

CONCOMITANT ADOLESCENT VACCINATION: THE INFLUENCE OF SEASONAL
VARIATION, SCHOOL REQUIREMENTS, AND PATIENT-PROVIDER
COMMUNICATION

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ABSTRACT

Jennifer L. Moss: Concomitant Adolescent Vaccination: The Influence of Seasonal Variation, School Requirements, and Patient-Provider Communication
(Under the direction of Noel T. Brewer)

Introduction. Human papillomavirus (HPV) vaccination has the potential to prevent thousands of cases of anogenital cancers each year, but coverage falls short of national goals. Other vaccines recommended for adolescents (tetanus, diphtheria, and pertussis (Tdap) booster and meningococcal vaccine) have much higher coverage. Administering HPV vaccine with other adolescent vaccines concomitantly (i.e., at the same healthcare visit) could improve HPV vaccine coverage. This dissertation examined factors likely to influence concomitant uptake, namely, seasonal variation in vaccination, vaccination school entry requirements, and patient-provider communication style.

Methods. Data came from 99,921 participants in the 2008 to 2012 versions of the National Immunization Survey (NIS)-Teen. Each year, NIS-Teen gathers data on about 20,000 adolescents (ages 13–17) using telephone interviews administered to parents and written questionnaires mailed to healthcare providers to verify vaccination. In the first study, I used the Edwards method to examine the annual, seasonal cycles in uptake of individual vaccines and concomitant vaccination. In the second study, I conducted longitudinal mediation analysis with bootstrapping to test the attenuating effects of these cycles on the relationship between states' vaccination school entry requirements and coverage rates. In the third study, I analyzed the interaction between vaccination school entry requirements and

providers' communication style in their relationship with adolescents' uptake of individual vaccines and concomitant vaccination.

Results. Uptake of individual vaccines was 5–10 times as common, and concomitant vaccination was 3–6 times as common, at the peaks of the seasonal cycles compared to their troughs (all $p < .001$). States with vaccination school entry requirements had more extreme vaccination cycles than other states and higher coverage rates for both the vaccines targeted by the requirements (more than 20% higher) and the other adolescent vaccines (6–18% higher) (all $p < .001$). However, contrary to my hypothesis, vaccination cycles did not mediate the relationship between states' school entry requirements and coverage. Regardless of states' vaccination school entry requirements, uptake of individual vaccines was higher when parents reported that providers used a more collaborative communication style (all $p < .05$), but concomitant vaccination did not vary by providers' communication style.

Conclusion. Concomitant vaccination is more common in the summer months, especially in states with policies requiring students to receive one or more adolescent vaccines prior to school entry. Patient-provider communication was less influential for concomitant vaccination than for receipt of individual vaccines. To increase HPV vaccination (individual or concomitant administration), quality improvement and health promotion activities should precede summer peaks and the implementation of new school entry requirements.

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CHAPTER 1: OVERVIEW AND SPECIFIC AIMS

Human papillomavirus (HPV) vaccine is effective and safe.¹⁻³ Widespread uptake among adolescents now could prevent thousands of cases of cervical, vaginal, vulvar, anal, and other cancers in the years to come.^{1,4} National guidelines recommend that all 11- and 12-year-olds in the United States receive 3 doses of HPV vaccine.¹ As of 2012, only 54% of adolescent girls had received at least one dose (i.e., vaccine initiation), and improvements in HPV vaccination have stalled in recent years.⁵ The CDC suggests that to increase HPV vaccine coverage, clinicians should administer HPV vaccine at visits at which they administer other adolescent vaccines such as the tetanus, diphtheria, and pertussis (Tdap) booster vaccine.¹ For this dissertation, I will use the term *concomitant vaccination* to refer to administration of HPV and Tdap vaccines during the same healthcare encounter. Tdap vaccine has an overall higher level of uptake than HPV vaccine, and 43 states require that adolescents receive Tdap prior to entering middle or high school. Linking HPV vaccination with receipt of Tdap could improve population-level coverage with HPV vaccine.

To date, research on adolescent vaccination has focused on intrapersonal factors including knowledge, attitude, and use of other preventive healthcare services. Higher-level factors that influence Tdap, HPV, and concomitant vaccination remain understudied. For instance, only a few studies have examined the effects of school entry requirements for Tdap vaccination on adolescent vaccination coverage, and no studies have investigated the effect of school entry requirements for HPV vaccine. Another important but unstudied higher-level factor is the yearly cycle in demand for vaccination. A preliminary investigation in North

Carolina found that over the past several years, healthcare providers delivered two times as many doses of HPV vaccine and almost five times as many doses of Tdap in August compared to December, and anecdotal evidence suggests that these summertime peaks in adolescent vaccination occur nationally. A third understudied factor is interpersonal communication style employed by healthcare providers when discussing vaccines with patients and parents. A provider's recommendation is one of the strongest correlates of vaccination behaviors,⁶ but little research has investigated recommendation style. Over the past few decades, healthcare practice has moved toward a collaborative decision-making model emphasizing joint communication between patient and provider, but emerging research suggests that a more directive approach to recommending vaccines results in higher levels of uptake. Understanding the influence of these factors could help public health researchers identify effective policy-level interventions, highlight periods during which promotion programs could be most efficient, and offer guidance for clinical practice.

The proposed dissertation will investigate the influence of these multilevel factors on HPV vaccination and cancer prevention. The research described in the following chapters focuses on HPV vaccine initiation (i.e., receipt of at least one dose) among adolescent females because the analysis uses a dataset capturing this behavior in this population over five years. An important mechanism for this research is concomitant vaccination (i.e., uptake of multiple vaccines at the same healthcare visit), which explicitly links uptake of HPV and Tdap vaccines. The dissertation project has two specific aims.

Aim 1. Quantify Cycles in Adolescent Vaccination

The first aim is to investigate the relationship between yearly cycles in vaccine demand and state-level HPV vaccination rates. This aim will quantify the extent to which

Tdap, HPV, and concomitant vaccination peaks in the summer months in all U.S. states. In addition, this aim will test the relationship between the magnitude of yearly peaks in Tdap, HPV, and concomitant vaccination and state-level vaccination rates. Finally, this aim will establish whether summer peaks in concomitant vaccination mediate the relationship between school entry requirements for Tdap and HPV vaccine coverage.

Aim 2. Determine the Effect of Collaborative Patient-Provider Communication on Adolescent Vaccination

The second aim is to determine how dimensions of collaborative decision making influence vaccination. This aim will determine whether collaborative *information exchange*, *deliberation*, and *decisions* correlate with increased uptake of adolescent vaccines and concomitant vaccination. In addition, this aim will examine whether this relationship varies by the presence of school entry requirements.

CHAPTER 2: LITERATURE REVIEW

In this chapter, I summarize background information on human papillomavirus (HPV) vaccine, including the public health significance of HPV vaccination, patterns of adolescent vaccination in the United States, and vaccine legislation. This review of the literature focuses on issues surrounding HPV vaccine initiation (i.e., receipt of at least one dose) among adolescent females. Although national guidelines recommend that both male and female adolescents receive HPV vaccine, the proposed research will focus on five years of data on vaccination among adolescent females. The recommendation for males is more recent than the recommendation for females. In addition, data on males are not available for a long enough period of time, and vaccination remains infrequent enough in all years except the most recent, to give reliable estimates at the state level.

Public Health Significance of HPV Vaccination

Sustained infection with human papillomavirus (HPV) causes several cancers, including anal, cervical, oral, penile, vaginal, and vulvar cancers.^{7,8} These cancers cause significant morbidity and mortality. For example, each year in the United States, almost 11,000 women are diagnosed with and more than 4,000 women die from, cervical cancer.⁸ More than 99% of these cases are attributable to HPV infection.^{8,9} Annually, HPV-associated cancers result in thousands of deaths and \$3.7 billion in lost lifetime productivity in the United States, disproportionately burdening young women.¹⁰

HPV is the most common sexually transmitted infection.⁷ Although prevalence among older women is low, rates among younger women are high: 25% among 14- to 19-

year-old women and 45% among 20- to 24-year-old women.^{11,12} For most women who contract HPV, their first infection occurs within a year of sexual debut.¹³ About 90% of HPV infections resolve within two years of infection,⁷ but persistent infection with high-risk subtypes of HPV can lead to cancer. For example, two strains of HPV, types 16 and 18, cause 70% of cervical cancer cases.¹⁴ Estimates of the prevalence of these subtypes in U.S. women range from 2% to 18% (HPV 16) and from <1% to 5% (HPV 18).¹¹

In 2006, the Food and Drug Administration (FDA) licensed the first prophylactic vaccine to protect against infection with HPV, and now two HPV vaccines are available.¹⁵ Both three-dose vaccines protect against HPV 16 and HPV 18.¹ National guidelines recommend routine administration of HPV vaccine to 11- to 12-year-old adolescents.¹⁵ Studies of the effectiveness and safety of HPV vaccine report promising results. Although the long-term effects of the vaccine in reducing the incidence of HPV-attributable cancers are as yet unknown, vaccination is associated with striking reductions in HPV infection,¹⁶⁻¹⁹ genital warts,^{3,16,19} and lesions that may develop into cancer.^{16,19} In Australia, which implemented a nationalized HPV vaccination program in 2007, population-based estimates of the prevalence of genital warts among women under age 21 dropped from 12% in 2007 to <1% in 2011.³ Numerous large-scale safety monitoring studies have found no evidence for increased risk of adverse events associated with receiving the vaccine.^{2,20,21}

Despite the demonstrated effectiveness and safety of HPV vaccine, uptake among adolescents in the United States remains low. As of 2012, only 54% of adolescent girls had initiated HPV vaccine (i.e., received at least one dose).⁵ Other countries have achieved high levels of HPV vaccination among the target age group, with rates of completion (i.e., receipt of three doses) exceeding 70%.²²⁻²⁴ These suboptimal levels of HPV vaccination in the

United States leave millions of young people at risk for HPV infection, genital warts, and HPV-associated cancers.

Adolescent Vaccination in the United States

In addition to HPV vaccine, the routine adolescent vaccine platform in the United States includes the tetanus, diphtheria, and pertussis (Tdap) booster vaccine and meningococcal vaccine.¹⁵ Since the introduction of these vaccines, Tdap and meningococcal vaccination coverage has increased steadily. However, recent surveillance data suggest that improvements in HPV vaccination coverage have slowed.^{25,26} In 2012, coverage of Tdap and meningococcal vaccination reached 85% and 74%, respectively, figures that are 20 to 30 percentage points higher than the estimate for HPV vaccine initiation among adolescent females (54%).⁵ Figure 1 illustrates the widening gap between adolescents' coverage levels for Tdap and meningococcal vaccine versus HPV vaccine.

The U.S. Department of Health and Human Services released performance objectives for Tdap, meningococcal, and HPV vaccination as part of the Healthy People 2020 initiative. The three objectives set a benchmark for 80% of 13- to 15-year-old adolescents to complete each vaccine (for HPV vaccine, among girls only).²⁷ As of 2012, vaccine coverage rates for this age group were 85% (Tdap booster vaccine), 74% (meningococcal vaccine), and 28% (HPV vaccine completion).⁵ Thirty-six states met the Healthy People 2020 goal for Tdap vaccination, 12 met the goal for meningococcal vaccination, and none met the goal for HPV vaccination.⁵ These data suggest that uptake of HPV vaccine is too low, while uptake of other recommended adolescent vaccines is closer to levels that achieve public health goals.

National estimates for adolescent vaccination coverage mask wide variation in uptake by state. Among 13- to 17-year-old adolescents in 2012, statewide coverage with Tdap

ranged from 54% in Mississippi to 96% in New Hampshire. Statewide coverage with meningococcal vaccine ranged from 38% in Arkansas to 94% in Rhode Island. Coverage with at least one dose of HPV vaccine among adolescent females ranged from 39% in Florida to 74% in Rhode Island, and coverage with all three doses ranged from 12% in Mississippi to 58% in Rhode Island.⁵ These 35 to 56 percentage point differences in uptake by state dwarf those based on other important characteristics such as adolescent's race/ethnicity or poverty status, which generally demonstrate differences of less than 10 percentage points.⁵

Inadequate and variable uptake of adolescent vaccines occurs partially as a consequence of lower use of preventive healthcare services among adolescents in the United States.²⁸ Although the American Academy of Pediatrics recommends annual preventive check-ups for young people up to age 21,²⁹ a recent national study found that fewer than half of 10- to 17-year-old adolescents had attended a preventive healthcare visit in the previous year.³⁰ In response to these trends, the CDC recommends that healthcare providers administer adolescent vaccines at all eligible visits (i.e., preventive and sick visits) and administer multiple vaccines during the same visit (i.e., concomitant vaccination).¹ Concomitant vaccination is safe and produces comparable immune responses to instances of vaccination at separate healthcare encounters.³¹ Using these two techniques to reduce missed opportunities for vaccination could be incredibly effective in increasing uptake of adolescent vaccines, especially for HPV vaccine. Stokley and colleagues²⁵ reported that eliminating missed opportunities (defined as any type of healthcare visit at which an eligible female adolescent received at least one other vaccine but not HPV vaccine) would result in 93% coverage with at least one dose of HPV vaccine among adolescent females, an estimate almost 40 percentage points higher than the current level of coverage.⁵

In summary, patterns of adolescent vaccination differ by vaccine and by state. That adolescents often forego their recommended preventive check-ups is a challenge to efforts to improve vaccination rates, but minimizing missed opportunities for vaccine administration could increase coverage among adolescents who eventually interact with the healthcare system.

Legislating Adolescent Vaccination

An alternative solution to the problem of adolescents' poor use of preventive check-ups is to adopt new regulations, such as a state policy requiring that adolescents receive vaccinations before entering a certain grade in public school. For example, North Carolina has a policy requiring students to receive Tdap prior to entering sixth grade, but the state does not have a policy requiring HPV vaccination. School entry requirements are highly effective in improving rates of vaccine uptake.³²⁻³⁴

Much discussion in the media and in research literature has considered the constitutionality and ethics of school entry requirements and whether they needlessly reduce individuals' autonomy in making healthcare decisions for themselves or their children. According to legal precedent, school entry requirements are constitutional as long as (1) they address a public health necessity by preventing disease, (2) they involve a vaccine that has a demonstrated effect on preventing the disease it targets, (3) receipt of the vaccine is not overly burdensome, and (4) they are approved by the legislature.³⁵ Authors have argued that school entry requirements are ethical,^{32,33,36} although all of these articles note that exemptions from school entry requirements are necessary for medical and perhaps philosophical reasons.

Most of the United States currently has school entry requirements for at least one adolescent vaccine. Across the 50 states and Washington D.C., 43 jurisdictions had school

entry requirements for Tdap that were effective by Fall 2012, 16 had requirements for meningococcal vaccine, and 2 had requirements for HPV vaccine.³⁷ School entry requirements for HPV vaccine have faced considerable resistance from the general public and from legislators. In 2007, the first year after the CDC recommended HPV vaccine for routine use in adolescent females, 24 states introduced legislation for school entry requirements, but 22 of these states did not adopt the proposed policies, in part because the public became aware that advocacy for the policies was funded by Merck, who makes HPV vaccine.³⁸ Since then, only a handful of state legislatures have debated school entry requirements for HPV vaccine. Schwartz and colleagues³⁹ argue that the initial enthusiasm for HPV vaccine plummeted when states began considering school entry requirements because the public believed the vaccine was too new and potentially unsafe; however, other factors, such as drug company involvement, negative media attention, and concerns about vaccine cost, may have also contributed to the relative unpopularity of HPV vaccine requirements versus requirements for Tdap and meningococcal vaccines. Though years have passed since the introduction of HPV vaccine, public health officials and providers remain wary of HPV vaccine school entry requirements,^{40,41} despite parental support being quite high for HPV vaccination policies that allow parents to exempt their child from the requirement.^{42,43}

The promise of HPV vaccine school entry requirements is tempered by the potential detrimental effects of the generous exemption provisions needed to make such a policy politically feasible. For instance, Reiter and colleagues⁴² found that among parents who intended to vaccinate their adolescent sons, about 50% more parents would consent to vaccination given a policy requiring active permission for the child to receive the vaccine

than would consent to vaccination given a policy requiring active refusal for the child to receive an exemption from vaccination (75% versus 52%). However, generous opt-out provisions could theoretically weaken the default effect described above by diluting the implied message from policymakers, reducing the effort needed to opt-out of the default, and/or changing the reference point from which parents evaluate vaccination decisions. The rate at which parents seek exemptions for their children appears to be rising,⁴⁴ driven in part by public doubt about the safety of vaccines.^{45,46}

States that have implemented school entry requirements for adolescent vaccines have higher rates of vaccine uptake than states without such policies. For example, Tdap coverage levels are 10 percentage points higher in states with Tdap school entry requirements than states without them.⁴⁷ School entry requirements likely increase vaccination rates by establishing a default for a health behavior.^{48,49} Johnson and Goldstein⁴⁸ demonstrated that a default, or a “condition ... imposed when an individual fails to make a decision” (p. 1338), increases the rates at which people engage in the target behavior. Three mechanisms contribute to the creation of a default effect:⁴⁸ (1) individuals may interpret a default behavior as a suggestion from policymakers, thereby changing perceived norms in support of the behavior; (2) engaging in the default behavior often requires less effort than an alternative behavior; and (3) because individuals evaluate the pros and cons of alternative behaviors in reference to the default behavior, acting against the default may seem unappealing due to the psychological phenomenon of loss aversion.⁵⁰

In the context of school entry requirements, uptake of the targeted vaccine is similar to a default behavior. These policies reflect explicit recommendations from policymakers and health authorities (suggestion, explanation 1 above). Parents wishing to forego vaccination

must file waivers justifying their child's exemption (effort, explanation 2 above). Finally, parents evaluate the alternative behavior (i.e., not vaccinating) in reference to the default of vaccinating, and the relative losses of exempting from vaccination versus getting a vaccine may not seem worthwhile (loss aversion, explanation 3 above). The effort explanation may be less relevant to vaccination because both options, seeking or foregoing vaccination, require effort.

Additionally, studies have demonstrated that Tdap school entry requirements are associated with increased uptake of both meningococcal vaccine⁵¹ and HPV vaccine.⁵² This carry-over effect is not well understood, but presumably it occurs via concomitant administration of the non-targeted vaccines when adolescents seek Tdap. Dempsey and colleagues⁵² described other potential explanations for this carry-over effect, including increased demand for and availability of all adolescent vaccines in states with school entry requirements, improved office procedures that facilitate carry-over vaccination, and normalization of adolescent vaccination. For parents in states with school entry requirements, the suggestion and loss aversion explanations of the default effect described previously could generalize from Tdap to the non-targeted vaccines. That is, parents could perceive endorsements from policymakers and health authorities not just for Tdap but for all adolescent vaccines (similar to Dempsey's normalization explanation), or they may extend the potential losses of refusing Tdap (e.g., leaving an adolescent at risk for communicable disease) to the losses of refusing a non-targeted vaccine.

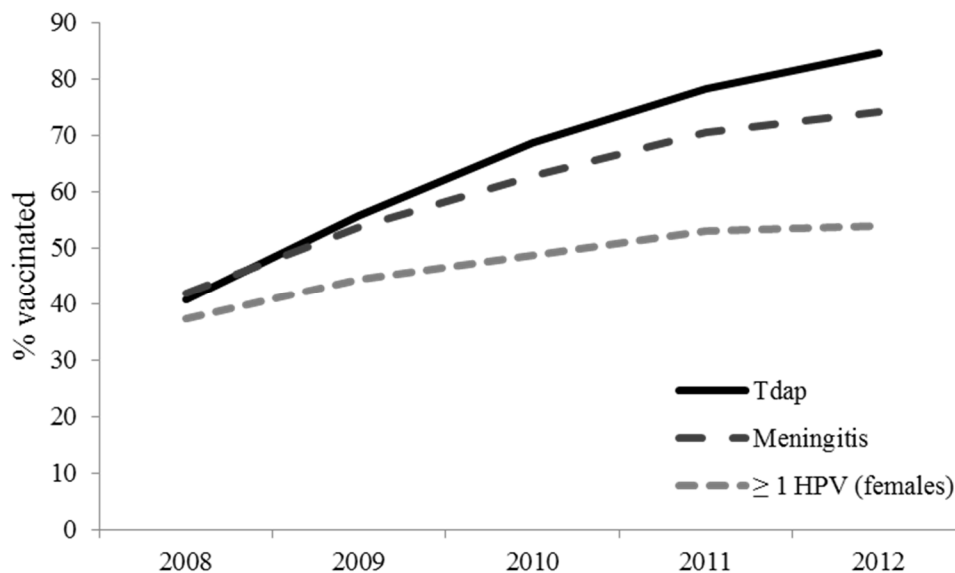
In conclusion, school entry requirements for adolescent vaccination can be effective in increasing rates of uptake. Requirements for childhood and selected adolescent vaccines

are associated with higher coverage with targeted vaccines, with smaller, carry-over effects on other vaccines.

Conclusion

Widespread uptake of HPV vaccine could prevent thousands of cases of cancer in the coming decades. Coverage with HPV vaccine among adolescent females in the United States varies among states but overall is too low, especially compared to levels of uptake for Tdap and meningococcal vaccines. Routine concomitant vaccination with both Tdap and HPV vaccines during the same healthcare encounter could greatly improve rates of HPV vaccination. School entry requirements for Tdap successfully increase coverage with HPV vaccine through a carry-over effect. However, more research is needed on how these variables relate to each other.

Figure 1. Vaccine coverage among U.S. adolescents ages 13 to 17. (Source: National Immunization Survey (NIS)-Teen.)



CHAPTER 3: ANNUAL CYCLES IN ADOLESCENT VACCINATION

Few studies have moved beyond the individual person or healthcare encounter to examine the role of population-level patterns in adolescent vaccination. Anecdotal evidence suggests that more adolescents seek vaccines during summer months than during the rest of the year. The timing of healthcare providers' interactions with adolescents to administer vaccines has important implications for healthcare practice and future interventions. In this chapter, I will examine the effect of annual cycles in adolescent vaccination on overall levels of vaccine coverage. I introduce the literature on cyclical effects in health outcomes, report preliminary results of an investigation of cyclical trends in adolescent vaccination in one state, present the conceptual model for Aim 1, describe the analytic methods, and summarize the implications of annual cycles for healthcare practice and public health.

