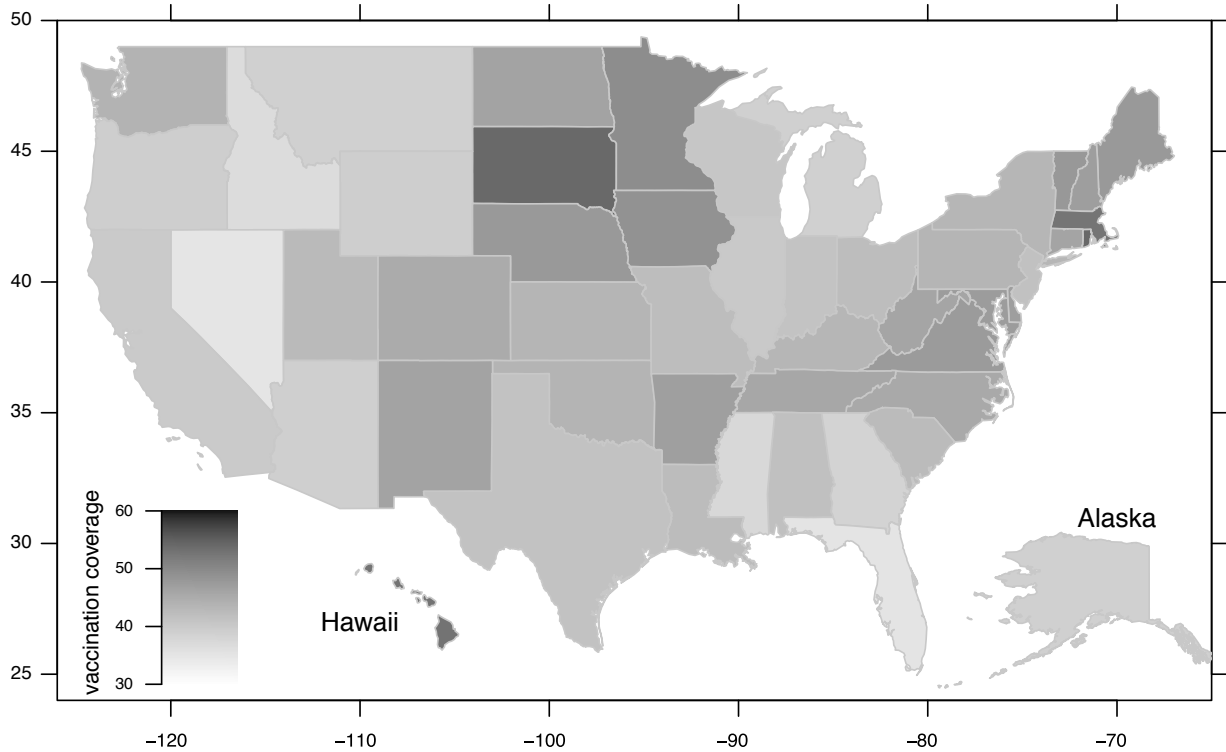
Figure 1. Mean influenza vaccination rates of 50 States and DC. Higher-rate states are colored in darker gray, and lower-rate states are colored in lighter gray. Hawaii and Alaska are shifted, and Alaska is scaled by 1/3.