Cyclical Effects in Public Health

Many health behaviors demonstrate cyclical patterns, including cycles that recur yearly (e.g., increased incidence of suicide during the summer months⁵³), monthly (e.g., more substance abuse during the first week of each month⁵⁴), and weekly (e.g., increased internet searches for smoking cessation information on Mondays⁵⁵). Much of the research on cyclical effects focuses on trends in mortality, which demonstrates an increase in the winter months relative to the summer months.⁵⁶ Studies of cyclical effects often highlight the causal influence of environmental factors such as air quality, heat, or insect activity,⁵⁶⁻⁵⁹ but other studies find relationships that may be attributable to social factors that affect health such as isolation, school stress, or resolutions to change.^{53-55,60}

Anecdotal evidence suggests that the demand for adolescent vaccination increases during the summer months, but no research studies have examined this phenomenon. Logically, at least two social factors may contribute to a summer peak in vaccination. First, most adolescent children do not attend school during the summer months. Thus, to the extent that parents view taking children out of school to seek healthcare as a barrier to vaccination, visiting a provider during the summer months may be associated with reduced perceived barriers and increased ease of vaccination relative to visiting a provider throughout the rest of the year. Second, some families living in states with school entry requirements for certain vaccination(s) may not be motivated to seek them until just before the beginning of the targeted school year.

Preliminary Study on Cyclical Effects in Vaccination

In a preliminary study of vaccination trends in North Carolina, we found evidence of an annual cycle with a peak in the summer (Figure 2). Averaged over 2008 to 2012, healthcare providers across North Carolina administered twice as many doses of HPV vaccine and almost five times as many doses of Tdap each August compared to December. This descriptive summary of the monthly vaccination patterns does not allow for inferential analysis but instead establishes preliminary evidence of cyclical vaccination trends in one state.

Notably, North Carolina has had a school entry requirement for Tdap since Fall 2008, targeting adolescents entering sixth grade; however, the state does not have a school entry requirement for HPV vaccination. The Tdap requirement likely contributes to the more dramatic peak in Tdap than HPV vaccination evidenced by these data. The peak in uptake of

HPV vaccine probably emerges due to concomitant vaccination during a summertime visit at which an adolescent received Tdap.

Not pictured in Figure 2 is the cycle in concomitant vaccination, that is, instances when adolescents received both Tdap and HPV vaccines during the same healthcare encounter. Concomitant vaccination may peak in the summer due to the increased numbers of adolescents receiving each individual vaccine. As described above, the CDC recommends that providers administer both doses at the same healthcare encounter to optimize adolescent vaccination.¹ A cycle in concomitant vaccination may explain the carry-over effect of state vaccine school entry requirements on other vaccines described above. That is, a dramatic increase in the number of adolescents receiving Tdap and HPV vaccines concomitantly during the summer could explain the elevated HPV vaccine coverage levels in states with Tdap school entry requirements.

Conceptual Model and Hypotheses

The conceptual model in Figure 3 summarizes the main relationships of interest in the proposed research for Aim 1. In brief, this aim will involve (1) replication of the finding that school entry requirements are associated with increased coverage of adolescent vaccination, (2) examination of cycles in adolescent vaccination, and (3) a test of the mediational effect of cyclical effects in concomitant vaccination on the relationship between Tdap school entry requirements and states' HPV vaccine coverage.

In Aim 1, I will examine four main constructs. *State cycles of vaccination* captures the presence and magnitude of a cyclical effect in adolescent vaccination for Tdap or HPV vaccine, or both vaccines concomitantly; details on measurement of cycles of vaccination appear in the next section. *School entry requirements* indicates whether a state had a policy

requiring Tdap or HPV vaccination prior to school entry in effect by fall of a given year. Finally, *state vaccine coverage* reflects the proportion of adolescents in a state who had received Tdap or HPV vaccine for each year under study. I describe more fully the proposed relationships among these variables in the hypotheses below.

Hypothesis 1a. States with Tdap school entry requirements will have higher vaccine coverage for Tdap and HPV vaccines than states without Tdap school entry requirements.

As described previously, research has already established that more adolescents receive Tdap⁴⁷ and HPV vaccine⁵² in states with Tdap school entry requirements. I will test this relationship using a nationally representative dataset including observations from 2008 to 2012.

Hypothesis 1b. States with HPV vaccine school entry requirements will have higher HPV vaccine coverage than states without HPV vaccine school entry requirements.

[Exploratory hypothesis]

Only two jurisdictions, Virginia and Washington D.C. (called “states” for simplicity), currently have HPV vaccine school entry requirements. Previous literature demonstrates that school entry requirements are associated with increased rates of uptake for targeted vaccines.^{32,34,47} I will conduct an exploratory analysis to examine whether HPV vaccine coverage is higher in states with school entry requirements than in other states.

Hypothesis 1c. Nationally and within each state, monthly Tdap and HPV vaccination will peak in the summer (i.e., July, August, or September), as will concomitant administration of the two vaccines.

Our preliminary investigation in North Carolina found evidence for dramatic yearly cycles in adolescent vaccination during the summer months compared to the winter months

(see Figure 2). Anecdotal evidence from physicians, colleagues at the CDC, and a vaccine manufacturer suggests that this pattern occurs across the United States.

Hypothesis 1d. State cycles of concomitant vaccination will mediate the positive association between Tdap school entry requirements and HPV vaccine coverage.

As described previously, states with Tdap school entry requirements have higher levels of HPV vaccination among their adolescent female populations than states without such policies.⁵² I propose that cycles in concomitant vaccination mediate this relationship. School entry requirements likely exaggerate cyclical effects of adolescent vaccination, such that the peaks of vaccination (for Tdap, HPV, and concomitant vaccination) that occur in the summer become larger. The increased volume of adolescents receiving concomitant vaccination with both Tdap and HPV vaccine during the summer could explain the carry-over effect of the Tdap policy onto a non-targeted vaccine.

Proposed Analytical and Statistical Methods

Data Sources

The proposed study analyzed national data to examine adolescent vaccination between 2008 and 2012. To test the hypotheses described previously, I analyzed data from three sources: the National Immunization Survey-Teen (NIS-Teen), the Immunization Action Coalition's (IAC) database of vaccine school entry requirements, and the CDC's estimates of state-level adolescent vaccine coverage.

The CDC, the National Center for Immunization and Respiratory Disease, and the National Center for Health Statistics have administered NIS-Teen each year since 2008.⁶¹ NIS-Teen has two parts: (1) telephone interviews with caregivers ("parents") to assess adolescents' vaccination history, and (2) verification by healthcare providers of adolescents'

vaccination history (i.e., vaccinations recorded in a patient's record as having been delivered at that clinic or at another clinic). At the beginning of the survey, interviewers obtained verbal consent and sought additional consent from parents to contact the adolescent's primary healthcare provider. Each year's data originated from a nationally representative sample of parents of 13- to 17-year-old adolescents. Sampling frames for survey years 2008 through 2010 were U.S. landline phone numbers; beginning in 2011, the CDC expanded the sampling frame to include cell phone numbers. Each year, the CDC sent invitation letters to a sample of eligible participants, and parents from more than 80% of contacted households completed the survey. On average, 9,350 adolescent girls had provider-verified data on vaccination each year, for an estimated total of more than 45,000 participants. The CDC releases survey weights for the data; using these weights may increase the generalizability of vaccination estimates.⁶¹

The IAC compiles data from state health departments on school entry requirements for vaccination, including whether each state has a Tdap requirement and, if so, when it became effective.³⁷ I also used the IAC database to gather data on HPV vaccine requirements.

The CDC uses NIS-Teen to calculate each state's vaccination coverage among 13- to 17-year-olds, published annually in *Morbidity and Mortality Weekly Report (MMWR)*.^{5,62-65} The sample I used in Aim 1 and the sample used in *MMWR* estimates are identical. I calculated uptake of Tdap and HPV vaccine initiation as a preliminary step to confirm that my approach yielded the same estimates of states' coverage as those reported in *MMWR*.

Measures

This study examined HPV vaccine initiation (i.e., receipt of at least one dose, hereafter referred to as “HPV vaccination” for the sake of simplicity) and receipt of Tdap vaccine. I captured monthly vaccination and cycles of vaccination with items on the provider survey in NIS-Teen that reflect the date that each participating adolescent female received Tdap and HPV vaccine. I classified instances in which Tdap and HPV vaccination occurred on the same date as concomitant vaccination. Analyses used aggregated data that reflect the weighted number of adolescent girls receiving vaccines each month from 2008 to 2012, separately for each state and Washington D.C. ($n=51$, hereafter referred to as “states” for simplicity).

I measured school entry requirements using dichotomous indicator variables for the presence of a Tdap or HPV vaccine requirement in effect by the fall of each year.

Finally, I measured state vaccine coverage with the CDC’s annual estimates of the proportions of 13- to 17-year-old adolescents in each state that had received Tdap and HPV vaccines.

Data Preparation

I created monthly counts of adolescents vaccinated for each year and averaged across years (e.g., January data will be the average of that month in 2008, 2009, 2010, 2011, and 2012). Vaccination could have occurred at any time previous to the participant’s NIS-Teen interview; thus, this surveillance system accumulates more doses administered in earlier years than in later years. To ensure that each year contributes equally to the overall cycle, I applied weights to each year’s monthly counts equal to the inverse probability of a

vaccination being reported in that year. I divided doses delivered per month by the number of days in the month to reduce the influence of month length.

The dependent variable in these analyses, state vaccine coverage, was a proportion and therefore did not meet the statistical assumptions required for linear regression analysis.⁶⁶ To increase the linearity of this variable to meet the statistical assumptions of linear regression analysis, I transformed the proportion prior to analysis using a logit transformation:⁶⁶ $\ln \frac{p}{1-p}$.

Analytic Approach for Each Hypothesis

Statistical tests were two-tailed with a critical alpha of .05. Models involving school entry requirements for Tdap controlled for the presence of requirements for meningococcal vaccine ($n=16$ states in 2012) and HPV vaccine ($n=2$ states in 2012). For analyses using structural equation modeling (SEM), I evaluated model fit using standard indices,⁶⁷ including the root mean square error of approximation (RMSEA), which should be ≤ 0.05 with an upper confidence interval that does not include 0.08. If the data did not fit the models adequately, I searched for modifications to improve model fit according to standard guidelines,⁶⁷ and if adequate fit was still not achieved, I fit path models using ordinary least squares regression. SEM models employed maximum likelihood estimation with robust standard errors that accounted for repeated measurement across years. I implemented SEM analyses in Mplus v7; all other analyses used SAS version 9.3. Analyses incorporated survey weights provided by NIS-Teen to account for non-equal probability of selection.

Hypothesis 1a tested whether Tdap and HPV vaccine coverage is higher in states with Tdap school entry requirements than in states without such requirements. I tested this relationship for study years 2008 to 2012 (Figure 4). I used longitudinal SEM to examine the

association between having a Tdap school entry requirement in a given year and Tdap and HPV vaccine coverage in the following year (i.e., lag of one year). If this hypothesis were supported, I expected that the coefficients for the paths from school entry requirements to vaccine coverage would be statistically significant (diagonal arrows in Figure 4), controlling for contemporaneous and prior measures of vaccine coverage. In addition, I tested the invariance of these coefficients over the study period; I expected that the magnitude of this relationship will be invariant over time.

Hypothesis 1b was an exploratory test of the effect of state HPV vaccine school entry requirements on state coverage with HPV vaccine. The analytic approach for this hypothesis followed the approach used for *Hypothesis 1a*, except that the independent variable was state HPV vaccine school entry requirements instead of requirements for Tdap. I viewed these analyses as exploratory given that only two jurisdictions (i.e., Virginia and Washington, D.C.) have instituted the policies, albeit they have been in effect for several years.³⁷

For *Hypothesis 1c*, I used Edwards's method of cyclical analysis⁶⁸ to examine the significance and magnitude of annual cyclical effects in Tdap, HPV, and concomitant vaccination for each state and for the United States overall. Edwards's method is the most commonly used strategy for testing seasonal effects.^{53,56,58,59} Edwards's method tests how far the data differ from a pattern of non-seasonality (i.e., flat rate or no peak) by fitting a harmonic sine curve with one peak and one trough per year to the observed data.

First, Edwards's method establishes whether a statistically significant cyclical effect exists in the observed data. Edwards's T is defined as:

$$T = \frac{[8 \sum_{i=1}^{12} N_i] \times \left[\left(\sum_{i=1}^{12} \sqrt{N_i} \sin \theta_i \right)^2 + \left(\sum_{i=1}^{12} \sqrt{N_i} \cos \theta_i \right)^2 \right]}{\left(\sum_{i=1}^{12} \sqrt{N_i} \right)^2}$$

where i is the month, N_i is equal to the number of adolescents vaccinated in month i , and θ_i is equal to $(2i - 1) * (\pi/12)$. Edwards's T statistic has a χ^2 distribution with 2 degrees of freedom.

Second, Edwards's method establishes the magnitude of the observed peak, i.e., the size of the cyclical effect. It uses as a metric, d , defined as:

$$d = \frac{\sqrt{\left(\sum_{i=1}^{12} \sqrt{N_i} \sin \theta_i\right)^2 + \left(\sum_{i=1}^{12} \sqrt{N_i} \cos \theta_i\right)^2}}{\sum_{i=1}^{12} \sqrt{N_i}}$$

A more intuitive measure of the magnitude of the peak is the ratio of the highest to the lowest (RHL) incidence. I used this measure to summarize peaks in vaccination. RHL and its variance are defined as:

$$RHL = \frac{1 + 4d}{1 - 4d} \quad ; \quad var(RHL) = \frac{2}{N}$$

In addition, Edwards's method also offers an equation to calculate the maximum point on the fitted sine curve, i.e., the time when vaccination peaks.

$$\theta_{max} = \tan^{-1} \left(\frac{\left(\sum_{i=1}^{12} \sqrt{N_i} \sin \theta_i\right)}{\left(\sum_{i=1}^{12} \sqrt{N_i} \cos \theta_i\right)} \right)$$

To test whether cyclical effects exist, I compared Edwards's T statistic to the critical value for a χ^2 distribution with 2 degrees of freedom at $p < .05$ (i.e., 5.99) separately for each state and the United States, for each year and averaged across the study period. T statistics that exceeded that value indicated that the RHL for each adolescent vaccination cycle was significantly greater than 1. Finally, I verified that the peak of the vaccination occurs during the summer months (i.e., July, August, or September) using the θ_{max} calculation coupled with visual inspection. I described an overall period that contained the national peak and at least 50% of states' peaks to highlight a few months in which adolescent vaccination was most

common. Months of maximum vaccination may have differed for the three outcomes, but I expected that they would all be in the summer.

Finally, for *Hypothesis 1d*, I examined whether cyclical effects in concomitant vaccination (summarized by *RHL*) mediated the relationship between Tdap school entry requirements and state HPV vaccine coverage using longitudinal SEM (Figure 5).⁶⁷ This approach allowed me to inspect the temporal relationships among the study variables by examining the lagged effects of Tdap requirements on concomitant vaccination and HPV vaccine coverage (paths from Tdap requirements to HPV vaccine coverage in the following year are excluded from Figure 5 for simplicity). If *Hypothesis 1d* was supported, the coefficients for the indirect effects of Tdap school requirements to peaks in vaccination to HPV vaccine coverage would be statistically significant. That is, controlling for state cycles of concomitant vaccination would result in a statistically significant reduction in the strength of the relationship between state Tdap school entry requirements and state HPV vaccine coverage. I tested the invariance of this indirect effect over the five years in the study period; I expected that the magnitude of this effect would be invariant over time. In addition, I expected the cross-sectional relationships between (1) Tdap school entry requirements and cyclical effects in concomitant vaccination, (2) Tdap school entry requirements and state HPV vaccine coverage, and (3) cyclical effects in concomitant vaccination and state HPV vaccine coverage to be statistically significant.

Power Analysis

The longitudinal SEM analysis for *Hypothesis 1d* examined 255 observations (51 states with 5 observations each). The intra-class correlation for states' HPV vaccine coverage from 2008 to 2012 is equal to 0.40, for a design effect of 2.6. Applying this design effect to

the power analysis calculations accounts for clustering within states. Across the study period, a median of 32 states had Tdap requirements and 19 states did not. The median level of HPV vaccine initiation between 2008 and 2012 was 49.4% (logit-transformed=-0.024). With a critical alpha of .05 and a beta of .80, the main analysis had the power to detect a mean difference of 4% in HPV vaccine coverage between states with and without Tdap requirements.

Implications of Cyclical Effects in Adolescent Vaccination

Documenting and analyzing cyclical effects in adolescent vaccination is important for understanding and improving the context in which adolescent vaccination takes place. Recognizing these peaks can help identify times during which programs promoting adolescent vaccines could be most effective and efficient. Just as retailers focus their marketing efforts during times of peak consumption (e.g., Christmas), so could public health focus its limited resources on adolescent vaccine promotion campaigns during regular vaccination peaks. For instance, agencies promoting adolescent vaccination may implement educational or social media campaigns in the late spring or summer months to encourage parents to have their children vaccinated. These interventions could exaggerate the already existing summer peaks, with overall greater numbers of adolescents protected with their recommended vaccines. Interventions that occur in fall or winter months may have less influence on rates of uptake because vaccination behaviors dwindle during that period. To our knowledge, interventionists do not currently consider the role of annual cycles in vaccination on the potential outcomes of their promotional programs.

In addition, cyclical effects in adolescent vaccination could explain the relationship between Tdap school entry requirements and rates of uptake of a non-targeted vaccine, i.e.,

HPV vaccine. Given that implementing HPV vaccine school entry requirements is currently politically infeasible, this finding could demonstrate that, in the context of Tdap requirements, promoting concomitant vaccination (especially during summer months) could advance efforts to increase HPV vaccine coverage.

Figure 2. Average number of adolescent vaccine doses administered per month, 2008–2012, North Carolina.

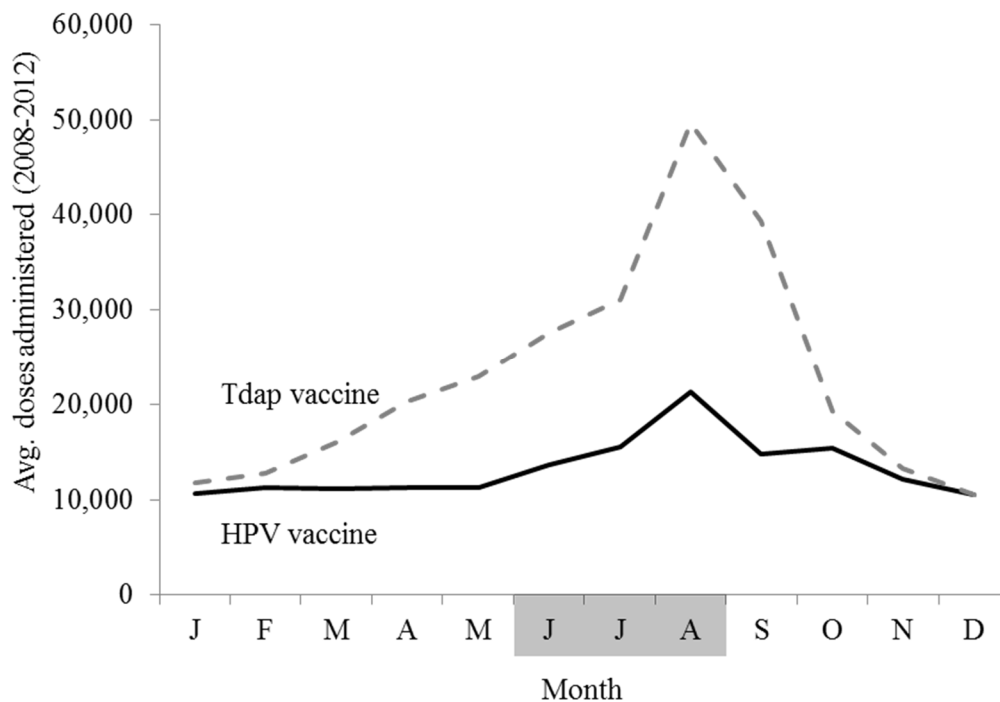


Figure 3. Conceptual model of the effects of cycles in adolescent vaccination on the relationship between school entry requirements and state vaccine coverage (Aim 1).

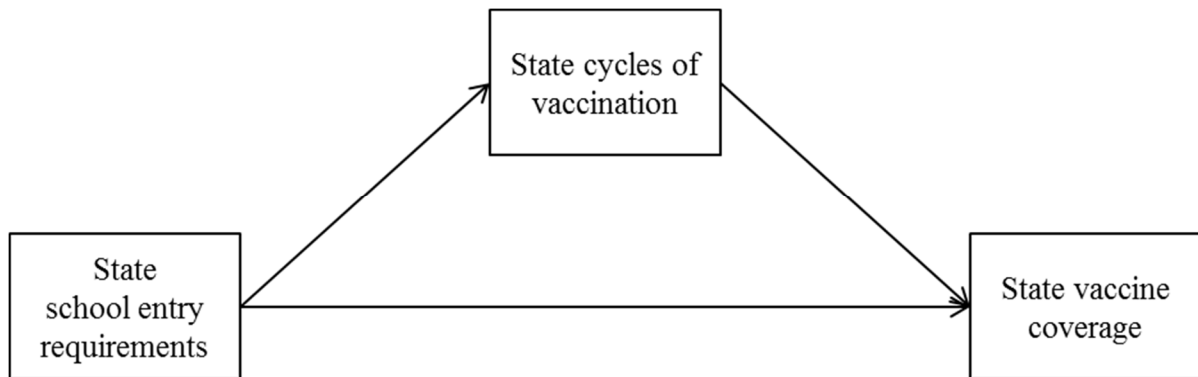


Figure 4. Path analytic model for longitudinal effects of Tdap school entry requirements on state vaccine coverage with Tdap and HPV vaccine, *Hypothesis 1.a*.

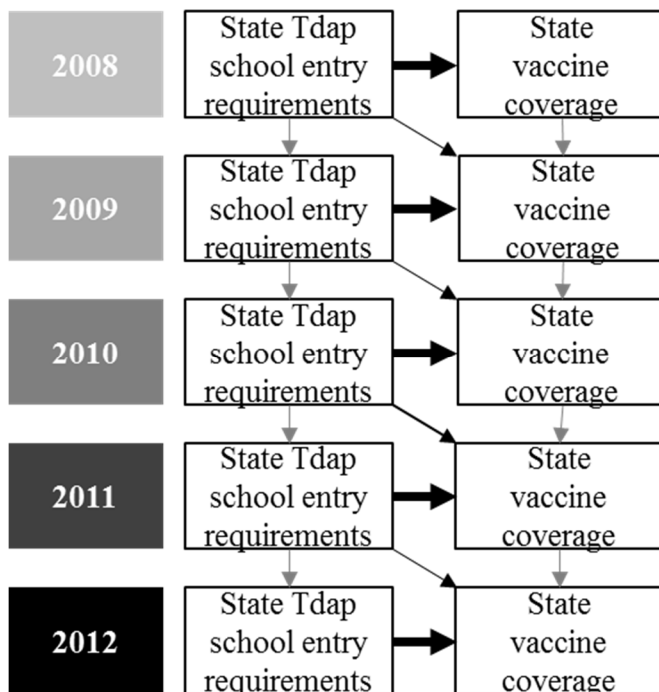
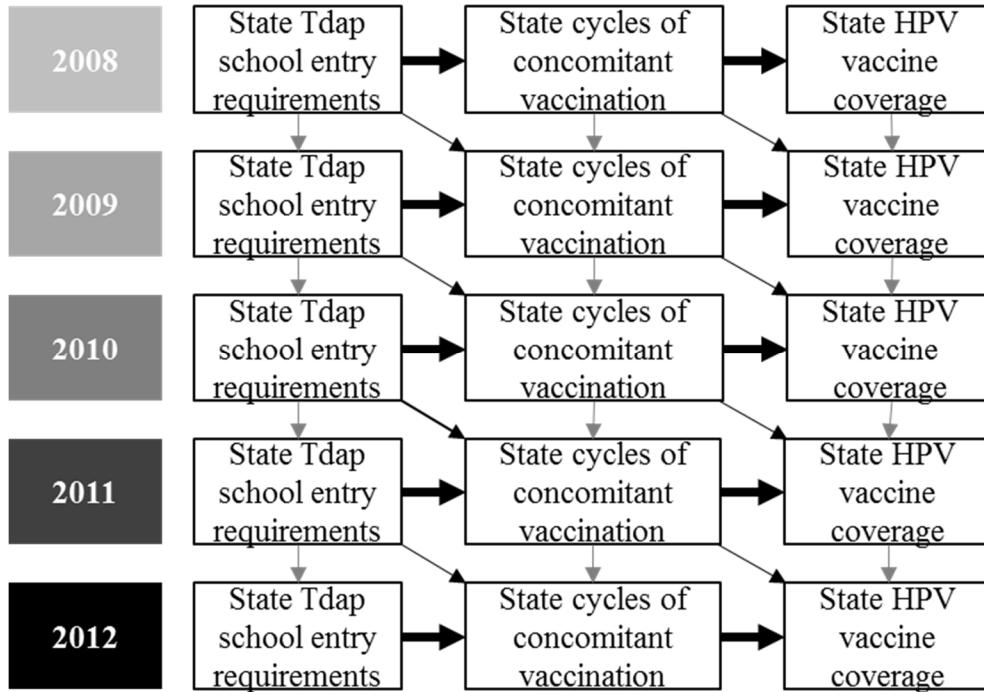


Figure 5. Path analytic model for longitudinal mediation of state cycles of concomitant vaccination of the relationship between state Tdap school entry requirements and state HPV vaccine coverage, *Hypothesis 1.d*.



CHAPTER 4: PATIENT-PROVIDER COMMUNICATION ABOUT VACCINES

Aim 2 of the dissertation addresses the association between patient-provider communication and uptake of HPV vaccine. It also addresses how this relationship may vary depending on vaccine school entry requirements. In this chapter, I summarize the research literature on patient-provider communication and its relationship to vaccination, present the conceptual model and hypotheses for this aim, describe the proposed analytic methods, and discuss implications of this research.

Patient-Provider Communication and Vaccination Decisions

Parents are the primary decision makers regarding vaccinations for adolescents.⁶⁹⁻⁷¹ In the United States, parental vaccine hesitancy or opposition is becoming more common. Although Gust and colleagues⁷² reported in 2005 that less than 3% of parents in the United States were seriously opposed to vaccination, three more recent studies found that at least 15% of parents had actively refused a vaccine during a healthcare encounter.^{45,73,74} Rates of vaccine refusal are increasing,^{33,46,74} and outbreaks of vaccine-preventable diseases have resulted.^{33,75-77} Parental vaccine refusal is becoming a serious threat to public health in the United States, but healthcare providers may be able to intervene to increase vaccination rates.⁷⁷

Parents often solicit the advice of healthcare providers before having their children vaccinated,^{33,34,70,73,78} and regardless of parents' own personal opinions, most accept vaccination of their children.^{34,45,46,71-73,79-83} During a healthcare visit, a provider can educate

a vaccine-hesitant parent on vaccine safety and the potential harms of refusing to vaccinate, helping the parent consent to vaccination.^{45,73,84} For example, Freed and colleagues⁴⁵ surveyed a national sample of parents and found that half reported concerns about serious side effects of vaccines and 25% believed that vaccines cause autism. However, almost 90% of these parents reported following their doctors' recommendations regarding vaccines for their children.⁴⁵

Indeed, a recommendation from a physician is one of the strongest and most consistent predictors of uptake of HPV vaccine.^{70,71,85-92} However, many healthcare providers report being uncertain how to offer such a recommendation.^{69,93-96} Some providers are not knowledgeable enough about HPV and HPV vaccine to offer an appropriate response if parents ask for specific information.^{71,95} Many providers indicate that they anticipate resistance from parents toward vaccines^{69,94,97} or anticipate that the cost of HPV vaccine may be too burdensome to some families.^{95,97} Among providers who recommend HPV vaccine, a subset selectively offer the vaccine only to older adolescents or those they believe to be at risk for acquiring HPV.^{69,71,94,96}

Many researchers and clinicians have concluded that primary healthcare providers need more training on how to offer HPV vaccine recommendations.^{28,33,45,69,70,74,80,84,85,94-96,98} However, less agreement exists regarding the style with which providers should offer recommendations. In the past few decades, primary healthcare has moved toward a more collaborative, rather than directive, model of decision making.⁹⁹ Collaborative decision making simultaneously respects the patient's autonomy and values the provider's healthcare training, and such models often emphasize the importance of rapport, dialogue, and emotional communication.⁹⁹⁻¹⁰⁴ Compared to more directive models of decision making,

collaborative approaches are associated with improved parental satisfaction with the healthcare encounter¹⁰³ and healthcare decisions,¹⁰⁵ reduced parental concerns about safety of a medical intervention,¹⁰² increased adherence to medical recommendations,^{103,106} and improved clinical outcomes.¹⁰³ For example, Murray, Charles, and Gafni¹⁰¹ presented a model for communication between providers and patients in the context of primary healthcare that emphasized *information exchange*, *deliberation*, and *decision making*; the authors suggested that when all three of these processes occur collaboratively, patients engage in the optimal health-related behavior.

However, medical ethics generally deems collaborative decision making unnecessary in situations in which there is only one medically acceptable choice, as is the case with vaccines.¹⁰⁷ In these latter situations, it is the provider's responsibility to guide the patient toward the healthful decision and not encourage the patient to make an alternative choice to avoid putting the patient at undue risk.¹⁰⁷ In the context of adolescent vaccines, collaborative decision making may put patients at risk by encouraging parents to opt out of vaccination. Recent research findings support this conclusion.^{69,108}

Opel and colleagues¹⁰⁸ evaluated provider communication practices when discussing vaccines in 111 videotaped healthcare encounters with patients and parents. The authors classified patient-provider communication as presumptive (i.e., non-collaborative) when providers presupposed that the parent would accept vaccines, e.g., by giving declarations that the provider would give the child shots that day. For conversations that did not presuppose that parents would accept vaccines, e.g., because providers gave parents latitude to refuse vaccines by asking questions, the authors classified communication as participatory (i.e., collaborative). They found that 74% of providers used a presumptive approach and 26% used

a participatory approach. In response to presumptive patient-provider communication, 74% of parents accepted vaccination, but only 4% of parents accepted vaccination when providers used a participatory approach (odds ratio adjusted for parental vaccine hesitancy = 17.5, 95% confidence interval = 1.2, 253.5).¹⁰⁸ In that study, collaborative patient-provider communication hindered parent acceptance of vaccines for their children, potentially endangering their children's health.

Non-collaborative patient-provider communication can result in higher levels of vaccine uptake by framing vaccination as the default choice.^{48,49} Consider again the three explanations for the default effect: interpreting the default choice as a suggestion from health authorities, less effort required to engage in the default choice, and loss aversion when evaluating an alternative in reference to the default choice. The effort involved in accepting versus refusing a vaccine once a patient is already at the healthcare provider's office is fairly equivalent, so communication style probably does not influence a parent's perceptions about how effortful a given behavior is. However, the suggestion and loss aversion explanations are likely to be relevant for the relationship between patient-provider communication and vaccination behaviors. Providers who use a presumptive approach during vaccine discussions offer implicit (or even explicit) endorsements of vaccination, while providers who use a collaborative approach may appear less enthusiastic about vaccination or may imply that uncertainty exists about the vaccine. In addition, when providers use a presumptive communication style, parents must evaluate the potential losses of vaccine refusal in reference to the default of vaccine acceptance. In contrast, when providers use a collaborative communication style, parents may perceive that there is no default behavior or that vaccine

refusal is the default, and therefore loss aversion may not tip their decision making process in favor of vaccine acceptance.

In sum, though collaborative patient-provider communication is associated with healthful decision making in many healthcare contexts, collaborative discussions about vaccines may actually be associated with lower uptake. Ethically, presumptive communication may be more appropriate than collaborative communication given that medically appropriate alternatives to vaccination do not exist. In addition, presumptive communication may frame vaccine acceptance as a default choice, which can optimize vaccination behaviors. Overall, the effect of communication style on receipt of adolescent vaccines remains unclear.

Studies have not yet investigated whether school entry requirements might moderate the association of providers' communication style with uptake of adolescent vaccines. In states *without* school entry requirements, communication style may be particularly influential for parents' decisions. Because policymakers in those states do not endorse vaccination, providers' expectations about vaccination, conveyed through their communication style, may become even more important in affecting vaccine uptake. In contrast, parents in states *with* school entry requirements may be motivated to seek vaccinations regardless of physician communication style to comply with the vaccine policy. However, many states have policies that require adolescents to receive Tdap but do not require HPV vaccine. In these contexts, communication style may become more important for acceptance of HPV vaccine because providers must compensate for policymakers' failure to frame HPV vaccination as the default choice.

In conclusion, healthcare providers' advice strongly influences parents' decisions to vaccinate their children. Although some parents have doubts about whether or not to vaccinate and vaccine refusals are becoming more common, most parents follow the advice of their providers. Specifically for HPV vaccine, providers need more education on how to offer effective recommendations. Although style of communication is likely important for decision making around adolescent vaccines, genuine uncertainty exists around whether a collaborative or non-collaborative approach is preferable for increasing uptake. It is plausible that provider recommendation interacts with the policy environment around adolescent vaccines, but more research is needed.

Conceptual Model and Hypotheses

The conceptual model in Figure 6 depicts the relationships under study in Aim 2. In brief, this aim examined (1) how three aspects of collaborative patient-provider communication correlated with uptake of HPV vaccine, and (2) how these relationships varied across states with and without school entry requirements for Tdap vaccine.

In Aim 2, I studied three aspects of collaborative patient-provider communication (i.e., information exchange, deliberation, decision), as well as uptake of adolescent vaccines and state vaccine school entry requirements. Following Charles and colleagues'^{100,101} description of collaborative patient-provider communication, *information exchange* indicated whether providers talked with parents about a given vaccine. *Deliberation* captured whether providers gave parents time to discuss and think about whether or not to have a child vaccinated. *Decision* reflected whether providers played a role in the parents' decision making process. *Uptake of adolescent vaccines* was a measure of an individual's receipt of Tdap and HPV vaccines, as well as receipt of both vaccines concomitantly. Finally, per the

description of this construct above, *state Tdap school entry requirements* indicated whether a state had a policy in effect requiring that adolescents receive Tdap vaccine prior to school entry. Note that I examined the relationship between state school entry requirements and vaccination behaviors as part of Aim 1 (*Hypotheses 1a* and *1b*). I describe more fully the proposed relationships among the variables in Aim 2 in the hypotheses below. Due to the genuine uncertainty regarding the relationship between collaborative patient-provider communication and uptake of adolescent vaccines, particularly HPV vaccine, I present two competing hypotheses about the main effects of dimensions of collaborative communication, as well a moderating hypothesis.

Hypothesis 2a. Collaborative patient-provider communication will be positively associated with adolescents' receipt of Tdap and HPV vaccines.

Collaborative patient-provider communication is associated with several positive healthcare outcomes.¹⁰²⁻¹⁰⁶ Charles and colleagues^{100,101} propose that patients make optimal healthcare decisions when providers use a collaborative communication style. Per these empirical and theoretical findings, I hypothesized that collaborative patient-provider communication would be positively associated with uptake of adolescent vaccines.

Hypothesis 2b. Collaborative patient-provider communication will be negatively associated with adolescents' receipt of Tdap and HPV vaccines.

Collaborative patient-provider communication is often unnecessary for decisions about vaccines, given that there is no medically acceptable alternative.¹⁰⁷ Non-collaborative communication styles frame adolescent vaccination as a default choice,^{48,49} and empirical

studies find that parents are more likely to accept vaccines when providers use a non-collaborative approach.¹⁰⁸ Thus, I hypothesized that collaborative patient-provider communication would be negatively associated with uptake of adolescent vaccines.

Hypothesis 2c. Collaborative patient-provider communication and state Tdap school entry requirements will interact in their association with uptake of HPV vaccine and concomitant vaccination such that the relationship between collaborative communication and vaccination will be stronger in states with Tdap school entry requirements than in states without Tdap school entry requirements.

Most states with Tdap school entry requirements do not have comparable policies requiring HPV vaccination. In those contexts, parents may perceive policymakers' implicit endorsement of Tdap and rejection of HPV vaccine. Therefore, provider communication style becomes even more important in a parent's decision-making process, particularly in regards to whether or not a provider endorses of the vaccine. A collaborative communication style about HPV vaccination does not convey the provider's endorsement of the vaccine, while a non-collaborative style does convey an endorsement. For parents living in states without Tdap school entry requirements, parents do not have to compensate for policymakers' implicit rejection of HPV vaccine as they decide whether to vaccinate, and provider communication style may be less influential for HPV vaccine uptake.

In addition, the relationship described previously will have a smaller carry-over effect on concomitant vaccination, so I anticipated that analysis of this outcome would demonstrate a comparable pattern of results.

However, I did not expect that Tdap school entry requirements would moderate the relationship between collaborative patient-provider communication and uptake of Tdap vaccine. States that do not have Tdap school entry requirements do not require students to receive other adolescent vaccines, so providers' communication styles in these states may be less influential in terms of compensating for policymakers' implicit vaccine rejection in parental decision making.

Proposed Analytical and Statistical Methods

Data Sources

As part of Aim 2, I analyzed data from two sources: National Immunization Survey-Teen (NIS-Teen) and the Immunization Action Coalition (IAC).

In two quarters of survey year 2010, NIS-Teen (described previously) included the Parental Attitudes Module.⁶¹ Measures of collaborative patient-provider communication for Aim 2 came from the second section of the Parental Attitudes Module, "Influences on parents' decisions about vaccines." Information on uptake of HPV vaccine came from NIS-Teen records for participants who completed the Parental Attitudes Module.

As described previously, the IAC compiles data from state health departments on school entry requirements for vaccination, including whether each state has a Tdap requirement, and, if so, when it became effective.³⁷

Measures

The conceptual model for Aim 2 (Figure 6) includes five constructs: information exchange, deliberation, decision, uptake of adolescent vaccines, and state Tdap school entry requirements. I analyzed these items only among the subsample of parents who answered questions about female adolescents. This analysis was limited to respondents from two

quarters of the 2010 survey year, when NIS-Teen implemented the Parental Attitudes Module.

I measured information exchange with one item: “At visits made for [teen name]’s vaccinations, did his/her healthcare provider talk to you about HPV shot?” Parents could respond *yes* or *no* to this item, or interviewers could select *don’t know* or *refused* if appropriate. I created a dichotomous measure of information exchange by assigning a value of 1 (for collaborative information exchange) for parents who responded *yes* and a value of 0 (for non-collaborative information exchange) for parents who responded *no*, *don’t know*, or *refused*.

I measured deliberation with one item: “At visits made for [teen name]’s vaccinations, did his/her healthcare provider give you enough time to discuss the HPV shot?” Again, parents could respond *yes* or *no* to these items. I created a dichotomous measure of deliberation by assigning a value of 1 (for collaborative deliberation) for parents who responded *yes* and a value of 0 (for non-collaborative deliberation) for parents who responded *no*, *don’t know*, or *refused*.

I measured decision with one item: “At visits made for [teen name]’s vaccinations, did his/her healthcare provider play a role in your decision to get [teen name] vaccinated or not to get [teen name] vaccinated with the HPV shot?” Again, parents could respond *yes* or *no* to these items. I created a dichotomous measure of decision by assigning a value of 1 (for collaborative decision) for parents who responded *yes* and a value of 0 (for non-collaborative decision) for parents who responded *no*, *don’t know*, or *refused*.

Adolescent vaccine uptake came from provider-verified reports of whether or not an adolescent had received at least one dose of HPV vaccine before completing the survey.

Finally, I measured whether or not a state had a Tdap school entry requirement in effect by Fall 2010 using a dichotomous indicator variable.

Analytic Approach for Each Hypothesis

Statistical tests were two-tailed with a critical alpha of .05. Models involving school entry requirements controlled for the presence of requirements for meningococcal vaccine ($n=11$ states in 2010) and HPV vaccine ($n=2$ states in 2010). All analyses used SAS version 9.3. Analyses incorporated survey weights provided by NIS-Teen to account for non-equal probability of selection.

To test *Hypotheses 2a* and *2b*, I used bivariate and multivariate logistic regression to examine the effect of collaborative patient-provider communication on uptake of adolescent vaccines. I tested the effects of three dimensions of collaborative communication individually (i.e., in bivariate regression), and then I built a model including all of the dimensions of collaborative communication that demonstrated statistically significant relationships with uptake of adolescent vaccines in bivariate models. If *Hypothesis 2a* were supported, the beta coefficients for the communication variables would be statistically significant and positive, but if *Hypothesis 2b* were supported, the beta coefficient would be statistically significant and negative.

Hypothesis 2c involved examining the moderating effect of Tdap school entry requirements on the relationship between collaborative communication and uptake of adolescent vaccines. I conducted additional logistic regression analyses, adding interaction terms for the dimensions of collaborative communication with presence of a Tdap school entry requirement. If *Hypothesis 2c* were supported, then the interaction terms for the relationship of Tdap requirements and dimensions of collaborative communication on HPV

and concomitant vaccination would be statistically significant. I did not expect the interaction terms for the relationship of Tdap requirements and dimensions of collaborative communication on Tdap vaccination to be statistically significant. In addition, post-hoc tests would reveal that the association between the communication variables and adolescent vaccination were stronger for states with Tdap requirements than for states without Tdap requirements.

Power Analysis

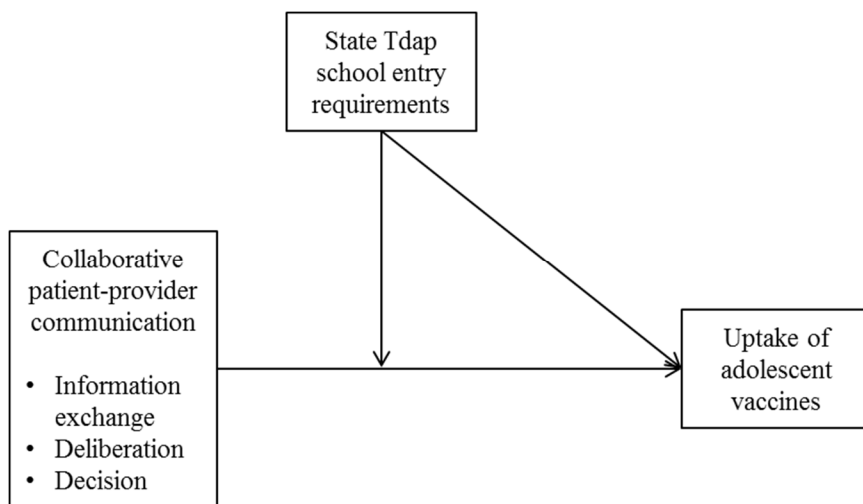
Parents of 4,610 adolescent females completed the NIS-Teen Parental Attitudes Module and have provider-verified data on HPV vaccine uptake. Opel and colleagues¹⁰⁸ estimated that the proportion of providers using a collaborative communication style was 26% and the proportion using a non-collaborative style was 74%. In 2010, 49% of all adolescent females had received at least one dose of HPV vaccine. With a critical alpha of .05 and a beta of .80, the analysis in *Hypotheses 2a* and *2b* had the power to detect a mean difference of <5% in HPV vaccine coverage between adolescents whose providers used a collaborative versus a non-collaborative communication style.

Implications of the Effect of Patient-Provider Communication on Adolescent Vaccination

Parsing out the effects of collaborative patient-provider communication on uptake of adolescent vaccines has consequences for provider training in how to encourage adolescent vaccination. Although provider recommendation is one of the strongest and most consistent correlates of vaccination, little is known about how style of communication influences vaccine uptake. Ethics, theory, and empirical findings on patient-provider communication about childhood vaccines provide contradictory suggestions about whether this relationship could be positive or negative. The findings from this aim could inform educational

interventions that teach providers how to discuss adolescent vaccines, especially HPV vaccine, with patients and their parents. In addition, understanding how the health policy context moderates the association between patient-provider communication and adolescent vaccination will deepen the scientific understanding of how policies shape behaviors.

Figure 6. Conceptual model of the relationships among collaborative patient-provider communication, state vaccine school entry requirements, and uptake of adolescent vaccines.