All continuous regression variables are standardized to unit standard deviation. Thick lines show 50% confidence intervals, and thin lines show 95% confidence intervals. Figure 2 shows our model results for the overall population (with and without region as a random factor). Health care access has a significant positive association with influenza vaccination rates at 5% level; it is the
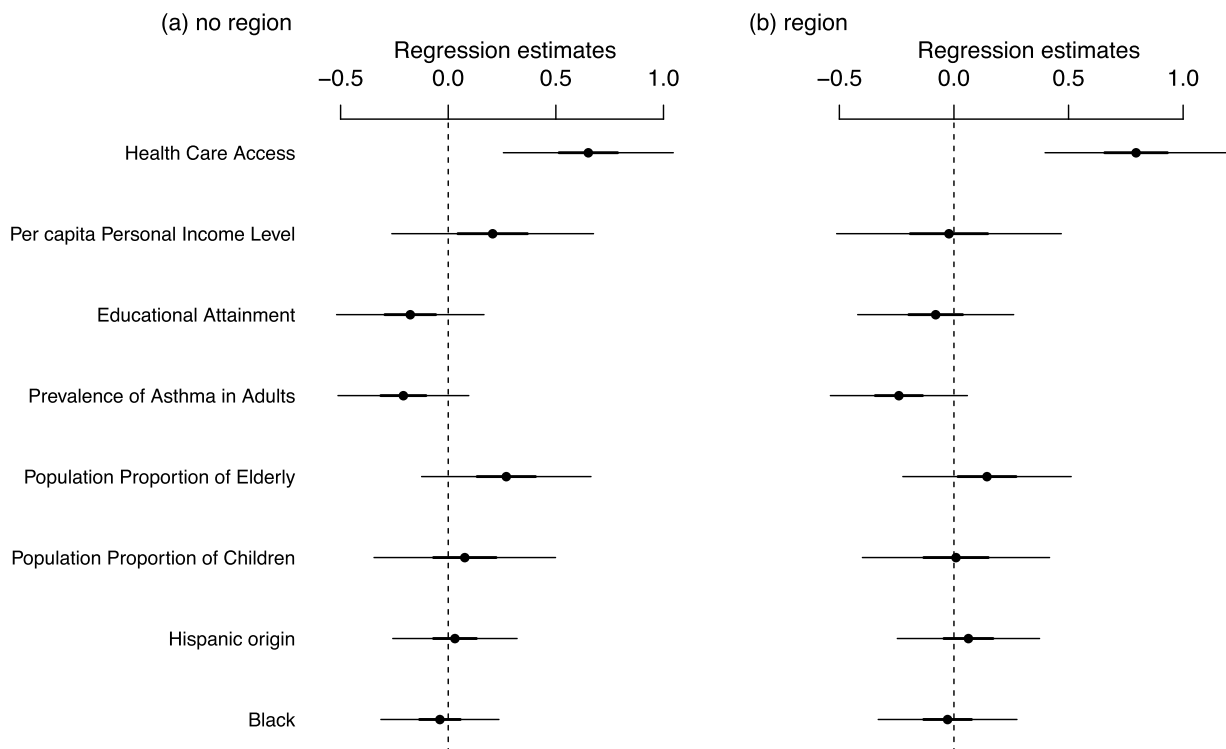
Figure 2. Estimates for the overall population without (left) or with (right) region as a factor.
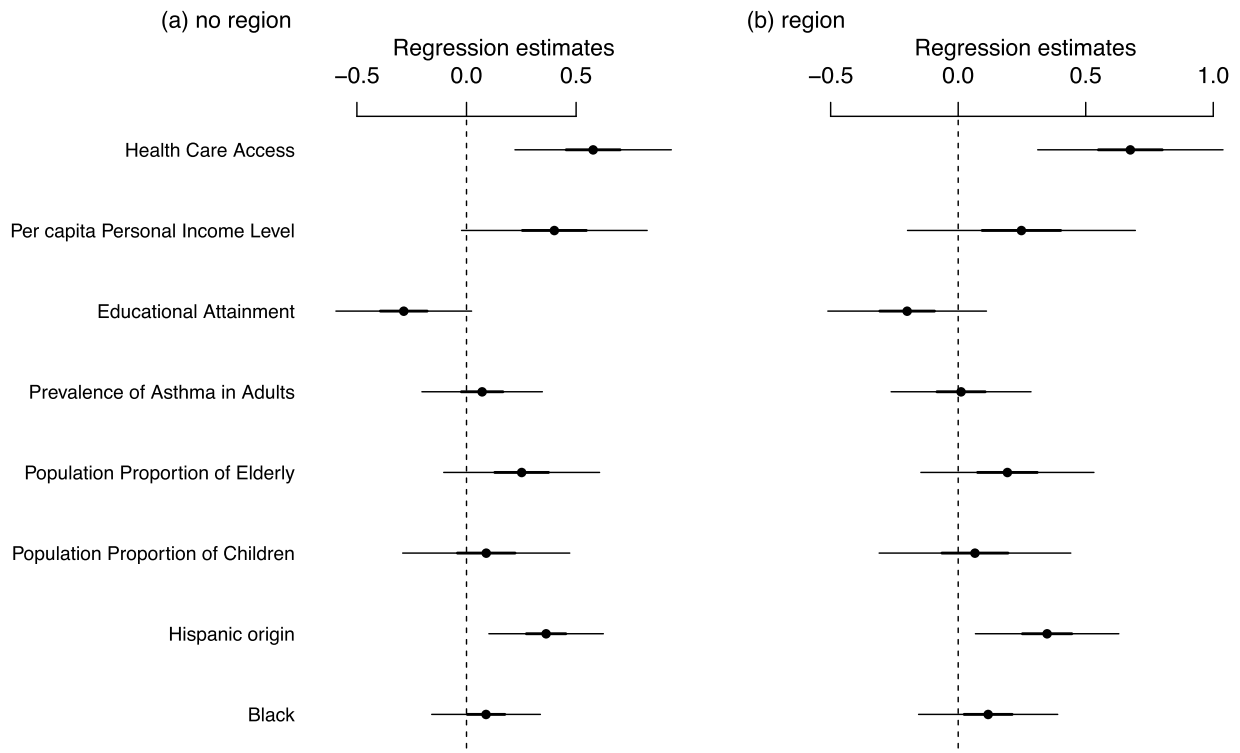
Figure 3. Estimates for elderly without (left) or with (right) region factor.
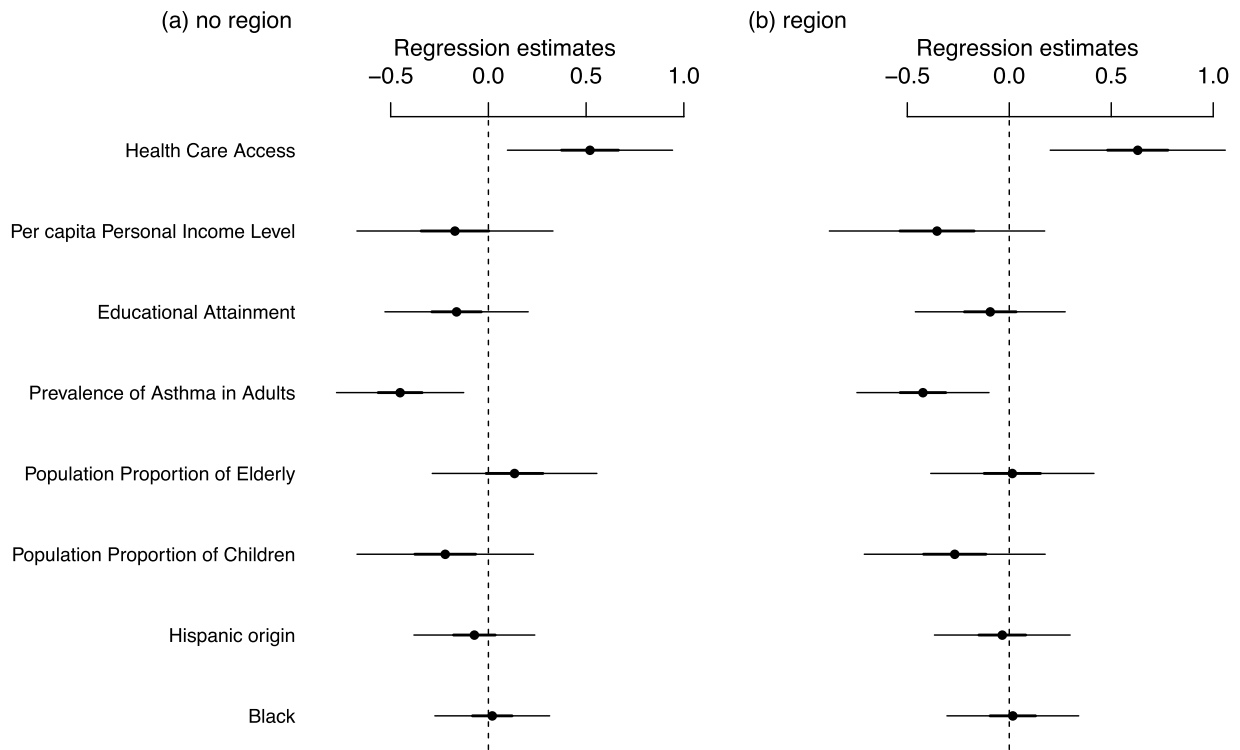