CHAPTER 5: YEARLY CYCLES IN ADOLESCENT VACCINATION, UNITED STATES

Introduction

National guidelines recommend that 11- and 12-year olds routinely receive three adolescent vaccines: tetanus, diphtheria, and pertussis (Tdap) booster, meningococcal vaccine, and a three-dose series of human papillomavirus (HPV) vaccine.¹⁵ Healthy People 2020 set the goal for 80% of 13- to 15-year-old adolescents to receive each of these vaccines,²⁷ and though coverage for Tdap booster has surpassed that level and meningococcal vaccine is quickly approaching it, coverage for HPV vaccine falls far short. Only 28% of females and 7% of males in this age group have received the entire HPV vaccine series as of 2012.^{5,27} Failing to meet these goals could have a tremendous impact on population health; achieving 80% coverage with HPV vaccination could prevent an additional 53,000 cases of cervical cancer over the lifetime of females who are now age 12 or younger.¹⁰⁹ For this reason, the Centers for Disease Control and Prevention (CDC), the National Cancer Institute, and other national organizations have prioritized increasing HPV vaccination.^{27,110,111}

In some locations in the United States, adolescent vaccination appears to demonstrate a cyclical pattern, with increased numbers of adolescents receiving vaccines during the summer months compared to the rest of the year.^{112,113} However, whether this is a national phenomenon is unknown and previous demonstrations of cyclical patterns have mostly employed descriptive rather than inferential methods. Several factors could give rise to this

pattern, including parents seeking to comply with vaccine school entry requirements³⁷ before the school year begins, requirements for summer camps, the relative ease of pursuing preventive healthcare when most students are on summer break, and the tendency to schedule well-child visits around the time of a child's birthday (which is slightly more likely to occur in the summer compared to winter months¹¹⁴). Understanding cyclical variation in adolescent vaccination has implications for healthcare practice and public health in terms of timing quality improvement or promotional programs, an especially important consideration for HPV vaccination. Our study sought to evaluate patterns in adolescent vaccination in the United States using several years of population-based clinical data.

Patients and Methods

Data Source

Data came from the 2008–2012 versions of the National Immunization Survey (NIS)-Teen conducted by the CDC.⁶¹ NIS-Teen is a two-part survey consisting of telephone interviews administered to a national probability sample of caregivers of 13- to 17-year-old adolescents (hereafter referred to as “parents”) and questionnaires mailed to the adolescents' primary healthcare providers.

NIS-Teen employed list-assisted random-digit dialing methods to compile telephone numbers for a sample of potential participants. Using a national database of residential telephone numbers, NIS-Teen staff then sent advance letters to addresses that were linked to the sample telephone numbers, alerting the household to the upcoming phone contact. In 2008–2010, NIS-Teen staff contacted parents through landline numbers, and in 20112012, staff also contacted parents through cell phone numbers.

At the end of the telephone interviews, interviewers asked participating parents for consent to contact the pediatricians, family practitioners, or other clinical providers who may have medical records containing adolescents' vaccination history. Parents provided contact information for these providers, allowing NIS-Teen staff to mail two-page written questionnaires to providers' offices. If providers did not return questionnaires within 2 weeks, NIS-Teen staff called providers to encourage them to complete and return them.

Between 2008 and 2012, NIS-Teen collected provider-verified vaccination data for about 20,000 adolescents living in the 50 states and Washington D.C. (hereafter referred to collectively as "states" for the sake of simplicity) each year, for a cumulative total of 101,517 adolescents.⁶¹ Because we were interested in dates of adolescent vaccination, which is conditional on actually receiving at least 1 vaccine, we excluded participants who had no provider-verified vaccination ($n=19,932$). In addition, we excluded participants who had received at least 1 vaccine but their provider either reported that all dates of administration fell outside of the study period ($n=8,642$) or did not report the dates of administration ($n=12$), for a final analytic sample of 72,931 adolescents. NIS-Teen staff calculated sampling weights for each participant with provider-verified data to account for non-equal probability of selection.

Data collection for NIS-Teen was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board. Analysis of de-identified data from the survey is exempt from the federal regulations for the protection of human research participants. Analysis of restricted data through the NCHS Research Data Center is also approved by the NCHS Ethics Review Board. The University of North Carolina Institutional Review Board exempted our study from review.

Measures

On the mailed questionnaires, healthcare providers reported whether adolescents received Tdap booster, meningococcal vaccine, and HPV vaccine and, if so, the month, date, and year of administration. Although data collection took place beginning in 2008, we included instances of vaccination that occurred on or after January 1, 2007, in this analysis because providers could report any vaccine administration that took place before (and up to the date of) the NIS-Teen phone interviews. We used data for HPV vaccine initiation (i.e., receipt of the first dose of the three-dose series) only among female adolescents because the CDC did not introduce a recommendation for routine administration to male adolescents until 2011.⁴ We coded participants as receiving vaccines concomitantly if providers reported administration of the vaccines on the same day.³¹ Thus, we captured whether adolescents concomitantly received 4 possible combinations of vaccines: (1) Tdap booster and meningococcal vaccine; (2) Tdap booster and HPV vaccine; (3) meningococcal and HPV vaccines; and (4) Tdap booster, meningococcal vaccine, and HPV vaccine. State of residence and demographic characteristics came from parental report in the NIS-Teen telephone survey.

Data Analysis

Data preparation. We combined data from the 2008 to 2012 versions of NIS-Teen using NCHS's recommended procedures that include creating new weighting variables.⁶¹ Then we categorized participants according to the month and year in which they received vaccines and generated weighted estimates of the total number of vaccine doses administered in each month of the study period. We standardized the length of each month by dividing the monthly vaccination totals by the number of days in the month and multiplying by 30, so that

each month contributed equally to the yearly cycles. This approach may be unnecessary when analyzing large samples,⁶⁸ but some researchers have noted the value of using this standardization technique to remove the influence of month length from studies of seasonality.^{56,115} For analyses that combined vaccination data from multiple years, we weighted each year's observations so that years contributed equally to the combined cycles.

To create figures depicting vaccination peaks for individual states and for the United States, we put the number of people receiving a vaccine in a given month on a common metric, following recommendations by Rau.^{56,116} To do so, we calculated the number of people who received the vaccine each month, and then rescaled the data so that the yearly total was 1,200. Any month with a scaled vaccination total exceeding 100 contained greater vaccination than would be expected if vaccination were randomly distributed over time, and any month with a scaled vaccination total of less than 100 contained less vaccination than expected. This approach facilitates descriptive comparison of cyclical patterns between units of geography with different population sizes. Note that the inferential procedures described next did not use these scaled observations but instead analyzed month- and year-standardized data (described previously).

Inferential analysis. For all data years combined, we examined cyclical patterns for the United States overall and within each state, and then within each study year for the United States. These three approaches allowed us to check for consistency of cyclical patterns across geography and time. We performed these calculations separately for the Tdap booster, meningococcal vaccine, and HPV vaccine, as well as for each of the four possible concomitant vaccination outcomes. Small sample sizes precluded generating estimates for each study year separately within states; for concomitant vaccination within states; and for

2012, the final study year, separately from the preceding years (i.e., because vaccination that occurred in 2012 could only be reported by participants in the 2012 survey).

To test the statistical significance of cyclical patterns, we used Edwards's method,^{56,68} the most commonly used analytic approach in seasonality research.⁵⁶ Briefly, the Edwards method involves fitting a harmonic sine curve with one peak and one trough to the observed data in each month. (Before implementing these methods, we verified with visual inspection that the data did not follow a qualitatively different form, e.g., bimodal, which would require different analytic tools.) Edwards's *T* statistic, which measures how far the fitted curve differs from non-seasonality (i.e., a flat line), follows a chi-square distribution with 2 degrees of freedom. The ratio of highest to lowest (RHL) incidence examines the amplitude of the fitted curve to describe the relative increase in the outcome at the cycle's maximum (i.e., its peak) compared to its minimum (i.e., its trough).^{56,68} Previous studies in public health have used Edwards's method to assess cyclical patterns in outcomes such as cardiovascular disease, suicide, and malaria.^{53,58,59} For each vaccination outcome in the current study, we fitted a sine curve to the observed vaccination data and calculated the resulting *T* statistic. In addition, we examined the RHL to summarize the magnitude of the cyclical pattern in vaccination.

All analyses were conducted in SAS version 9.2 (Cary, NC). Statistical tests used a two-tailed *p* value of .05. Analyses incorporated survey weights to account for non-equal probability of selection.

Results

The 72,931 vaccinated adolescents were nearly evenly distributed by sex and age (Table 1). Most adolescents were non-Hispanic white (57.2%), had private health insurance

(60.7%), and had a preventive healthcare visit in the past year (87.1%). The majority of adolescents lived in metropolitan households (86.8%) above the poverty level (74.3%).

Uptake of Single Adolescent Vaccines

Adolescent vaccination in the United States increased in late spring, crested in August, and decreased rapidly thereafter (black lines in Figure 7). For 2007–2012 combined, uptake was highest in the months of June, July, and August; healthcare providers administered about 40% of all vaccine doses during this period (Tdap booster: 40.2%; meningococcal vaccine: 41.1%; HPV vaccine: 38.7%) (Table 2). Each vaccination outcome demonstrated cyclical patterns (all $p < .001$) (Table 3). For Tdap booster, the RHL was 5.1, indicating that vaccination was 5 times as frequent at the cycle's peak as at its trough. The RHL was 10.1 for meningococcal vaccine and 4.7 for HPV vaccine.

Adolescent vaccination in individual states largely demonstrated the same summer peaks as in the United States overall (gray lines in Figure 7). For each state, each vaccination outcome demonstrated cyclical patterns (all $p < .001$) (Supplementary Table S1). The RHLs of states' cycles varied from 3.0 in Washington, D.C., to 13.3 in Utah for Tdap booster; from 4.9 in Arizona to 40.3 in Nevada for meningococcal vaccine; and from 2.5 in New Mexico to 98.2 in Nevada for HPV vaccine.

The pattern of increased vaccination in the summer was also present when examined within each individual year (Figure 8). For each year, each vaccination outcome demonstrated cyclical patterns (all $p < .001$) (Table 3). Over time, the RHLs of the cycles for Tdap booster increased slightly, from 4.5 in 2008 to 6.6 in 2011. For meningococcal vaccine, the RHLs increased dramatically, from 7.5 in 2007 to 21.2 in 2011. However, for HPV

vaccine, the RHLs varied from year to year with no clear pattern, ranging from 4.5 in 2008 to 5.7 in 2010.

Concomitant Uptake of Adolescent Vaccines

Concomitant vaccination showed a pattern similar to the findings for individual vaccines, increasing in late spring, cresting in the summer months, and decreasing rapidly thereafter (Supplementary Figure S1). Concomitant adolescent vaccination was highest in the months of June, July, and August; about 40% of all concomitant vaccination took place during this period (Table 2). Each concomitant adolescent vaccination outcome demonstrated cyclical patterns for the United States both across and within study years (all $p < .001$) (Table 4).

Conclusion

Across the United States, uptake of adolescent vaccines demonstrated consistent yearly cycles with peaks in the summer. From 2007 to 2012, healthcare providers administered around 40% of these vaccines during June, July, and August. Compared to vaccination at the trough of each cycle, vaccination at the peak was about 5 times as high for Tdap booster and HPV vaccine and about 10 times as high for meningococcal vaccine. The pattern of summer peaks in adolescent vaccination occurred across years and within each state. For concomitant vaccination, the peaks were similar though somewhat smaller.

Summer peaks in adolescent vaccine provision appear to be robust, but more research is needed to better understand what causes them. Vaccination requirements for school entry may encourage parents and adolescents to seek vaccination in the summer months.³⁷ As of Fall 2014, 47 states had school entry requirements for Tdap and 20 states had requirements for meningococcal vaccination.³⁷ In support of this hypothesis, we found that cycles of

adolescent vaccination generally reached their peaks in August, which coincides with the beginning of the school year in most areas of the United States. These policies could also explain some of the difference in magnitude of cyclical effects for Tdap booster versus meningococcal vaccine: generally, states with requirements for the latter vaccine adopted them more recently. Their more recent implementation may exaggerate the observed summer peaks as parents newly rush to comply. Additional research is needed on the possible connection between school entry requirements and summer peaks in adolescent vaccination.

An alternative explanation is that seeking adolescent vaccination is easier when students are out of school. Were this the case, vaccination should have a secondary, albeit smaller, peak when schools close for winter break; however, we found that vaccination was actually least common in November and December. Any effect of adolescents being out of school during portions of those months may have been overwhelmed by the influence of families' and healthcare clinics' restricted schedules (due to travel, closures for the winter holidays, etc.). More research is needed on what motivates adolescents and parents to seek vaccination in the summer months.

Our results extend the findings of two recent descriptive studies. Sull and colleagues¹¹² used the New York City immunization information system (IIS) to measure monthly administration of Tdap booster, meningococcal vaccine, and HPV vaccine among 11-year-old adolescents from 2005 to 2013. Starting in 2007, they found large increases in uptake of Tdap booster and meningococcal vaccine and small increases in uptake of HPV vaccine in the summer compared to the rest of the year. Cullen and colleagues¹¹³ used IIS data at 8 sentinel sites in the United States to analyze the weekly number of HPV vaccine doses administered among male and female adolescents aged 11–18 years. The authors

reported relative increases in HPV vaccination during the summers of 2010–2012. We expanded on these studies by using nationally representative data to quantify the magnitude of summer peaks across time and in each state, test their statistical significance, and examine cycles in concomitant vaccination. Taken together, these studies illustrate the presence of consistent cycles in the demand for adolescent vaccines, which has important implications for clinical practice and public health.

Cyclical patterns in adolescent vaccination influence clinical practice for pediatric and family practice providers in at least three important ways. First, clinics should increase their supplies of adolescent vaccines during the summer and, potentially, reduce their supplies during the winter. Based on the observed data, clinics were able to serve more adolescents seeking vaccination in the summer, but we could not determine whether demand for vaccination exceeded availability of vaccine doses. Were this the case, summer peaks could be even larger in magnitude than we observed. Second, providers should consider implementing immunization quality improvement efforts during the spring months because the relative decrease in vaccination during those times affords more organizational capacity to make structural changes in preparation for summer increases in vaccination. Undertaking such programs during the summer would potentially be crowded out by the more immediate needs of serving adolescent patients. Third, summer peaks in uptake of single vaccines translate into increased opportunities for providers to recommend adolescent vaccines concomitantly. Given that a provider's recommendation is the strongest and most consistent correlate of adolescent vaccination,^{6,70} recommending additional vaccines during immunization visits in the summer could bring about large increases in coverage for the entire adolescent vaccine platform.

In addition, these vaccination cycles have implications for public health practice and research. Promotion programs aimed at improving attitudes or intentions around adolescent vaccination may be especially fruitful if they occur in the late spring and early summer and can capitalize on the existing peaks. Similarly, interventions that happen during the summer peak may face reduced capacity among clinicians who are partners in evaluation. In addition, public health researchers need to account for these cyclical patterns when conducting evaluations to avoid misattributing secular increases in coverage in the summer to promotion or intervention activities. This issue of potential confounding is of greatest concern for uncontrolled research study designs.

Study strengths include that we analyzed vaccination dates drawn from several years of a large, nationally representative survey.⁶¹ We used an objective measure of vaccination status (i.e., verified by healthcare providers). Our study employed a canonical analytic technique used in studies of seasonal phenomena across disciplines.⁵⁶ In addition, our inclusion of concomitant vaccination is somewhat unique. Finally, we analyzed cycles of vaccination across three combinations of geography and time. Together, these strengths support the validity and reliability of our study conclusions. Study limitations include that we could not distinguish between adolescents' current state of residence (the unit of analysis in this study) and the state in which they received their vaccines. Because the United States has high residential mobility,¹¹⁷ we can assume that some adolescents relocated during the time between vaccination and participation in NIS-Teen. For those adolescents, the state in which they received vaccines was likely misattributed. However, given the similarity of the vaccination cycles evident across states and across years, the effect of this misattribution is likely minimal. Another limitation is that although we were able to document and analyze

this cyclical phenomenon, we were unable to evaluate why and how it emerged. Future studies should examine parental motivations to vaccinate in the summer and their effects on the observed cycles

In summary, we found marked summer peaks in uptake of adolescent vaccines from 2007 to 2012. For the United States as a whole and for individual states, vaccination increased substantially during the summer months. Healthcare providers administered about 40% of all adolescent vaccines during June, July, and August. These cycles have implications for both clinical practice (e.g., stocking up on adolescent vaccines during the summer) and public health (e.g., timing of vaccine promotion efforts). Future studies should evaluate how cyclical patterns emerge and how they affect population-level coverage with adolescent vaccines.

Table 1. Descriptive Statistics of Participating Adolescents and Their Families (Source: National Immunization Survey-Teen)

	Total Sample		Male		Female	
	n	(%)	n	(%)	n	(%)
Total	72,931		35,862	48.2%	37,069	51.8%
Survey year						
2008	8,317	13.3%	3,256	11.9%	4,791	14.6%
2009	12,766	17.6%	5,943	16.8%	6,823	18.5%
2010	14,673	20.7%	7,237	21.0%	4,736	20.4%
2011	19,969	23.5%	10,156	24.3%	9,813	22.8%
2012	17,206	24.9%	9,000	26.1%	8,206	23.7%
<i>Child characteristics</i>						
Age						
13	15,822	21.0%	8,069	21.7%	7,753	20.3%
14	15,907	21.0%	8,046	21.6%	7,861	20.4%
15	15,183	21.9%	7,448	22.0%	7,735	21.9%
16	14,134	19.6%	6,784	19.2%	7,350	19.9%
17	11,885	16.5%	5,515	15.5%	6,370	17.5%
Race/ethnicity						
Hispanic	9,869	20.5%	4,832	20.6%	5,037	20.4%
Non-Hispanic white	49,577	57.2%	24,467	57.4%	25,110	57.0%

Non-Hispanic black	7,355	14.3%	3,615	14.3%	3,740	14.4%
Other	6,130	8.0%	2,948	7.8%	3,182	8.2%
Private health insurance						
Yes	49,747	60.7%	24,351	60.0%	26,396	61.4%
No	22,796	39.3%	11,317	40.0%	26,396	38.7%
Preventive visit in the last year						
Yes	64,202	87.1%	31,466	86.5%	32,736	87.7%
No	8,729	12.9%	4,396	13.5%	4,333	12.3%
<i>Parent characteristics</i>						
Relationship of respondent to teen						
Mother/female guardian	58,030	76.8%	28,268	75.3%	29,762	78.3%
Father/male guardian	11,712	17.3%	6,022	18.7%	5,690	16.0%
Other	3,189	5.9%	1,572	6.0%	1,617	5.8%
Education level						
Less than high school	6,739	13.9%	3,276	14.0%	3,463	13.8%
High school	13,834	25.3%	6,895	25.7%	6,939	24.8%
Some post-high school	20,255	25.7%	9,858	25.0%	10,397	26.3%
College graduate	32,103	35.2%	15,833	35.3%	16,270	35.1%
<i>Household characteristics</i>						
Poverty status						
Below poverty level	10,291	20.7%	5,031	20.6%	5,260	20.8%
Above poverty level, ≤\$75,000	27,397	38.6%	13,562	39.2%	13,835	38.0%
Above poverty level, >\$75,000	32,481	35.7%	15,885	35.2%	16,596	36.1%
Unknown	2,762	5.0%	1,384	5.0%	1,378	5.0%
Urbanicity						
Metropolitan	52,442	86.8%	25,746	86.1%	26,696	85.5%
Non-metropolitan	13,661	14.2%	6,577	13.9%	7,084	14.5%
Census region						
Northeast	15,850	19.4%	7,797	19.3%	8,053	19.6%
Midwest	16,217	21.6%	7,892	21.6%	8,325	21.5%
South	24,846	34.5%	12,256	34.6%	12,590	34.4%
West	16,018	24.6%	7,917	24.6%	8,101	24.5%

Note. We present unweighted *n*'s and weighted percentages.

Table 2. Adolescent Vaccine Doses Administered Per Month in the United States

	Single vaccination			Concomitant vaccination			
	Tdap	Meng	HPV ¹	Tdap and Meng	Tdap and HPV ¹	Meng and HPV ¹	All three
<i>n</i>	55,269	53,200	22,849	26,999	6,520	8,894	4,371
January	6.7%	6.2%	8.0%	6.3%	10.2%	7.1%	8.9%
February	6.3%	7.2%	7.6%	6.0%	5.3%	7.2%	5.7%
March	7.8%	7.6%	7.2%	8.2%	6.9%	7.8%	6.9%
April	8.1%	7.8%	8.0%	8.4%	8.2%	8.9%	9.3%
May	8.6%	7.4%	6.8%	8.2%	7.8%	7.2%	8.5%
June	9.2%	10.0%	10.2%	9.1%	8.5%	8.5%	8.0%
July	12.0%	13.1%	12.6%	12.9%	13.0%	12.8%	13.3%
August	19.0%	18.0%	15.9%	18.9%	20.0%	17.6%	20.3%
September	8.2%	7.9%	7.4%	7.8%	7.7%	9.0%	6.2%
October	6.5%	6.4%	7.2%	6.8%	6.1%	6.1%	6.5%
November	4.4%	5.2%	5.6%	4.4%	3.9%	5.1%	4.2%
December	3.2%	3.4%	3.5%	2.9%	2.4%	2.7%	2.2%

(Source: National Immunization Survey-Teen).

Note. Tdap=tetanus, diphtheria, and pertussis booster; Meng=meningococcal vaccine; HPV=human papillomavirus vaccine.¹Uptake of first dose among female adolescents only.

Table 3. Cyclical Effects in Adolescent Vaccine Uptake

		Tdap booster		Meningococcal vaccine		HPV vaccine ¹	
		<i>T</i>	magnitude (RHL[var])	<i>T</i>	magnitude (RHL[var])	<i>T</i>	magnitude (RHL[var])
Combined years		12,173,702*	5.1 (0.01)	19,067,776*	10.1 (0.01)	5,037,752*	4.7 (0.01)
Year	2007	3,552,048*	4.6 (0.01)	4,793,365*	7.5 (0.01)	2,145,027*	5.7 (0.01)
	2008	3,099,100*	4.5 (0.01)	5,333,919*	8.3 (0.01)	1,349,452*	4.5 (0.01)
	2009	2,458,182*	5.0 (0.01)	3,873,037*	9.1 (0.01)	876,756*	5.3 (0.01)
	2010	1,654,178*	5.7 (0.01)	2,366,461*	10.5 (0.01)	563,744*	5.7 (0.01)
	2011	868,275*	6.6 (0.01)	1,354,808*	21.2 (0.01)	341,771*	4.8 (0.01)

(Source: National Immunization Survey-Teen).

Note. Tdap=tetanus, diphtheria, and pertussis; HPV=human papillomavirus; *T*=Edwards' T statistic; RHL=ratio of highest to lowest vaccination (i.e., the ratio of frequency of vaccination in the month when it is most common to the month when it is least common); var=variance. * $p<.001$.

¹Uptake of first dose among female adolescents only.

Table 4. Cyclical Effects in Concomitant Adolescent Vaccine Uptake

		Tdap and Meng			Tdap and HPV			Meng and HPV			All three		
		<i>T</i>	magnitude (RHL[var])		<i>T</i>	magnitude (RHL[var])		<i>T</i>	magnitude (RHL[var])		<i>T</i>	magnitude (RHL[var])	
Combined years		6,848,772*	5.6	(0.01)	1,504,766*	4.6	(0.01)	1,915,599*	4.2	(0.01)	744,320*	3.3	(0.01)
Year	2007	1,641,649*	5.1	(0.01)	640,471*	6.2	(0.01)	761,522*	4.8	(0.01)	288,103*	4.5	(0.01)
	2008	1,756,694*	4.7	(0.01)	373,947*	4.0	(0.01)	619,119*	4.3	(0.01)	195,484*	3.1	(0.01)
	2009	1,420,718*	4.8	(0.01)	395,753*	7.2	(0.01)	487,682*	6.4	(0.01)	213,425*	4.2	(0.01)
	2010	1,152,333*	7.5	(0.01)	280,421*	10.4	(0.01)	243,709*	5.8	(0.01)	160,424*	5.6	(0.01)
	2011	482,161*	6.9	(0.01)	135,135*	8.3	(0.01)	128,367*	5.2	(0.01)	38,752*	3.3	(0.01)

(Source: National Immunization Survey-Teen).

Note. Tdap=tetanus, diphtheria, and pertussis booster; Meng=meningococcal vaccine; HPV=human papillomavirus; *T*=Edwards' *T* statistic; RHL=ratio of highest to lowest vaccination (i.e., the ratio of frequency of vaccination in the month when it is most common to the month when it is least common); var=variance. * $p < .001$.

¹Uptake of first dose among female adolescents only.

Supplemental Table S1. Cyclical Effects in Uptake of Adolescent Vaccines and Concomitant Adolescent Vaccine Uptake By State

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	Tdap booster				Meningococcal vaccine				HPV vaccine ¹			
	<i>N</i>	<i>T</i>	magnitude (RHL[<i>var</i>])		<i>T</i>	magnitude (RHL[<i>var</i>])		<i>T</i>	magnitude (RHL[<i>var</i>])			
Alabama	1252	6,998*	4.4	(0.01)	8,216*	6.8	(0.01)	3,031*	4.2	(0.01)		
Alaska	1058	1,413*	7.2	(0.01)	1,792*	17.9	(0.01)	695*	6.3	(0.01)		
Arizona	1391	9,413*	3.6	(0.01)	16,821*	4.9	(0.01)	6,685*	5.2	(0.01)		
Arkansas	833	4,033*	7.8	(0.01)	3,657*	15.0	(0.01)	3,046*	37.7	(0.01)		
California	1582	48,407*	4.0	(0.01)	90,966*	7.4	(0.01)	29,461*	4.5	(0.01)		
Colorado	1408	11,533*	5.9	(0.01)	11,910*	12.1	(0.01)	3,239*	4.3	(0.01)		
Connecticut	1588	5,352*	4.1	(0.01)	10,525*	8.8	(0.01)	2,183*	3.4	(0.01)		
Delaware	1409	935*	3.5	(0.01)	1,712*	5.0	(0.01)	499*	3.2	(0.01)		
District of Columbia	1517	308*	3.0	(0.01)	1,347*	7.9	(0.01)	469*	7.0	(0.01)		
Florida	1374	30,650*	6.2	(0.01)	36,766*	8.8	(0.01)	10,910*	4.4	(0.01)		
Georgia	1258	12,250*	3.9	(0.01)	21,645*	7.5	(0.01)	6,479*	5.6	(0.01)		
Hawaii	1143	1,718*	5.2	(0.01)	2,059*	5.9	(0.01)	1,025*	4.6	(0.01)		
Idaho	903	2,640*	7.7	(0.01)	3,316*	15.4	(0.01)	2,054*	56.9	(0.01)		
Illinois	2748	21,718*	5.2	(0.01)	34,551*	16.4	(0.01)	6,925*	4.8	(0.01)		
Indiana	1584	8,551*	3.7	(0.01)	16,902*	7.3	(0.01)	3,611*	5.0	(0.01)		
Iowa	1074	4,544*	5.7	(0.01)	5,005*	7.9	(0.01)	2,439*	5.7	(0.01)		
Kansas	1248	6,174*	6.2	(0.01)	5,521*	13.1	(0.01)	2,820*	12.3	(0.01)		
Kentucky	1020	6,264*	6.5	(0.01)	6,779*	8.0	(0.01)	1,670*	3.4	(0.01)		
Louisiana	1387	8,867*	6.6	(0.01)	16,836*	15.6	(0.01)	3,653*	4.3	(0.01)		
Maine	1309	1,168*	3.1	(0.01)	2,294*	5.4	(0.01)	670*	3.5	(0.01)		
Maryland	1384	9,519*	6.3	(0.01)	13,793*	6.8	(0.01)	3,139*	3.9	(0.01)		
Massachusetts	1479	5,877*	3.1	(0.01)	20,215*	8.2	(0.01)	5,903*	4.5	(0.01)		
Michigan	1334	14,617*	5.1	(0.01)	19,849*	6.1	(0.01)	6,099*	4.4	(0.01)		
Minnesota	1156	8,162*	5.3	(0.01)	12,251*	13.3	(0.01)	5,061*	8.5	(0.01)		
Mississippi	686	1,926*	4.0	(0.01)	2,822*	8.1	(0.01)	965*	4.1	(0.01)		
Missouri	1266	10,394*	6.3	(0.01)	10,037*	7.4	(0.01)	3,977*	5.4	(0.01)		
Montana	1086	1,615*	6.2	(0.01)	1,183*	8.4	(0.01)	910*	12.3	(0.01)		
Nebraska	1153	2,588*	4.7	(0.01)	4,398*	10.6	(0.01)	814*	3.2	(0.01)		
Nevada	1183	5,973*	6.5	(0.01)	9,005*	40.3	(0.01)	4,328*	98.2	(0.01)		
New Hampshire	1359	1,435*	3.0	(0.01)	3,618*	7.4	(0.01)	1,282*	4.9	(0.01)		

New Jersey	1614	19,648*	5.7	(0.01)	36,139*	9.6	(0.01)	7,210*	6.9	(0.01)
New Mexico	1441	4,531*	5.1	(0.01)	4,798*	9.5	(0.01)	777*	2.5	(0.01)
New York	2715	39,260*	4.5	(0.01)	43,429*	6.1	(0.01)	22,260*	7.6	(0.01)
North Carolina	1260	15,837*	4.3	(0.01)	18,101*	7.2	(0.01)	9,634*	8.9	(0.01)
North Dakota	1242	1,335*	5.7	(0.01)	2,235*	11.8	(0.01)	455*	6.1	(0.01)
Ohio	1137	12,420*	4.1	(0.01)	20,629*	5.8	(0.01)	9,375*	6.5	(0.01)
Oklahoma	981	5,379*	6.3	(0.01)	6,440*	11.0	(0.01)	2,987*	5.8	(0.01)
Oregon	1226	5,783*	5.0	(0.01)	6,341*	9.6	(0.01)	2,976*	5.0	(0.01)
Pennsylvania	2907	20,082*	5.1	(0.01)	38,034*	9.0	(0.01)	11,219*	4.8	(0.01)
Rhode Island	1438	1,153*	4.0	(0.01)	1,963*	6.1	(0.01)	708*	2.9	(0.01)
South Carolina	909	3,834*	3.6	(0.01)	6,941*	7.3	(0.01)	1,011*	2.5	(0.01)
South Dakota	954	1,626*	11.7	(0.01)	1,690*	19.3	(0.01)	2,735*	50.0	(0.01)
Tennessee	1181	7,965*	5.1	(0.01)	15,161*	15.8	(0.01)	3,980*	5.3	(0.01)
Texas	6236	53,091*	6.0	(0.01)	74,826*	13.7	(0.01)	20,190*	6.4	(0.01)
Utah	1085	8,000*	13.3	(0.01)	7,343*	24.6	(0.01)	2,457*	10.3	(0.01)
Vermont	1441	947*	3.7	(0.01)	1,205*	7.4	(0.01)	527*	4.6	(0.01)
Virginia	1219	13,168*	5.4	(0.01)	15,761*	7.7	(0.01)	7,166*	6.6	(0.01)
Washington	1291	15,848*	6.1	(0.01)	16,774*	7.6	(0.01)	7,312*	4.9	(0.01)
West Virginia	940	1,708*	4.3	(0.01)	2,729*	9.2	(0.01)	1,648*	8.8	(0.01)
Wisconsin	1321	14,340*	5.9	(0.01)	17,355*	12.6	(0.01)	5,338*	5.7	(0.01)
Wyoming	1221	627*	3.8	(0.01)	1,217*	12.0	(0.01)	512*	6.2	(0.01)

(Source: National Immunization Survey-Teen).

Note. Tdap=tetanus, diphtheria, and pertussis; HPV=human papillomavirus; *T*=Edwards' T statistic; RHL=ratio of highest to lowest vaccination (i.e., the ratio of frequency of vaccination in the month when it is most common to the month when it is least common) (i.e., the ratio of frequency of vaccination in the month when it is most common to the month when it is least common); var=variance. Parents reported state of residence at the time of participation in NIS-Teen. **p*<.001.

¹Uptake of first dose among female adolescents only.

Figure 7. Summer peaks in adolescent vaccine uptake in United States (black lines) and states (gray lines). (A) Tdap booster, (B) meningococcal vaccine, and (C) HPV vaccine (first dose, among girls). Uptake from 2007 to 2012 combined and standardized at 100 per month.

(Source: National Immunization Survey-Teen.)

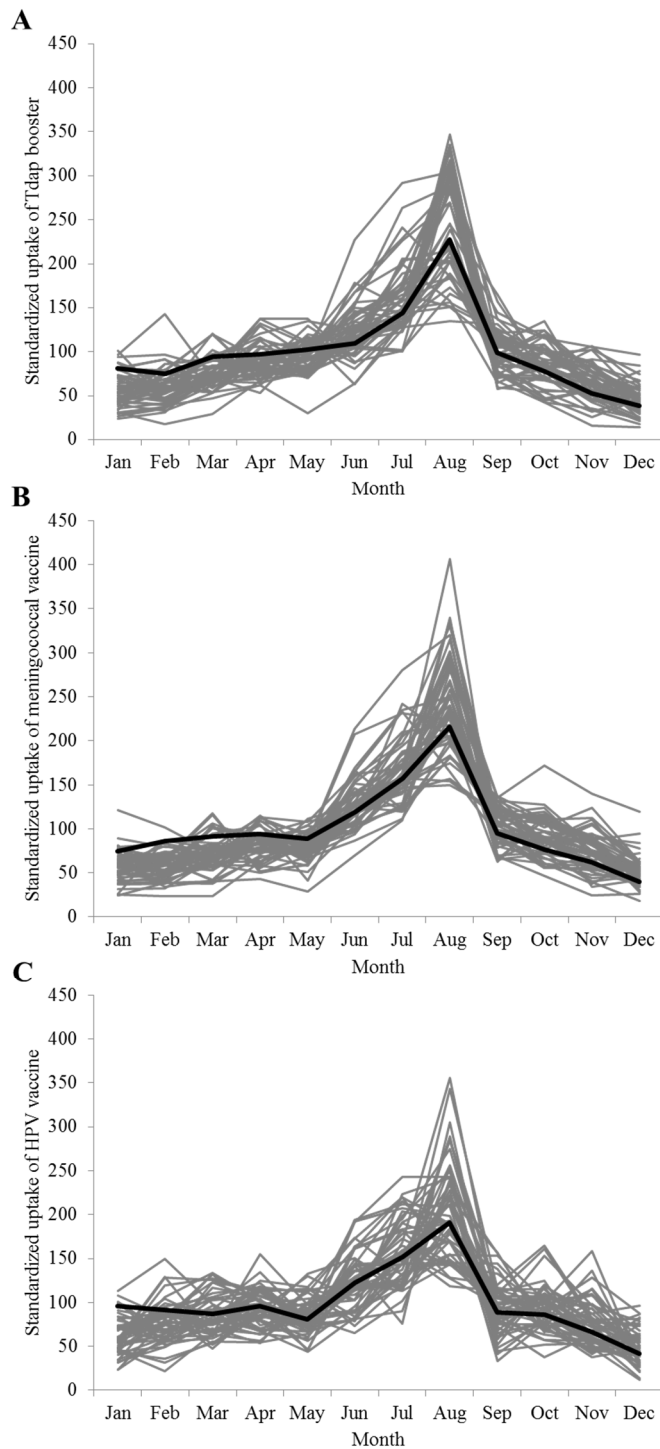
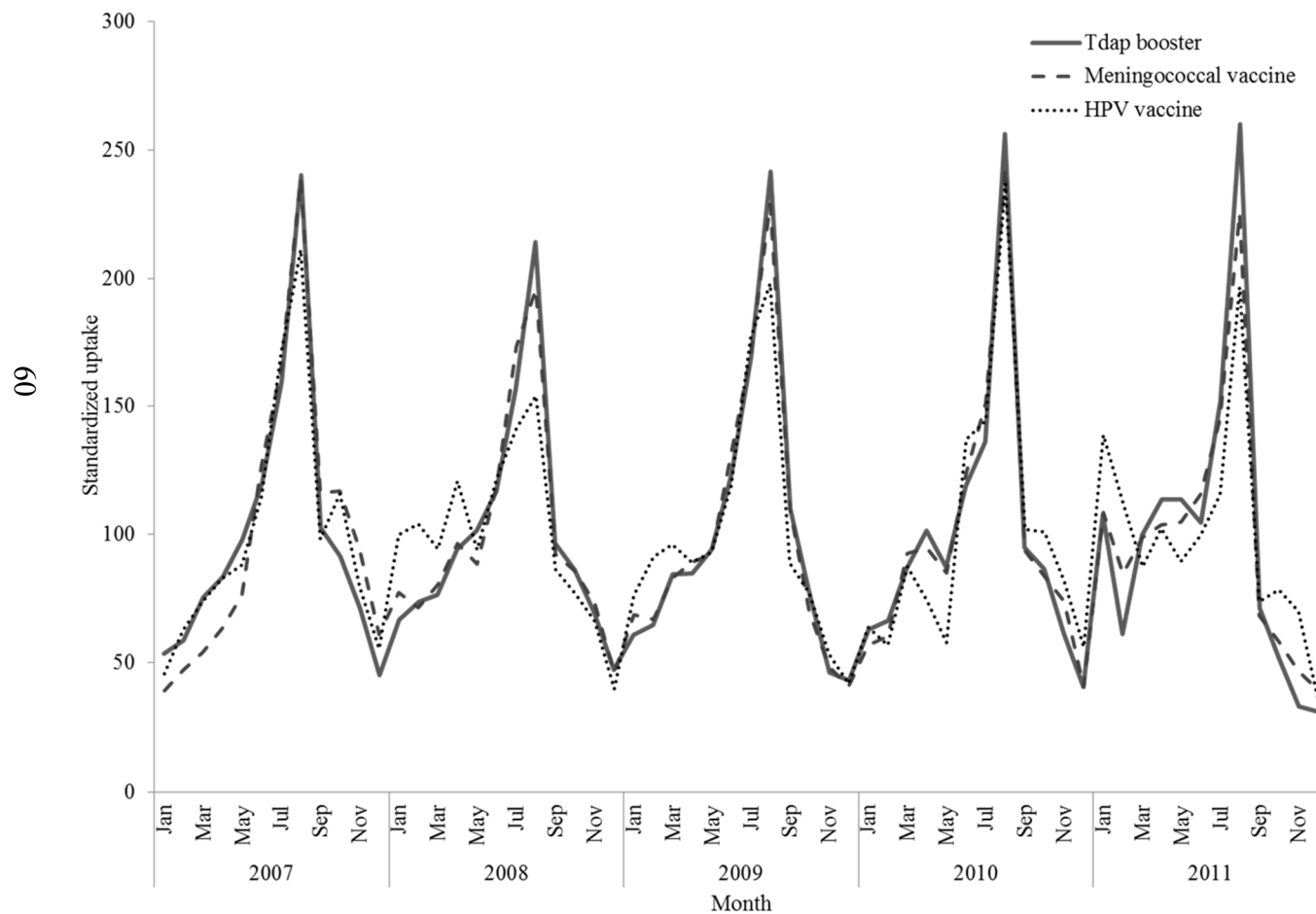


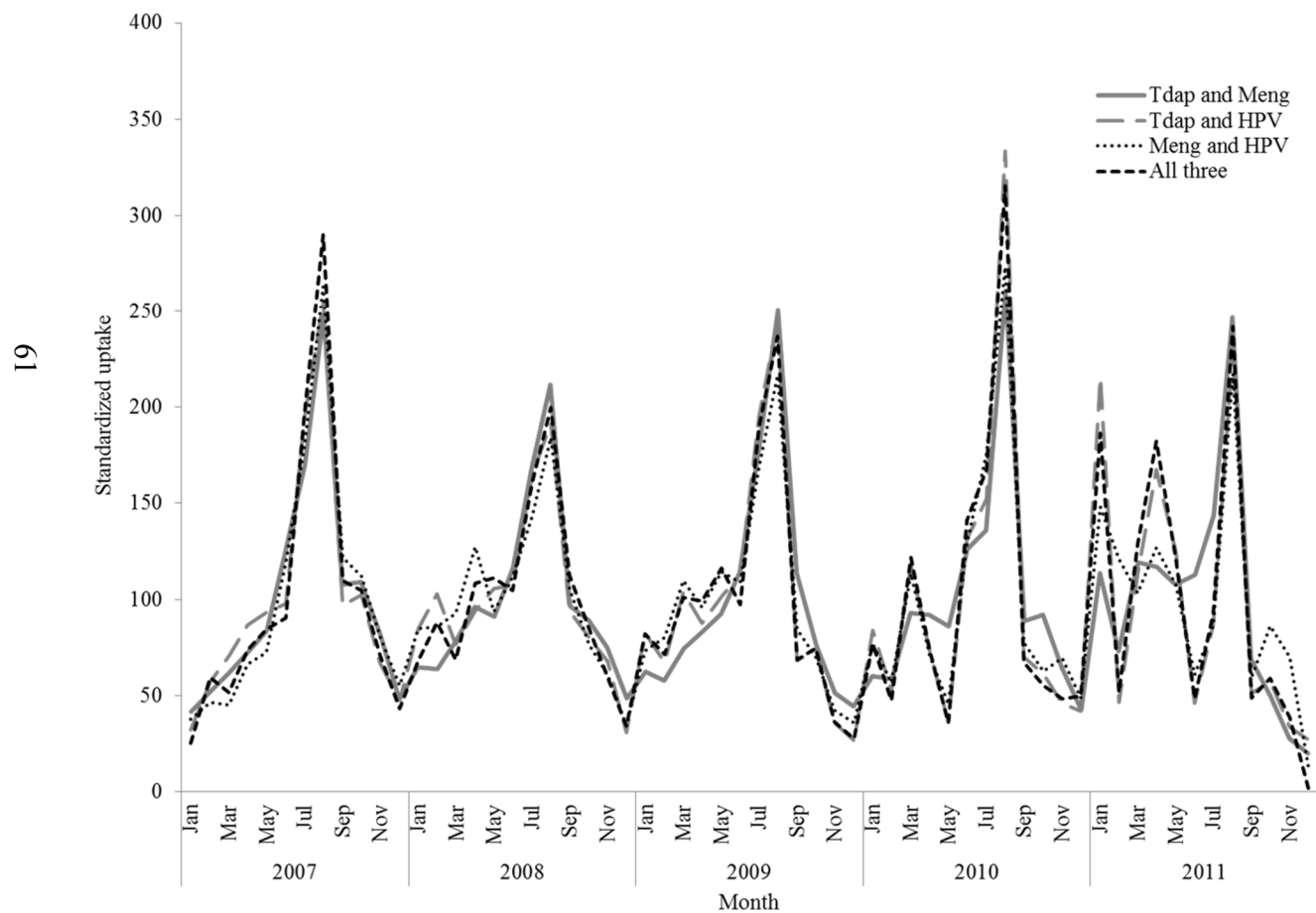
Figure 8. Summer peaks in uptake of Tdap booster, meningococcal vaccine, and HPV vaccine (first dose, among girls) in the United States. Uptake from 2007 to 2011, separately, and standardized at 100 per month.

(Source: National Immunization Survey-Teen.)



Supplemental Figure S1. Summer peaks in concomitant uptake of Tdap booster, meningococcal vaccine, and HPV vaccine (first dose, among girls) in the United States. Uptake from 2007 to 2011, separately, and standardized at 100 per month.

(Source: National Immunization Survey-Teen.)



CHAPTER 6: STATES' SCHOOL ENTRY REQUIREMENTS, SUMMER INCREASES IN VACCINATION, AND COVERAGE WITH RECOMMENDED ADOLESCENT VACCINES: 2007 TO 2012

Introduction

Since 2006, the United States has introduced recommendations for three vaccines for routine administration to adolescents: tetanus, diphtheria, and pertussis (Tdap) booster; meningococcal vaccine; and human papillomavirus (HPV) vaccine.¹⁵ As of 2013, coverage reached 86% (Tdap booster), 78% (meningococcal vaccine), and 57% (initiation of the three-dose HPV vaccine series among adolescent girls).¹¹⁸ However, these national figures mask considerable variation among states: Tdap vaccination ranges from 60% (Mississippi) to 96% (Rhode Island), meningococcal vaccination from 40% (Arkansas) to 94% (North Dakota), and HPV vaccine initiation among girls from 40% (Kansas) to 77% (Rhode Island).¹¹⁸ Understanding the factors driving these differences has important implications for achieving adequate adolescent vaccination coverage across the United States.