Figure 4. Estimates for children without (left) or with (right) region as a factor.

only one of our factors that shows a significant association. When comparing the two panels, all of the regression estimates are similar, and there were no changes in sign.

Figure 3 shows our model results for the elderly population. Health care access is positively associated with coverage as before. Additionally, prevalence of adult asthma is negatively associated

with vaccination rates in the elderly. No other factors show statistical significance. When comparing the two panels, all of the regression estimates are similar, and there were no changes in sign.

Figure 4 shows our model results for the children population. Again, health care access is positively associated with coverage. No other factors show statistical significance. When comparing the

two panels, all of the regression estimates are similar, and there were no changes in sign. Data and model are shown in the supporting Files 1 and 2.

Discussion

Main findings of this study

Health care access shows a consistent, positive and significant association with influenza vaccination coverage at the state level, across all of our population groups, and whether or not region is accounted for. We also found that a significant, negative association between the prevalence of asthma in adult vaccination coverage in the elderly population.

What is already known on this topic?

Our results were consistent with Fox et al., 2014 who showed that at the individual level, adults with health care access are more likely to receive influenza vaccination than those without such access.

Bish et al conducted a systematic review and found that being male, of older age, and being an ethnic minority are demographic factors associated with uptake of vaccination against pandemic influenza (Bish et al., 2011). Brien et al conducted another systematic review and found that being male, younger age, higher educational level, being a doctor, being in a priority group for influenza vaccination, receiving a seasonal vaccination in the past, believing in the safety and efficacy of the vaccine, and obtaining vaccine-related information from medical sources, are associated with uptake of pandemic influenza vaccination (Brien et al., 2012). These two systematic reviews considered pandemic influenza vaccination only, and they covered individual-level studies from many countries have varying levels of vaccination coverages. In contrast, our ecological study did not find evidence that educational attainment has a positive effect at the population level.

Similar studies investigating individual-level factors associated with influenza vaccination rates were conducted in other countries. A Korean study found that among adults, older age, lower educational attainment, lower personal income, health behaviour, being a non-smoker or having a chronic health condition (Yang and Cho, 2014). A similar study among middle- and older-aged Australian adults found that having a medical indication recommended for influenza vaccination suggested high uptake among those who have free access to influenza vaccine (Dyda et al., 2015).

Previous research studied the racial disparities in influenza vaccination coverage in the U.S. from 2007/08 through 2011/12. Their results showed that at the individual level, vaccination rates among the adult subgroups were lower among Hispanics and non-Hispanic blacks, when compared to non-Hispanic whites (Lu et al., 2014). Uscher-Pines et al. found that Hispanics and non-Hispanic whites have similar vaccination rates for pandemic influenza, and they suggested this could be due to the Mexican origin of the pandemic that leads to heightened awareness among Hispanics for pandemic influenza vaccination (Uscher-Pines et al., 2011). They also found that seasonal vaccination in 2009/10 was significantly higher among non-Hispanic whites than non-Hispanic blacks and Hispanics (Uscher-Pines et al., 2011). At the state level, we did not find a consistent pattern, nor any statistically significant evidence for associations between proportion Hispanic and influenza coverage.

However, our ecological findings showed that prevalence of asthma in adults was significantly and negatively associated with influenza coverage in the elderly. A South Korean population-based cross-sectional study showed that older age was associated with

increased vaccination rates among adult asthma patients (Chung et al., 2017).

Strengths of this study include a comparison of ecological factors across six different models, covering overall, elderly and children populations and taking region into account. We were also able to investigate several potentially relevant socio-demographic and health-related factors.

Limitations of this study

The main study limitation is that it is a state-level ecological study, so we cannot make direct conclusions about causation, nor examine effects at the individual level. Further, although we have studied a number of potentially relevant factors, other factors might be important at a relevant scale – for example, influenza epidemic levels, mass media reports on influenza, reimbursement rates for influenza vaccination, and vaccine availability (Yoo, 2011).

What this study adds

This study shows a population-level effect of health-care access on influenza vaccination level, while controlling for other covariates. The effect is robust to controlling for regional variation as a random effect. We additionally find that the amount of variance explained by region as a random effect is comparable to that seems to be explained by covariates; future studies could employ more formal techniques to investigate geospatial clustering of vaccination.

Conclusions

Our analysis of state level patterns found that health care access is positively associated with mean influenza vaccination rates in overall, elderly and children populations, both with and without region as a factor. Thus, reducing health care coverage could have a negative impact on influenza vaccination rates. We could also look at whether the burdens of influenza-related illnesses and deaths of the earlier years are correlated with the influenza vaccination rates of the current year.

We also found that prevalence of asthma among adults is negatively and significantly associated with vaccination coverage in the elderly population. This information may be helpful to identify target populations and to tailor future influenza vaccination campaigns according to these variations, so as to achieve the Healthy People influenza vaccination goals in 2020 for both children and adults (Healthy People 2020, 2017).

Author contributions statement

D.H., A.C., J.D. and D.Y. conceived the experiment(s) and conducted the experiment(s), D.H., A.C., J.D. analysed the results. All authors reviewed the manuscript.

Competing interests

The authors declare that they have no competing interests.

Acknowledgements

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ijid.2017.10.004.

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