States' vaccination school entry requirements³⁷ are one potential explanation for variation in vaccination coverage. These policies require that students receive vaccines before entering a certain grade in middle or high school, with exemptions allowed for medical reasons and, in some states, religious or philosophical reasons. As of Fall 2014, 47 states had school entry requirements in effect for Tdap, 20 for meningococcal vaccine, and 2 for HPV vaccine (initiation among adolescent girls).³⁷ These school entry requirements likely lead to increases in coverage for the vaccines they target,^{47,112,119-121} as well as spillover increases in coverage for non-targeted vaccines.^{51,52} The former effect is the desired outcome

of vaccination requirements, and the latter effect may arise due to concomitant vaccination—receipt of two or more vaccine(s) during the same healthcare visit. That is, adolescents seeking a vaccine targeted by a school entry requirement may concomitantly receive other vaccines, leading to increases in coverage for vaccines not targeted by the policy.

School entry requirements likely increase vaccination behaviors prior to the beginning of the academic year. A background level of vaccination throughout the entire calendar year persists, but these policies may increase adolescent vaccination during summer months.^{112,113} In our previous study of vaccination cycles, we found that adolescent vaccination is most common in June, July, and August, when healthcare providers deliver about 40% of individual and concomitant vaccinations to U.S. adolescents.¹²² In turn, these summer vaccination peaks may increase overall coverage.

In the present study, we evaluated the longitudinal effects of vaccination school entry requirements on coverage for targeted and non-targeted vaccines. In addition, we tested whether summer peaks in adolescent vaccination accounted for the impact of school entry requirements on vaccination coverage.

Methods

Data Sources

Data on vaccination school entry requirements came from the Immunization Action Coalition (IAC), which publishes information on school entry requirements compiled from health departments in all 50 states and Washington, D.C. (hereafter collectively referred to as “states” for simplicity).³⁷ The database includes an indication of whether each state has a school entry requirement for Tdap, meningococcal, or HPV vaccination and, if so, when it became effective.^{47,52,123}

Data on vaccination coverage and on summer increases in vaccination came from the National Immunization Survey-Teen (NIS-Teen). Each year, the CDC implements NIS-Teen to estimate national- and state-level coverage with each adolescent vaccine.⁶¹ NIS-Teen interviewers administered phone surveys to a population-based sample of caregivers (hereafter referred to as “parents”) of 13- to 17-year-old adolescents. After randomly selecting one adolescent in each household, interviewers gathered demographic and health information about the child. At the end of the survey, interviewers asked for parents’ consent to contact the adolescents’ primary healthcare providers to verify vaccination history. Since 2008, NIS-Teen has collected provider-verified vaccination data for about 20,000 adolescents each year, for a total of 99,921 adolescents over the five study years.

Data collection for NIS-Teen was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board. Analysis of de-identified data from the survey is exempt from the federal regulations for the protection of human research participants. Analysis of restricted data through the NCHS Research Data Center is also approved by the NCHS ERB. The University of North Carolina Institutional Review Board exempted this study from review.

Measures

School entry requirements. Separately for Tdap, meningococcal vaccine, and HPV vaccine, we coded states as 1 if they had a school entry requirement in effect by the fall semester of each year from 2007 to 2012, and we coded states as 0 if they did not. All states had complete data for all study years.

Adolescent vaccination coverage. We measured coverage for Tdap vaccination, meningococcal vaccination, and HPV vaccination (first dose among females) using NIS-

Teen's annual state-level estimates of coverage among 13- to 17-year-olds.^{5,62-65} Importantly, these estimates are based on the same samples as the ones used in the present study.

Summer vaccination peaks. We coded the month and year during which adolescents received vaccines. For each vaccination outcome, we excluded from analysis any adolescent without provider-verified data on receipt of that vaccine. For participants who had received at least two adolescent vaccines, we determined whether they had received the doses concomitantly, i.e., on the same day.³¹ We measured concomitant vaccination for each potential combination of adolescent vaccines. We descriptively inspected cycles in adolescent vaccination by calculating the average percentage of vaccine doses administered each month for states with and without school entry requirements. Consistent with previous work,¹²² we found that vaccination was most common in June, July, and August (see Figure 9 for an illustrative example of vaccination across months).

Then, for each single and concomitant vaccination outcome, we calculated the percentage of doses administered in these three months compared to the entire year. If vaccination patterns were constant across the calendar year, the summer vaccination percentage would equal .252 (because June, July, and August have 92 days, out of 365 total days); amounts over that figure would indicate excess vaccination in the summer months relative to the rest of the year. We calculated this percentage separately for each state, for each study year, for each vaccination outcome. Due to small cell sizes, we excluded from analysis summer peaks for vaccines delivered in 2012. Calculations of summer vaccination peaks incorporated NIS-Teen sampling weights to account for non-equal probability of selection.

For HPV vaccination, we measured initiation of the three-dose series among female adolescents only, because the CDC began recommending HPV vaccine for routine administration in girls in 2007¹⁵ but not in boys until 2011.⁴ Consequently, the summer vaccination peaks for HPV vaccination and for two concomitant vaccination outcomes (Tdap and HPV vaccine; meningococcal and HPV vaccines) reflect patterns of uptake only among girls.

Analytic Strategy

Analyses examined Tdap and meningococcal vaccination policies. We excluded HPV vaccination policies because only two states had them in effect during the entire study period. Because the effects of school entry requirements may not have emerged in the same year as policy adoption, and because of the time required to achieve universal implementation and for effects to spread through the population, we calculated the association of school entry requirements with summer vaccination peaks in a given year and with vaccination coverage in the following year (i.e., a one-year lag). Our preliminary analyses found that these lagged models provided a better fit to the observed data than non-lagged models (data not shown).

Next, we conducted formal mediation analysis using generalized estimating equations to test whether states' vaccination school entry requirements increased summer vaccination peaks, which in turn increased overall coverage. We used bootstrapping to examine the statistical significance of the mediated effect, following the steps outlined by Hayes.¹²⁴ Specifically, we ran three models: (1) estimating the main effect between school entry requirements and coverage (*c* path), (2) estimating the effect between school entry requirements and summer vaccination peaks (*a* path), and (3) the simultaneous effects of school entry requirements and summer vaccination peaks on coverage (*c'* and *b* paths,

respectively). We calculated the indirect (mediated) effect by multiplying the parameter estimates for the a and b paths. Next, we sampled with replacement among the observed data to create 1,000 simulated datasets. Then, we repeated the analysis described previously for each simulated dataset, calculated the resulting indirect effect, and examined the percentile-based bootstrapped 95% confidence interval. We repeated these analyses for each combination of school entry requirements and coverage, using summer peaks for the vaccines under study in that model.

Models controlled for school entry requirements, vaccination peaks, and coverage from previous years as well as the presence of state school entry requirements for adolescent vaccines besides the one under study (e.g., models testing the effects of Tdap vaccination requirements controlled for the presence of meningococcal vaccination and HPV vaccination requirements). We weighted states' observations according to the sample sizes included in NIS-Teen. We implemented mediation analysis with PROC GENMOD and resampling with PROC SURVEYSELECT in SAS version 9.2 (Cary, NC). Statistical tests used a two-tailed p value of .05.

As a supplementary analysis, we tested the invariance of the policies' effects over time by including interaction terms for study year and each of the explanatory variables (in the observed dataset only). We then used Wald tests to examine the joint contribution of each set of interaction terms to the overall fit of the models. If the Wald tests did not indicate that the explanatory variables interacted with study year, we dropped them from the model.

Results

From 2007 to 2012, between 7 and 42 states had Tdap vaccination school entry requirements, between 0 and 14 states had meningococcal vaccination requirements, and 2

states had HPV vaccination requirements (Table 5). National vaccination coverage estimates ranged from 30% to 85% for Tdap, 32-74% for meningococcal vaccine, and 25-54% for HPV vaccine. Averaged across the study years, summer vaccination peaks were between 53% and 55% for all outcomes.

Impact of Tdap School Entry Requirements

States with Tdap vaccination school entry requirements had higher Tdap vaccination coverage than states without such policies (77% versus 54%, respectively, $p<.001$; Figure 10), and they had higher summer Tdap vaccination peaks (52% versus 46%, $p<.001$; Figure 11) (Table 6). In addition, these states also had higher meningococcal vaccination coverage (67% versus 51%, $p<.001$; Figure 10) and higher summer peaks of concomitant vaccination with Tdap and meningococcal vaccines (54% versus 48%, $p<.001$; Figure 11). Finally, these states also had higher HPV vaccination coverage (52% versus 44%, $p<.001$; Figure 10) and higher summer peaks of concomitant vaccination with Tdap and HPV vaccines (52% versus 46%, $p<.001$; Figure 11).

Impact of Meningococcal Vaccination School Entry Requirements

States with meningococcal vaccination school entry requirements had higher meningococcal vaccination coverage than states without such policies (81% versus 54%, respectively; $p<.001$; Figure 10), and they had higher summer meningococcal vaccination peaks (55% versus 48%, $p<.001$; Figure 11) (Table 6). In addition, these states also had higher Tdap vaccination coverage (80% versus 62%, $p<.001$; Figure 10) and higher summer peaks of concomitant vaccination with meningococcal and Tdap vaccines (57% versus 48%, $p<.001$; Figure 11). Finally, these states also had higher HPV vaccination coverage (53%

versus 47%, $p < .001$; Figure 10) and higher summer peaks of concomitant vaccination with meningococcal and HPV vaccines (51% versus 46%, $p < .001$; Figure 11).

Mediation and Additional Analyses

Summer vaccination peaks did not mediate the relationships of either vaccination requirement and vaccination coverage for Tdap, meningococcal, or HPV (all $p > .05$; Table 4). In supplementary analyses, study year did not interact with (1) school entry requirements or (2) summer vaccination peaks in predicting vaccination coverage (all Wald chi-square statistics < 4 , all $p > .25$).

Conclusion

In a five-year sample of adolescents from all 50 states and Washington, D.C., we found that vaccination school entry requirements consistently led to higher vaccination coverage and higher summer vaccination peaks. School entry requirements account for some of the substantial variation in coverage among states. However, summer vaccination peaks did not explain the main effect between school entry requirements and coverage.

States' vaccination school entry requirements were associated with higher coverage for their targeted vaccines: a 23% absolute increase in Tdap vaccination and a 27% absolute increase in meningococcal vaccination. Previous studies have demonstrated similar though smaller magnitudes for policies targeting Tdap vaccination^{47,51,112} and meningococcal vaccination.^{47,121} In contrast to any of the previous studies, we used longitudinal analyses that included a lag of one year and controlled for the previous years' measurements to help establish the temporality of the relationships. Vaccination school entry policies appear to achieve their intended goals of increasing coverage. However, eight states still fall short of Healthy People 2020 guidelines for Tdap vaccination and 32 states fall short of the guidelines

for meningococcal vaccination,¹¹⁸ so more progress is needed to achieve optimal levels of coverage.

School entry requirements also had smaller, spillover effects of increasing coverage for non-targeted vaccines. Specifically, Tdap requirements were associated with a 16% absolute increase in meningococcal vaccination and an 8% absolute increase in HPV vaccination. Meningococcal vaccination requirements were associated with an 18% absolute increase in Tdap vaccination and a 6% absolute increase in HPV vaccination. Previous studies have demonstrated the spillover effects of Tdap requirements on meningococcal vaccination^{51,112} and HPV vaccination,⁵² but to our knowledge, no studies have yet investigated spillover effects of meningococcal vaccination requirements. As such, vaccination requirements have the unintended benefits of improving other vaccination outcomes. This finding is especially pertinent for HPV vaccination, given both the political difficulties in adopting school entry requirements for this vaccine^{36,39,125} and low rates of initiation and completion of the vaccine series among U.S. adolescents (as of 2013, 57% and 38% among females, respectively, and 35% and 14% among males, respectively).¹¹⁸ That is, absent HPV vaccination school entry requirements, implementing requirements for Tdap or meningococcal vaccine may lead to increases in HPV vaccination coverage.

Vaccination school entry requirements were also positively associated with increases in summer peaks, the percentage of single and concomitant vaccine doses administered in summer months. For example, if vaccination were equally distributed over the year, the summer peak would equal 25%, but even in states without Tdap school entry requirements, healthcare providers administered 43% of HPV vaccine doses in the summer months. Even more striking, in states with Tdap requirements, providers administered 49% of HPV vaccine

doses in the summer (see Figure 11). The absolute difference of 6% between the latter two percentages speaks to the potential change in vaccination behaviors during the summer months that healthcare providers may see immediately after a state institutes a school entry requirement. Anticipating this change could assist providers in preparing for this increased demand, perhaps through capacity-expanding initiatives such as adopting standing orders for recommended vaccines.¹²⁶

Finally, summer vaccination peaks demonstrated positive associations with coverage. We could not determine if adolescents' demand for vaccines or healthcare providers' ability to supply them limited the summer vaccination peaks. However, results from our study illustrate that states with healthcare systems that delivered more adolescent vaccines during summer months had higher overall coverage. This relationship held true for summer peaks of single or concomitant vaccination. As a result, interventions or quality improvement programs targeting adolescent vaccination that take place in the spring may be particularly effective in supporting higher summer vaccination peaks and, as a result, higher coverage. Future research is needed to examine the ideal timing and duration of programs that prepare healthcare providers for summer increases in adolescent vaccination.

However, findings from the present study did not support our hypothesis that summer vaccination peaks would mediate, or explain, the relationship between school entry requirements and coverage. Although all of these variables were interrelated, some other variable(s) must explain the association of school entry requirements and coverage. One viable intervening mechanism is the expansion of public funding for vaccination that accompanies adoption of a school entry requirement. That is, when states require students to receive certain vaccines, they must devote public funds to support vaccination for children

who cannot afford them.³² If cost limited the uptake of adolescent vaccines (which several studies have suggested is the case for HPV vaccine^{74,85,86}), states that expand public funding for vaccination may subsequently see increases in coverage. Additional studies are needed to explicate the causal pathway between these variables.

Study strengths include a large sample size (almost 100,000 adolescents) from a high-quality national dataset.⁶¹ Healthcare providers verified vaccine uptake for participants, increasing our confidence in the validity of these measures. Most previous studies of school entry requirements have focused on policies that require Tdap vaccination, but we also investigated the effects of school entry requirements for meningococcal vaccination. Although previous studies of vaccination school entry requirements have used cross-sectional designs, we used a longitudinal design to disentangle the temporal relationships among study variables and examine the consistency of these relationships over time. Study limitations include our inability to randomize states to adopting vaccination school entry requirements; because of this limitation, we were unable to eliminate the possibility that other variables confounded the observed relationships. In addition, due to small cell sizes, we could not analyze vaccination peaks in 2012, but with continuing data collection (i.e., survey years 2013 and 2014), future studies will be able to evaluate more recent vaccination peaks and their relationships with school entry requirements and coverage.

In conclusion, we found consistent, positive relationships between vaccination school entry requirements, the summer peaks in single and concomitant adolescent vaccination, and Tdap, meningococcal, and HPV vaccination coverage. These results suggest that school entry requirements lead to increases in uptake for targeted vaccines as well as spill-over increases in uptake for other vaccines. In addition, these results point to specific times when vaccine

promotion efforts may be particularly effective, i.e., immediately after a state adopts a school entry requirement and in the months before the summertime increase in vaccination demand.

Addendum

In addition to the research described in this chapter, I originally proposed examining the relationship between HPV vaccination school entry requirements and HPV vaccination coverage, and whether cycles in HPV vaccination mediated that association. I have described those analyses next.

I also discuss possible alternative mediation pathways that may explain why, despite the strong relationships among all the study variables, the mediation analysis did not find that summer vaccination peaks attenuated the association between vaccination requirements and coverage.

Impact of HPV Vaccination School Entry Requirements

States with HPV vaccination school entry requirements had higher HPV vaccination coverage than states without such policies (50% versus 48%, respectively; $p < .001$), and they had higher summer HPV vaccination peaks (49% versus 45%, $p < .001$). However, summer vaccination peaks did not mediate the relationships of HPV vaccination requirements and HPV vaccination coverage ($p > .05$).

Future Research on Alternative Mediation Pathways

The results of the present analysis did not support my hypothesis that summer vaccination peaks would mediate the relationship between school entry requirements and coverage (panel A in Figure S2). Instead, the results suggest that school entry requirements are associated with summer peaks and coverage, but these latter variables are only spuriously

(i.e., non-causally) related (panel B in Figure S2). At least two other possibilities exist for the actual relationships among these variables.

In the first possibility (panel C in Figure S2), vaccination coverage levels precede school entry requirements, which only become politically feasible after a critical mass of vaccination occurs (and attendant pro-vaccination norms spread through the population). After the school entry requirements go into effect, summer peaks increase because families become motivated to seek vaccinations in the summer months to come into compliance with the policies.

In the second possibility (panel D in Figure S2), school entry requirements lead to increases in coverage as families seek vaccinations to comply with the policies. As the absolute numbers of vaccinating adolescents increases, so too does the absolute number of doses administered in the summer (and, subsequently, the percentage of doses administered in the summer).

Going forward, I plan to evaluate both of these alternative models against the observed data to determine which provides a more valid description of the actual relationships among the study variables. In addition, I will recalculate summer vaccination peaks only among adolescents in a restricted age range (i.e., 11–13 years) that is most often the target of school entry requirements. I will rerun the mediation analysis with this measure of summer peaks that is more sensitive to change as a result of a new school entry requirement than the measure of peaks for the entire adolescent age group.

Table 5. The Number of States With School Entry Requirements, Mean Summer Vaccination Peaks, and Overall Vaccination Coverage

Year	States with school entry requirements	Tdap Summer vaccination peak (%)	Vaccination coverage (%)	States with school entry requirements	Meng Summer vaccination peak (%)	Vaccination coverage (%)	States with school entry requirements	HPV ¹ Summer vaccination peak (%)	Vaccination coverage (%)	Tdap and Meng Summer vaccination peak (%)	Tdap and HPV ¹ Summer vaccination peak (%)	Meng and HPV ¹ Summer vaccination peak (%)
2007	7	44.8	30.4	0	45.6	32.4	2	41.9	25.1	46.3	45.9	47.8
2008	16	43.3	40.8	3	44.0	41.8	2	38.9	37.2	45.3	43.1	42.7
2009	24	51.9	55.6	8	52.2	53.6	2	49.3	44.3	53.4	53.2	50.4
2010	32	66.8	68.7	10	68.4	62.7	2	69.6	48.7	67.7	70.0	69.3
2011	38	61.2	78.2	13	61.8	70.5	2	62.6	53.0	60.2	61.6	61.0
2012	42	--	84.6	14	--	74.0	2	--	53.8	--	--	--
Mean	27	53.6	65.5	8	54.4	58.9	2	52.5	47.9	54.6	54.8	54.2

Note. Tdap = tetanus, diphtheria, and pertussis booster; HPV = human papillomavirus vaccine; Meng = meningococcal vaccine. Vaccination coverage estimates come from NIS-Teen.⁶¹ Summer vaccination peaks from 2012 suppressed due to small cell sizes. ¹HPV vaccine initiation (i.e., receipt of ≥ 1 dose of the 3-dose series) measured among female adolescents only.

Table 6. Summary of Main Effects and Indirect Effects of Summer Vaccination Peaks on the Relationship Between State School Entry Requirements and Adolescent Vaccination Coverage

IV	Mediator	DV	IV to DV		IV to Mediator		Mediator to DV		Mediated effect	
School entry req.	Summer vaccination peak	Vaccination coverage	beta	SE	beta	SE	beta	SE	beta	Percentile-based bootstrapped 95% CI
Tdap	Tdap	Tdap	0.467	(0.003)*	0.088	(0.003)*	1.007	(0.016)*	0.089	(-0.077, 0.295)
Tdap	Tdap/Meng	Meng	0.018	(0.004)*	0.094	(0.004)*	1.668	(0.014)*	0.157	(-0.203, 0.466)
Tdap	Tdap/HPV	HPV	0.149	(0.003)*	0.010	(0.006)*	0.358	(0.007)*	0.003	(-0.161, 0.175)
Meng	Meng	Meng	0.803	(0.006)*	0.045	(0.003)*	2.201	(0.020)*	0.099	(-0.371, 0.500)
Meng	Tdap/Meng	Tdap	0.041	(0.005)*	0.163	(0.005)*	0.851	(0.013)*	0.138	(-0.074, 0.366)
Meng	Meng/HPV	HPV	0.105	(0.004)*	0.143	(0.006)*	0.455	(0.008)*	0.065	(-0.221, 0.281)

Note. IV = independent variable; DV = dependent variable; Tdap = tetanus, diphtheria, and pertussis booster; Meng = meningococcal vaccine; HPV = human papillomavirus vaccine; SE = standard error; CI = confidence interval. HPV vaccine initiation (i.e., receipt of ≥ 1 dose of the 3-dose series) measured among female adolescents only.

* $p < .001$, others are not significant at $p < .05$.

Figure 9. Percentage of tetanus, diphtheria, and pertussis (Tdap) booster doses administered per month for states with and without school entry requirements for Tdap, averaged across study years.

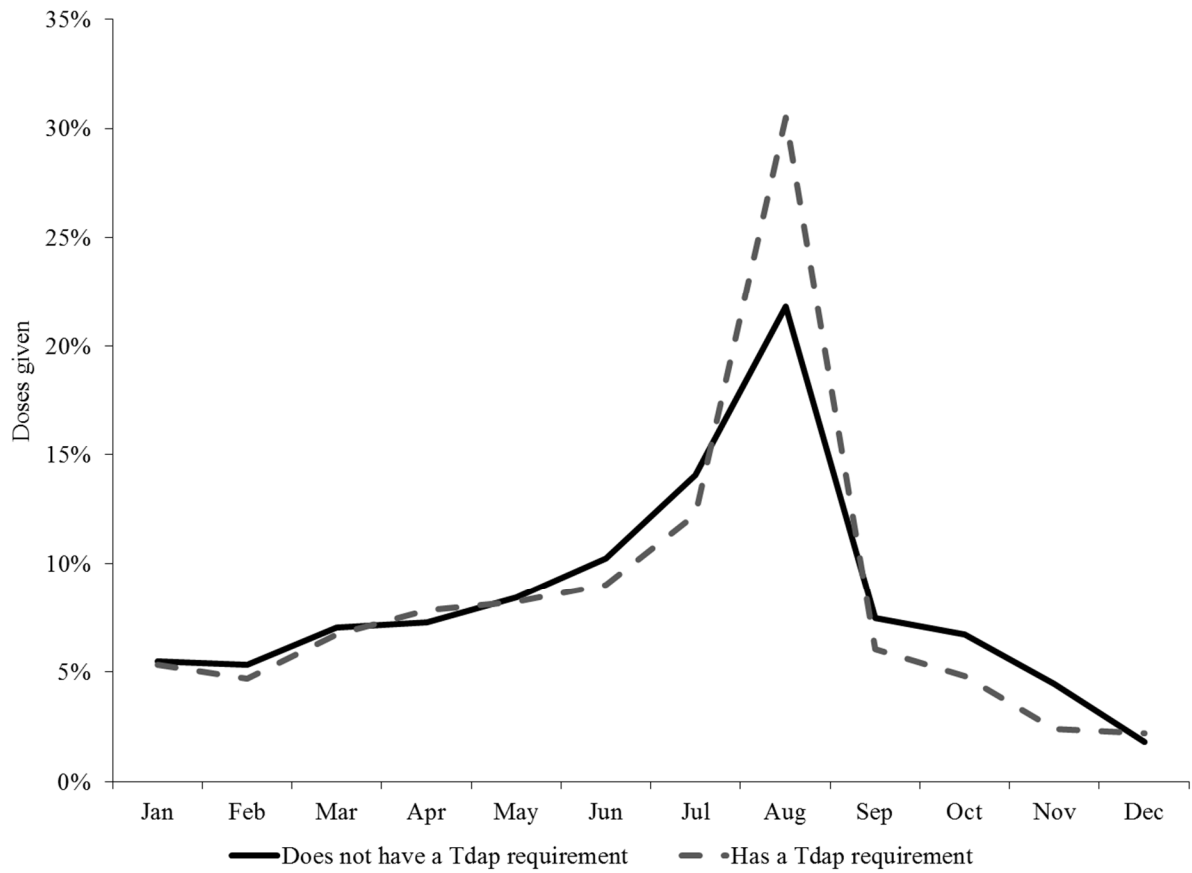


Figure 10. Vaccination coverage for states with and without school entry requirements for tetanus, diphtheria, and pertussis booster (Tdap, panel A) and meningococcal vaccine (Meng, panel B); HPV = human papillomavirus vaccine initiation (females only).

Error bars show standard errors.

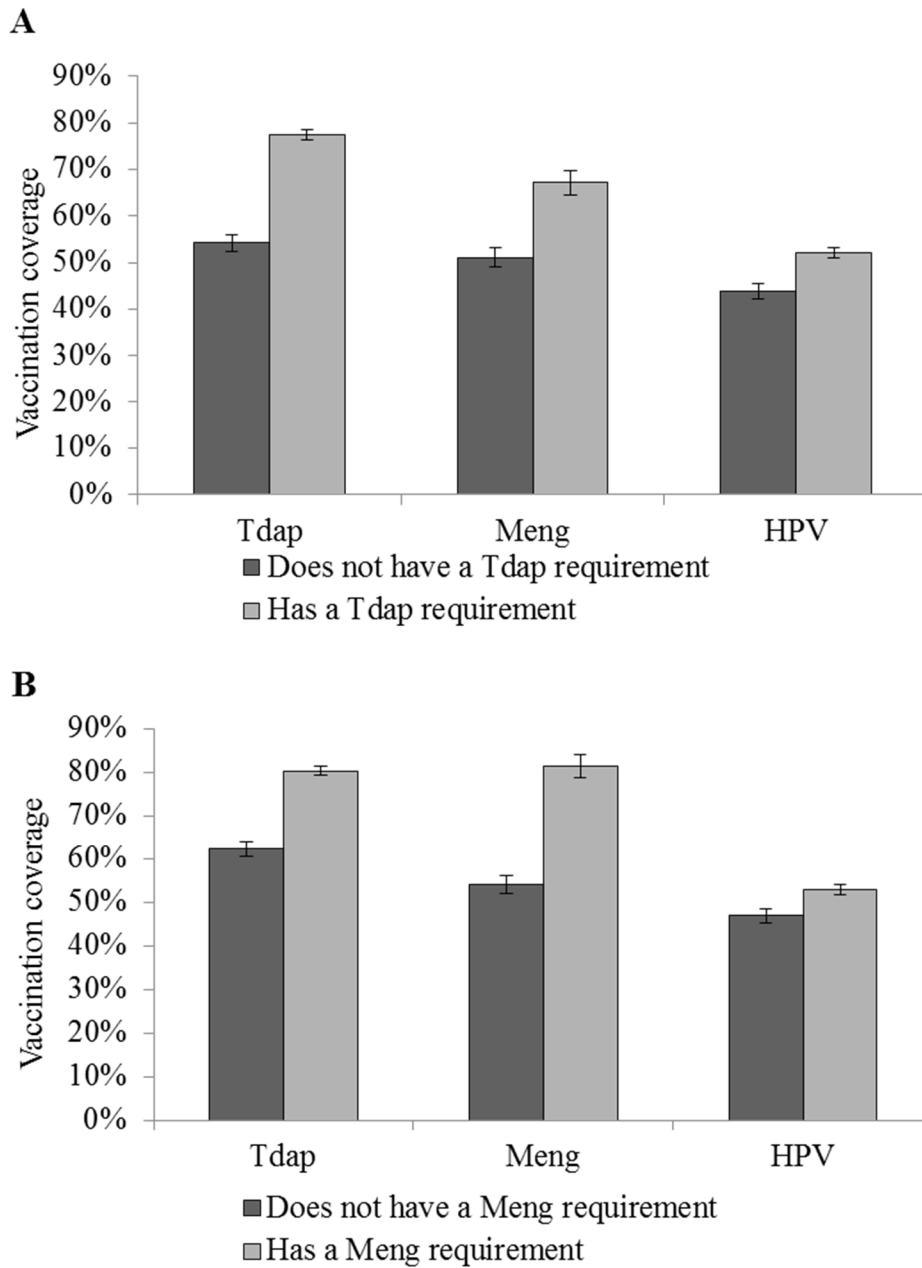
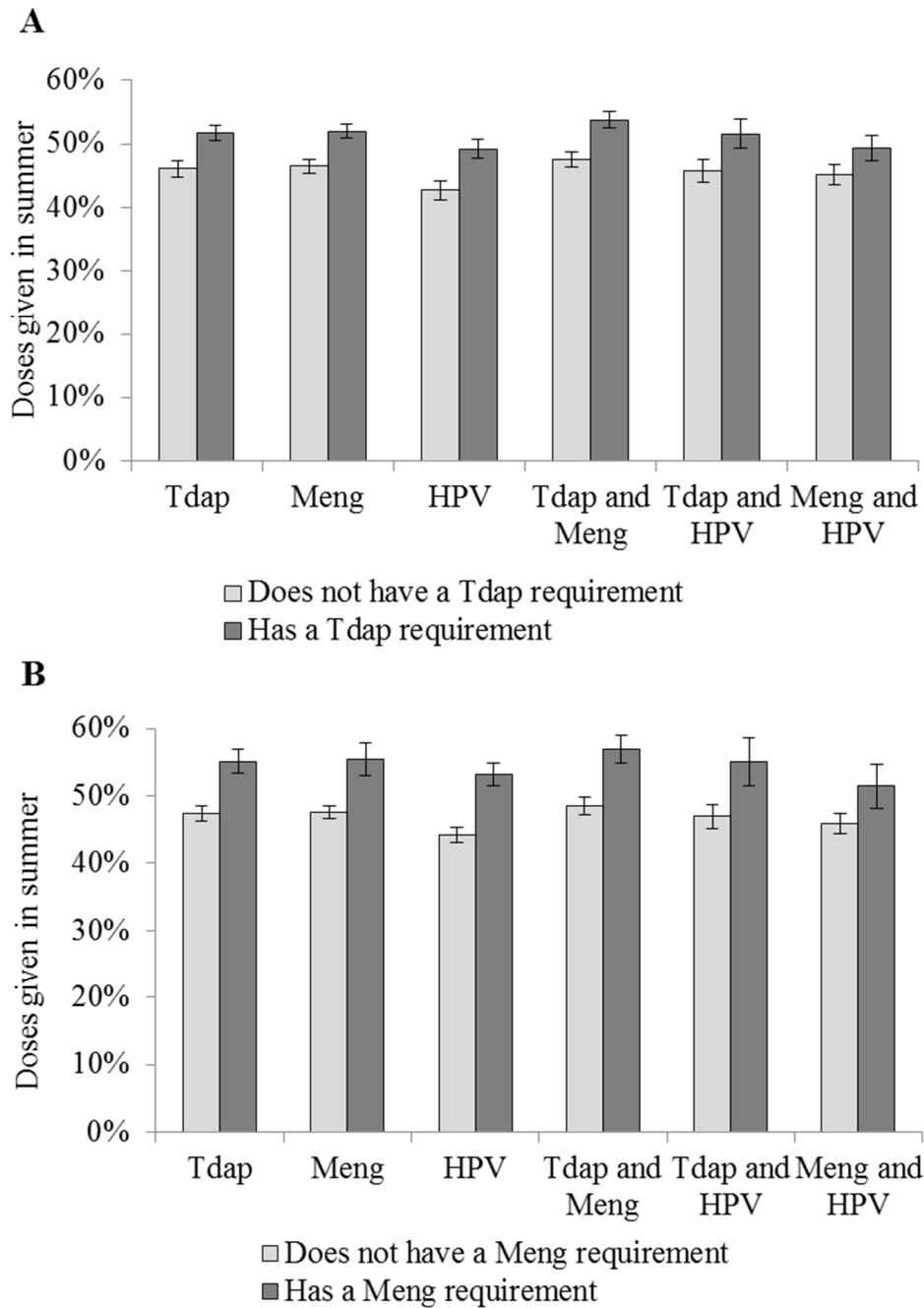
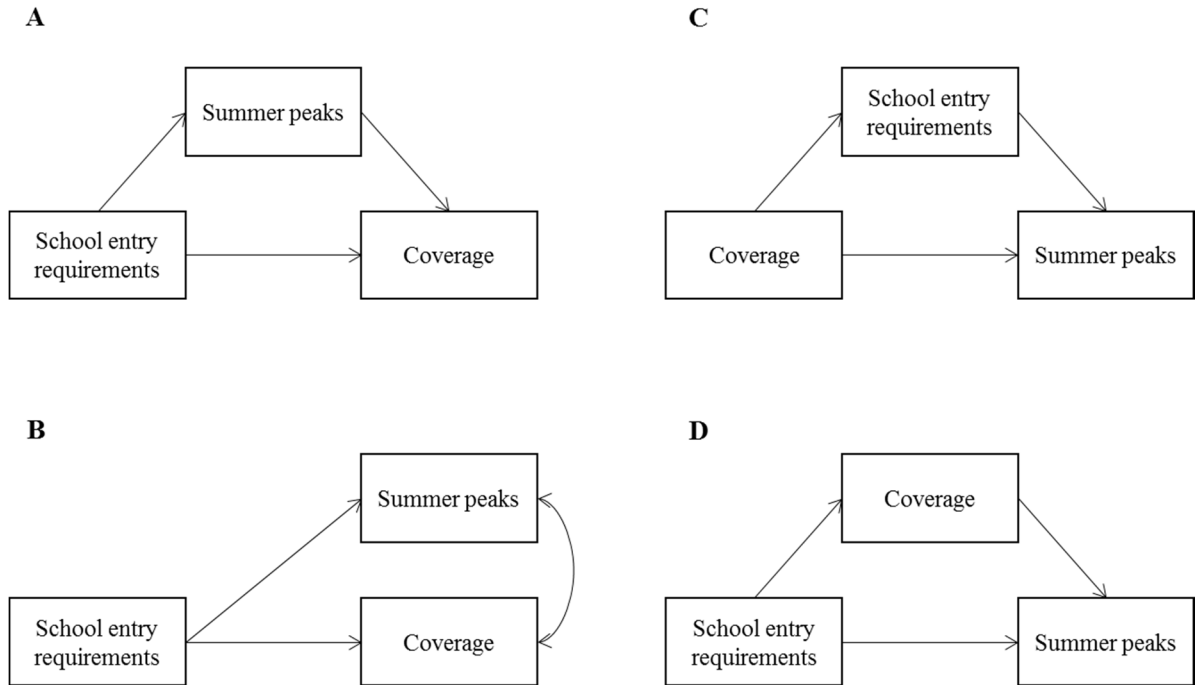


Figure 11. Summer vaccination peaks for states with and without school entry requirements for tetanus, diphtheria, and pertussis booster (Tdap, panel A) and meningococcal vaccine (Meng, Panel B); HPV = human papillomavirus vaccine initiation (females only).

Error bars show standard errors.



Supplemental Figure S2. Conceptual models depicting possible relationships among study variables: hypothesized relationships (Panel A); observed relationships (Panel B); first alternative, with vaccination coverage preceding adoption of school entry requirements and increases in summer peaks (Panel C); and second alternative, with school entry requirements and vaccination coverage preceding summer peaks (Panel D).



CHAPTER 7: VACCINATION POLICIES, PATIENT-PROVIDER COMMUNICATION, AND UPTAKE OF ADOLESCENT VACCINES

Introduction

National guidelines recommend that adolescents routinely receive three vaccines: tetanus, diphtheria, and pertussis booster (Tdap); meningococcal vaccine; and human papillomavirus (HPV) vaccine.¹⁵ Healthy People 2020 sets the goal for 80% coverage with each adolescent vaccine among 13- to 15-year-old adolescents,²⁷ but current coverage for meningococcal vaccine and HPV vaccine falls short of this benchmark.¹¹⁸

A socio-ecological analysis of this problem¹²⁷ would suggest that factors from the policy, community, institutional, interpersonal, and intrapersonal levels independently and interactively influence health behaviors. Most research on vaccination has focused on intrapersonal characteristics of adolescents or their parents, with relatively few studies examining factors at higher ecological levels that could influence decision making such as states' vaccine school entry requirements (policy level) or communication with healthcare providers (interpersonal level).

As Fall 2014, 47 states (including Washington, D.C.) had policies requiring adolescents to receive Tdap before entering a particular grade in school, 20 states had requirements for meningococcal vaccine, and 2 states had requirements for HPV vaccine.³⁷ Adolescents are more likely to receive Tdap^{47,51} or meningococcal vaccine^{47,121} if they live in states with school entry requirements for these vaccines than in other states. No studies we are aware of have yet quantified the effects of HPV vaccination requirements, although

previous research has demonstrated their acceptability to parents.^{42,43} In states with these requirements, parents and adolescents may be more likely to receive targeted vaccines because uptake becomes a default behavior, that is, one that occurs unless an individual makes a conscious decision to act against it.⁴⁸ A vaccination default may increase uptake if seeking an exemption from the school entry requirement is more burdensome than vaccinating.^{33,48,49} Thus, in the current study, we hypothesized that states with school entry requirements would have higher adolescent vaccination coverage than states without such requirements (Hypothesis 1).

Although research has highlighted the singular influence a provider's recommendation can have on adolescent vaccination coverage,^{6,70} fewer studies have investigated the style of a provider's communication with parents and adolescents. Ethicists and legal scholars have encouraged clinicians to use a collaborative or shared approach to communication in primary care to preserve patients' decision making autonomy,^{99,103,107,128,129} especially when discussing healthcare options that are complex or lack professional consensus.¹³⁰⁻¹³² For example, Charles and Gafni^{100,101,133} proposed a framework that articulates the necessary conditions for collaboration, namely, bidirectional exchange of information between patients and providers, opportunity for both parties to deliberate on the best course of action, and coming to a decision that both parties support. Use of a collaborative communication style has been associated with improved clinical outcomes compared to more directive communication styles.^{103,106}

However, many clinicians opt for a directive communication style due to concerns about the time needed to engage in collaborative communication.^{128,134} Collaborative communication may be unnecessary for decisions about healthcare services, such as

vaccination, that are minimally invasive, highly efficacious, and marked by professional consensus.^{107,132,135} Informed consent regulations ensure that patients and providers will always communicate prior to vaccination, but a less collaborative communication style may discourage parents from opting out of vaccination.^{69,108} For example, Opel and colleagues¹⁰⁸ found that 74% of parents accepted flu vaccination for their infants if providers used a directive communication style versus 4% of parents whose providers used a collaborative style.

Thus, ethical and empirical scholarship diverges in regard to the best way for providers to communicate with parents to achieve high levels of vaccine acceptance. Informed by this previous research on communication style, we created two competing hypotheses about the relationship between collaboration and vaccination. We hypothesized that collaborative patient-provider communication would be associated with higher adolescent vaccination coverage than other types of communication (Hypothesis 2a). Collaborative communication offers parents and adolescents adequate time to process information about vaccination and provides physicians with the opportunity to persuade hesitant patients, which could lead to increased levels of uptake. In contrast, we hypothesized that collaborative patient-provider communication would be associated with lower adolescent vaccination coverage than other types of communication (Hypothesis 2b). Collaborative communication affords parents and adolescents more opportunities to object and opt out of vaccination, which could lead to decreased levels of uptake.

The influence of provider communication style may vary depending on whether an adolescent lives in a state with a vaccination school entry requirement. To comply with school entry requirements in states with such policies, parents and adolescents may choose to

vaccinate regardless of providers' communication style. That is, states' vaccine school entry requirements may dampen the effects of patient-provider communication style on adolescent vaccination. As such, we hypothesized that regardless of the direction of the relationship between communication style and adolescent vaccination the effect would be moderated by states' vaccine school entry requirements such that communication style would be less influential in states with vaccine requirements than in states without vaccine requirements (Hypothesis 3).

Methods

Procedures

Data came from the 2010 National Immunization Survey (NIS)-Teen implemented by the CDC.⁶¹ NIS-Teen included phone interviews with a national sample of caretakers of 13- to 17-year-old adolescents (hereafter called "parents"), during which parents reported the vaccination history of a randomly selected adolescent in the household. At the end of the interview, NIS-Teen staff asked for consent to contact the adolescents' primary healthcare providers to verify vaccination history with written surveys. Among 39,811 eligible parents that NIS-Teen staff contacted, 32,429 (82% of those contacted) completed the interview. Of these, 23,738 (73% of those interviewed) consented to provider verification, and NIS-Teen staff mailed surveys to the clinics of all identified providers. Clinics returned surveys on the vaccination history of 19,257 adolescents (81% of those who consented). NIS-Teen staff developed sampling weights for each participant in the sample with provider-verified vaccination history to account for non-equal probability of selection.

During the final two quarters of the 2010 survey year, 11,860 participants completed the Parental Attitudes Module, a supplementary set of items measuring parents' attitudes,

beliefs, and experiences regarding adolescent vaccines, including patient-provider communication. Among these participants, 9,194 (77.5%) had provider verification of vaccination history. We used data from this sample in the current study. We excluded participants who had missing data for all communication items ($n=173$), for a final analytic sample of 9,021.

The National Center for Health Statistics (NCHS) Research Ethics Review Board approved data collection for NIS-Teen. Analysis of de-identified data from the survey is exempt from federal regulations for the protection of human research participants. Analysis of restricted data through the NCHS Research Data Center is also approved by the NCHS ERB. The Institutional Review Board at the University of North Carolina exempted this study from review.

Measures

School entry requirements. Parents reported state of residence (including Washington, D.C., hereafter referred to as a “state” for the sake of simplicity) in the NIS-Teen phone interview. The Immunization Action Coalition³⁷ (IAC) compiles data from state health departments on whether they have policies requiring students to receive vaccines prior to entry into certain grades in school and, if so, when the policies went into effect. Separately for each vaccine, we used this database to code states as 1 if they had a school entry requirement in effect by the fall semester of 2010 (the year of NIS-Teen data examined for this study) and 0 if they did not.

Patient-provider communication. Parents answered three items about conversations with their adolescents’ healthcare providers about each vaccine (total of nine items). These items mapped on to the components of collaboration proposed by the Charles and Gafni’s

framework of patient-provider communication:^{100,101,133} information exchange, deliberation, and decision.

Items began with “At visits made for [teen name]’s vaccinations, did [his/her] healthcare provider...” and concluded with “...talk to you about [vaccine]?” (information exchange); “...give you enough time to discuss [vaccine]?” (deliberation); and “...play a role in your decision to get [teen name] vaccinated or not to get [teen name] vaccinated with [vaccine]?” (decision). We created indicator variables for each component, separately for each vaccine. We coded responses as 1 if parents reported that the provider used that component of collaborative communication and 0 for all other responses (“no,” “don’t know,” or “refused,” or if parents reported that adolescents did not have visits for vaccinations).

Separately for each vaccine, we classified providers’ communication styles into three categories to describe the degree of collaboration in patient-provider conversations. The first category (“minimal” collaboration) included parents who reported that providers did not engage in information exchange. The second category (“moderate” collaboration) included parents who reported that providers engaged in information exchange and one additional component of collaborative communication, i.e., either deliberation or decision. The third category (“optimal” collaboration) included parents who reported that providers engaged in all three components of collaborative communication.

Parents with missing data on at least one communication item for a given vaccine were excluded from analysis of outcomes for that vaccine. We retained them in analyses of vaccination outcomes for which they provided complete data.

Control variables. In addition to the main study variables, analyses controlled for adolescents' age at the time of the interview (range: 13-17 years), adolescents' sex (male or female), and adolescents' insurance states (private health insurance or not). We also examined several other sociodemographic variables (e.g., adolescents' race/ethnicity, mothers' education level, number of children in the household); these factors were not associated with vaccination in bivariate analysis, so we excluded them from multivariate models. Analyses involving HPV vaccination excluded male adolescents because of the low prevalence of vaccine initiation (1.4%) in 2010.⁶⁴

Because we sought to isolate the effects of communication style on vaccine uptake, analyses also controlled for provider recommendation for each adolescent vaccine. Previous studies have demonstrated the strong influence of provider recommendation on vaccine uptake,⁶ including for this sample.⁷⁰ For each adolescent vaccine, we coded participants as 1 if they received a provider's recommendation and 0 for all other responses ("no," "don't know," or "refused").

Vaccination status. NIS-Teen measured receipt of Tdap, meningococcal vaccine, and HPV vaccine and verified it with providers' reports. We classified adolescents as having received each vaccine if their healthcare providers verified administration in the mailed questionnaire. For HPV vaccine, we measured initiation (i.e., receipt of at least 1 dose) of the 3-dose series, following the operationalization in our previous studies^{26,88,136} and in the CDC's publications using NIS-Teen data.⁶⁴

Statistical Analysis

To test the proposed hypotheses, we used multivariate logistic regression models to examine the association between vaccination and school entry requirements, communication

style, and their interaction, controlling for demographics and provider recommendation. We ran separate models for each vaccination outcome (coverage for Tdap, meningococcal vaccine, and HPV vaccine). We used Wald tests to examine the joint effects of the interaction terms in each model. If the Wald test indicated statistically significant moderation, we probed the interactions post-hoc to estimate the prevalence of vaccination according to communication style, separately for states with and without school entry requirements. If the Wald test did not indicate statistically significant moderation, we dropped the interaction terms and reran the model.

A supplementary analysis analyzed potential carry-over effects by examining whether the relationship between communication style and receipt of meningococcal and HPV vaccines varied depending on states' requirements for Tdap vaccination, which are the most common requirements across states. We used multivariate logistic regression models for each vaccination outcome consisting of Tdap vaccination school entry requirements, collaborative communication type for the vaccination outcome, and interaction terms for these two variables. We followed the procedures described above for evaluating moderation.

All analyses were conducted in SAS version 9.2 (Cary, NC). Statistical tests used a two-tailed critical p value of .05. Analyses controlled for clustering of observations within states and incorporated survey weights provided by NIS-Teen to account for non-equal probability of selection. Below, we report unweighted frequencies and weighted proportions.

Results

Adolescents were nearly evenly split between male (52%) and female (48%) (Table 7). Most adolescents were non-Hispanic white (60%), and 61% had private health insurance. Vaccination coverage among this sample was similar to the 2010 coverage for the entire

population:⁶⁴ 73% of adolescents had received Tdap, 66% had received meningococcal vaccine, and 49% of female adolescents had received at least 1 dose of HPV vaccine.

Thirty-two states had Tdap vaccination school entry requirements in effect by the fall semester of 2010; 60% of participating adolescents lived in these states, with the remaining adolescents in states without Tdap vaccination policies. Thirty-four percent of parents reported that providers used a minimally collaborative style in conversations about Tdap, 21% reported moderate collaboration, and 46% reported optimal collaboration. In multivariate analysis, Tdap vaccination was higher in states with school entry requirements compared to other states (odds ratio [OR]=1.22, 95% confidence interval [CI]=1.02, 1.45; $p<.05$) (Table 8). In addition, Tdap vaccination was higher when providers used a moderately collaborative style compared to minimally collaborative (OR=1.50, 95% CI=1.09, 2.05; $p<.05$) (Figure 12; Table 8).

Ten states had meningococcal vaccination requirements; 25% of adolescents lived in these states. Forty-six percent of parents reported that providers used a minimally collaborative style in conversations about meningococcal vaccine, 14% reported moderate collaboration, and 40% reported optimal collaboration. In multivariate analysis, meningococcal vaccination was higher in states with school entry requirements compared to other states (OR=1.89, 95% CI=1.56, 2.30; $p<.05$) (Table 8). In addition, meningococcal vaccination was higher when providers used an optimally collaborative style compared to minimally collaborative (OR=1.63, 95% CI=1.22, 2.18; $p<.05$) (Figure 12; Table 8).

Two states had HPV vaccination requirements; 2% of female adolescents lived in these states. Twenty-three percent of parents of female adolescents reported that providers used a minimally collaborative style in conversations about HPV vaccine, 24% reported

moderate collaboration, and 53% reported optimal collaboration. In multivariate analysis, HPV vaccination did not differ in states with versus without school entry requirements (Table 8). However, HPV vaccination was higher when providers used a moderately (OR=1.68, 95% CI=1.00, 2.84; $p<.05$) or optimally (OR=1.86, 95% CI=1.42, 2.42; $p<.001$) collaborative style compared to minimally collaborative (Figure 12; Table 8).

For each vaccination outcome, vaccination school entry requirements and communication style did not interact in their association with the respective vaccines (all $p\geq.14$). Supplementary analyses that examined the interactive effects of Tdap school entry requirements and collaborative communication type on uptake of meningococcal and HPV vaccines found no evidence of an interactive effect of these variables on either outcome (both $p\geq.41$).

Conclusion

In a nationally-representative sample of U.S. adolescents, we found evidence of independent effects of vaccination school entry requirements and provider communication style on uptake of routine adolescent vaccines. Requirements for Tdap and meningococcal vaccination were associated with higher vaccination coverage, while requirements for HPV vaccination were not associated with differences in coverage. Patient-provider conversations that included all three components of Charles and Gafni's framework for collaborative communication^{100,101,133} were associated with increased odds of meningococcal and HPV vaccination compared to conversations with fewer components. However, these two variables did not interact to predict vaccination.

Generally, our results supported Hypothesis 1: Compared to other states, vaccination was more common in states with school entry requirements for Tdap and meningococcal

vaccine. Tdap vaccination requirements were associated with a 5% absolute increase in coverage (from 70% to 75%), and meningococcal vaccination requirements were associated with a 14% absolute increase in coverage (from 63% to 77%). These state policies may normalize adolescent vaccination and make it the default behavior.^{48,49} Interestingly, HPV vaccination requirements had no effect on HPV vaccination coverage. This finding could reflect resistance to HPV vaccination requirements and widespread use of liberal opt-out clauses in these policies.⁴² Together, these results provide support for Tdap and meningococcal vaccination school entry requirements as a public health intervention to increase adolescent vaccination coverage. However, states considering HPV vaccination requirements should take steps to ensure public acceptance or adopt less liberal opt-out clauses to increase the possibility that these policies lead to increases in coverage.

In contrast to previous studies, we did not find that Tdap school entry requirements were associated with increased meningococcal or HPV vaccination coverage. We examined the influence of Tdap policies in a national, cross-sectional sample in 2010, versus Kharbanda and colleagues,⁵¹ who conducted a pre/post study in one state from 2006 to 2008, and Dempsey and colleagues,⁵² who conducted a national study in 2009 using a measure of school entry requirements that collapsed policies for Tdap and the tetanus and diphtheria (Td) vaccines. As Tdap school entry requirements have become more common, their influence on coverage levels for other vaccines may have been attenuated. Further studies are needed to investigate the longitudinal effects of Tdap school entry requirements on meningococcal and HPV vaccination in a national context across multiple years.

We examined competing hypotheses for the direction of the relationship between collaborative provider communication style and uptake of adolescent vaccines. We found

support for Hypothesis 2a in that more collaborative communication styles were positively associated with vaccination coverage. Parents who reported that providers used optimal levels of collaboration were more likely to have adolescents who received meningococcal and HPV vaccines compared to parents who reported that providers used minimal collaboration (the difference for Tdap vaccination approached statistical significance). These findings provide preliminary empirical support for the role of shared decision making in improving healthcare outcomes,^{103,106} but intervention studies are needed to establish a causal association.

Finally, our results did not support Hypothesis 3, that the health policy context would moderate the relationship between communication and vaccination. These findings suggest that providers' use of a collaborative communication style was associated with higher levels of vaccination regardless of states' school entry requirements. That is, even when parents had strong motivators for vaccination (i.e., school entry requirements), communication style was still associated with vaccination outcomes. Many previous studies have suggested additional training for primary care providers in how to engage parents and patients in discussions about vaccines,^{33,69,70,74} and our results underscore the importance of collaboration in these conversations, regardless of the policy context. Future studies should evaluate interventions to train physicians in collaboratively communicating with parents about adolescent vaccines while acknowledging state policies that require vaccination.

Descriptively, the difference between coverage across communication styles is more pronounced for HPV vaccine than for meningococcal vaccine, which in turn is more pronounced than for Tdap; it appears that the effects of communication style are larger for vaccines for which fewer states have adopted fewer school entry requirements. However,

other policies related to vaccination, such as requiring schools to disseminate information about vaccines or allowing for non-medical exemptions from school entry requirements, may influence these relationships. Future studies should examine the effects of these policies.

Study strengths include a large, nationally representative sample, allowing us to evaluate the effects of both policy and interpersonal factors on adolescent vaccination. The provider-verified adolescent vaccination records give us confidence in the validity of our dependent variable. Limitations include the cross-sectional nature of this analysis, which precluded our ability to draw causal inferences about the proposed relationships. Another limitation is that the data come from the 2010 NIS-Teen questionnaire. In the intervening years, vaccination coverage has increased, 15 more states have adopted Tdap vaccination requirements, and 10 states have adopted meningococcal vaccination requirements.³⁷ In addition, the CDC began recommending routine administration of HPV vaccine to both female and male adolescents.¹⁵ As a result, the context in which vaccination takes place now is different than in 2010, yet we have no reason to believe the relationships described in this study have changed. The small sample size of adolescents in states with HPV vaccine school entry requirements (just over 2% of the female sample) reduced our statistical power for that analysis. Additionally, vaccination school entry requirements were not randomly distributed across states, potentially introducing some bias in the analyses involving this variable.

Finally, due to the constraints of secondary data analysis, the minimally collaborative communication category combined several conceptually distinct conversation styles. That is, we could not distinguish between parents whose conversations with providers included absolutely no discussion of vaccines from others who had very limited conversations, including encounters in which (1) parents requested vaccines without prompting from their

provider, or (2) providers asked for consent to vaccinate without providing any information. However, even if this category combined several types of conversations, the comparison with other communication styles serves to isolate the effects of truly collaborative communication. In addition, these measures only captured parents' perceptions of communication, not the providers'; to the extent that these perceptions diverge, the effects of communication style on vaccination may vary. Items began with a stem stating "At visits for made for [teen's name]'s vaccinations..." and parents may have interpreted that to exclude conversations during healthcare visits that did not exclusively focus on vaccination (e.g., sick visits). Future studies are needed to further parse out different communication styles and their unique effects on vaccination.

In conclusion, uptake of adolescent vaccines was higher in states with school entry requirements for Tdap and meningococcal vaccines but not HPV vaccine and for adolescents whose providers employed a collaborative communication style. The health policy context did not modify the association of provider communication style with vaccination coverage. Because states' policies and providers' communication styles had independent associations with vaccination, public health programs may be able to use either or both of these approaches to improve coverage with adolescent vaccines.

Addendum

In addition to the procedures described in this chapter, I originally proposed analyses of the effects of Tdap policies on adolescent vaccination. I have summarized or excluded these results from the manuscript for the sake of simplicity and because they were mostly null findings, but I have described them in this section.

In addition to their main effects on Tdap vaccination, school entry requirements for Tdap vaccine have also demonstrated positive associations with increased levels of HPV vaccination coverage.⁵² These carry-over effects likely arise due to concomitant administration of HPV vaccine during the same healthcare encounter that adolescents receive Tdap.¹⁵ We hypothesized that uptake of HPV vaccine would be higher in states with Tdap requirements than states without such requirements. In addition, we hypothesized that concomitant vaccination (HPV and Tdap vaccines) would be higher in states with Tdap requirements than states without such requirements.

Further, we hypothesized that the association between providers' communication style and vaccination may vary depending on whether a state has a Tdap school entry requirement. Because these requirements frame Tdap vaccination and not HPV vaccination as a default behavior,^{48,49} the role of providers' communication style may become comparatively more influential in states with Tdap requirements compared to states without Tdap requirements.

In addition to the measures described previously, we measured concomitant uptake of Tdap and HPV vaccines. We examined the reported dates of vaccine administration from the questionnaires mailed to healthcare providers as part of NIS-Teen. If administration of both Tdap and HPV vaccines occurred on the same day, we coded participants as receiving these vaccines concomitantly; we coded all other participants as not receiving these vaccines concomitantly. We excluded male adolescents from analysis of concomitant uptake of these vaccines.

We followed the procedures described here for examining the main and interactive associations of Tdap school entry requirements and provider communication style with

uptake of HPV vaccine and concomitant uptake of Tdap and HPV vaccines. That is, we conducted multivariate logistic regression including terms for both independent variables and their interaction. We used Wald tests to examine the statistical significance of the joint effects of the interaction terms in each model. If the Wald tests reflected a statistically significant interaction of these variables in their association with vaccination, we conducted post-hoc tests to probe the prevalence of vaccination in different provider communication categories separately for states with and without Tdap requirements. If the Wald test did not reflect a statistically significant interaction, we dropped these terms from the model and reran the multivariate logistic regression.

As indicated above, HPV vaccination did not vary for states with or without Tdap vaccine school entry requirements (Supplemental Table S2). However, HPV vaccination was higher for adolescents of parents who reported that providers used a moderately (OR=1.71, 95% CI=1.01, 2.91; $p<.001$) or optimally (OR=1.88, 95% CI=1.44, 2.47; $p<.001$) collaborative communication style, compared to minimally collaborative. These factors did not interact in their association with HPV vaccination ($p=.41$).

Concomitant uptake of Tdap and HPV vaccines did not vary for states with or without Tdap vaccine school entry requirements (Supplemental Table S2). In addition, concomitant vaccination did not vary across providers' communication styles in conversations about Tdap or in conversations about HPV vaccine. These factors did not interact in their association with concomitant vaccination (Tdap requirement by Tdap communication style: $p=.43$; Tdap requirement by HPV vaccine communication style: $p=.25$).

Contrary to our hypotheses, Tdap vaccine school entry requirements were not associated with carry-over increases in adolescent vaccination, either for uptake of HPV

vaccine or for concomitant uptake of Tdap and HPV vaccines. In addition, providers' communication style did not interact with Tdap requirements in their association with vaccination.

As discussed previously, one study demonstrated an elevated HPV vaccination coverage level for states with Tdap vaccine school entry requirements compared to other states;⁵² however, that study examined the joint effects of policies for Tdap and the tetanus and diphtheria (Td) vaccines in place by Fall 2009. In contrast, our study examined the effects only of policies for Tdap that were in place Fall 2010. The secular trend in HPV vaccination coverage between 2009 and 2010 (increasing from 44% to 48%)⁶⁴ may have diluted the effects of Tdap requirements on vaccination. Alternatively, narrowing the independent variable from Td/Tdap policies to Tdap policies only may have reduced some of the statistical power to detect a difference across states. For either explanation, the results imply that Tdap vaccine school entry requirements do not have a carry-over association with HPV vaccination in this cross-sectional study.

Concomitant uptake of Tdap and HPV vaccines did not vary across states with or without Tdap vaccine school entry requirements. Because we hypothesized that concomitant vaccination was the mechanism connecting Tdap requirements with HPV vaccination coverage and we did not find a main effect of the relationship between these two variables, the lack of a statistical association between Tdap requirements and concomitant vaccination is not surprising. Although Tdap requirements were associated with increased Tdap vaccination, they did not appear to change parents' and adolescents' behaviors around HPV vaccination.

In addition, we found no effects of communication style on concomitant vaccination, either as a main effect or in interacting with Tdap vaccine school entry requirements. The lack of a statistically significant finding in this analysis may be related to vaccine hesitancy. Providers may be able to use a collaborative communication style to persuade vaccine-hesitant parents and adolescents to receive a single vaccine, but they may be extremely resistant to concomitant vaccination regardless of communication style. Further, these families may acquiesce to Tdap vaccination to comply with a state policy, but a provider's communication style may have no impact on their reluctance to consent to a second vaccination. Additional studies are needed to integrate vaccine attitudes (an intrapersonal factor) into this analysis of patient-provider communication (an interpersonal factor) and school entry requirements (a policy-level factor).

Table 7. Characteristics of Participants and Their Children

Parental Attitudes Module, National Immunization Survey (NIS)-Teen, 2010.

	Total Sample		Male		Female	
	n	(%)	n	(%)	n	(%)
Total	9,021		4,709	51.8	4,312	48.2
<i>Child characteristics</i>						
Age						
13	1,824	19.1	961	19.4	863	18.8
14	1,859	19.4	933	19.2	926	19.7
15	1,836	20.9	969	20.4	867	21.5
16	1,877	21.7	997	22.9	880	20.4
17	1,625	18.9	849	18.1	776	19.7
Race/ethnicity						
Hispanic	1,152	18.2	596	19.5	556	16.7
Non-Hispanic white	6,196	59.5	3,240	58.5	2,956	60.6
Non-Hispanic black	928	14.8	481	14.6	447	15.1
Other	745	7.5	392	7.4	353	7.6
Private insurance						
Yes	6,100	61.0	3,190	60.1	2,910	62.0
No	2,921	39.0	1,519	39.9	1,402	38.0
VFC-eligible						
Yes	2,663	34.8	1,399	35.2	1,264	34.5
No	6,358	65.2	3,310	64.8	3,048	65.5
Preventive check-up in last year						
Yes	7,737	85.0	4,013	83.5	3,724	86.6
No	1,284	15.0	696	16.5	588	13.4
Well child check-up at age 11-12						
Yes	6,755	88.8	3,518	88.0	3,237	89.7
No	861	11.2	462	12.0	399	10.3
<i>Parent characteristics</i>						
Relationship of respondent to teen						
Mother/female guardian	7,200	76.8	3,699	74.0	3,501	79.7
Father/male guardian	1,413	16.7	795	19.0	618	14.2
Other	408	6.5	215	7.0	193	6.0
Mother's age						

≤ 34 years	646	7.7	339	7.8	307	7.7
35-44 years	3,655	44.3	1,931	44.6	1,724	43.9
≥ 45 years	4,720	48.0	2,439	47.6	2,281	48.4
Mother's education level						
Less than 12 years	781	12.0	404	12.9	377	11.0
12 years	1,856	26.3	984	26.4	872	26.1
More than 12 years, non-college grad	2,623	26.1	1,341	25.1	1,282	27.2
College graduate	3,761	35.6	1,980	35.6	1,781	35.7
<i>Household characteristics</i>						
Region						
Northeast	1,850	18.2	959	18.1	891	18.4
Midwest	1,953	21.3	990	20.5	963	22.1
South	3,285	36.7	1,749	37.3	1,536	36.0
West	1,933	23.8	1,011	24.1	922	23.5
Urbanicity						
Metro	6,971	84.2	3,661	83.6	3,310	84.9
Non-metro	2,050	15.8	1,048	16.4	1,002	15.1
Annual income						
Below poverty level	1,296	18.4	675	18.9	621	18.0
Above poverty level, ≤\$75,000	3,493	38.5	1,839	39.2	1,654	37.8
Above poverty level, >\$75,000	3,872	37.4	2,012	35.9	1,860	39.0
Unknown	360	5.7	183	6.1	177	5.3
Number of children in household						
1	3,567	31.6	1,886	31.7	1,681	31.5
2-3	4,612	55.7	2,404	55.0	2,208	56.5
4 or more	842	12.7	419	13.3	423	12.0

Note. We present unweighted *n*'s and weighted percentages.

Table 8. Associations of Vaccine School Entry Requirements and Collaborative Communication Style with Adolescent Vaccination Coverage

	Model 1:				Model 2:				Model 3:			
	Tdap				Meningococcal vaccine				HPV vaccine ¹			
	n/N	%	OR	95% CI	n/N	%	OR	95% CI	n/N	%	OR	95% CI
Vaccine school entry requirement												
No	2,546/3,803	70.2		(ref)	4,418/6,818	63.2		(ref)	2,105/4,155	49.0		(ref)
Yes	4,006/5,218	74.7	1.22	(1.02, 1.45)*	1,757/2,203	76.8	1.89	(1.56, 2.30)*	86/157	47.1	1.17	(0.57, 2.41)
Collaborative communication style												
Minimal	1,965/3,002	66.6		(ref)	2,068/3,930	55.2		(ref)	257/928	25.1		(ref)
Moderate	1,207/1,621	76.4	1.50	(1.09, 2.05)*	808/1,172	67.6	1.06	(0.78, 1.44)	333/976	35.5	1.68	(1.00, 2.84)*
Optimal	3,254/4,216	75.5	1.30	(0.99, 1.69)	2,834/3,621	78.4	1.63	(1.22, 2.18)*	1,506/2,220	66.3	1.86	(1.42, 2.42)**

Note. School entry vaccination requirements and collaborative communication type referred to the specific vaccine in the model. Analyses controlled for adolescent age, sex, and insurance status, and receipt of a provider recommendation. Tdap = tetanus, diphtheria, and pertussis booster; HPV = human papillomavirus vaccine.

¹First dose among female adolescents only.

* $p < .05$; ** $p < .001$.

Supplemental Table S2. Associations of Tdap Vaccine School Entry Requirements and Collaborative Communication Style With Adolescent Vaccination Coverage

	HPV ¹				Tdap + HPV ¹			
	n/N	%	OR	95% CI	n/N	%	OR	95% CI
Tdap vaccine school entry requirement								
No	924/1,812	50.2		(ref)	246/1,812	16.6		(ref)
Yes	1267/2,500	47.7	0.86	(0.66, 1.10)	397/2,500	14.8	0.81	(0.58, 1.14)
Collaborative communication style								
Tdap								
Minimal	--	--	--	--	195/1,331	15.5		(ref)
Moderate	--	--	--	--	125/783	17.8	1.21	(0.60, 2.45)
Optimal	--	--	--	--	307/2,104	15.2	0.98	(0.55, 1.73)
HPV vaccine								
Minimal	257/928	25.1		(ref)	91/928	8.3		(ref)
Moderate	333/976	35.5	1.71	(1.01, 2.91)*	90/976	13.5	1.22	(0.45, 3.27)
Optimal	1,506/2,220	66.3	1.88	(1.44, 2.47)*	429/2,220	20.0	1.90	(0.83, 4.34)
Interaction terms (<i>p</i> -value)								
Tdap requirement x								
Tdap communication style				n/a				0.43
Tdap requirement x								
HPV vaccine communication style				0.41				0.25

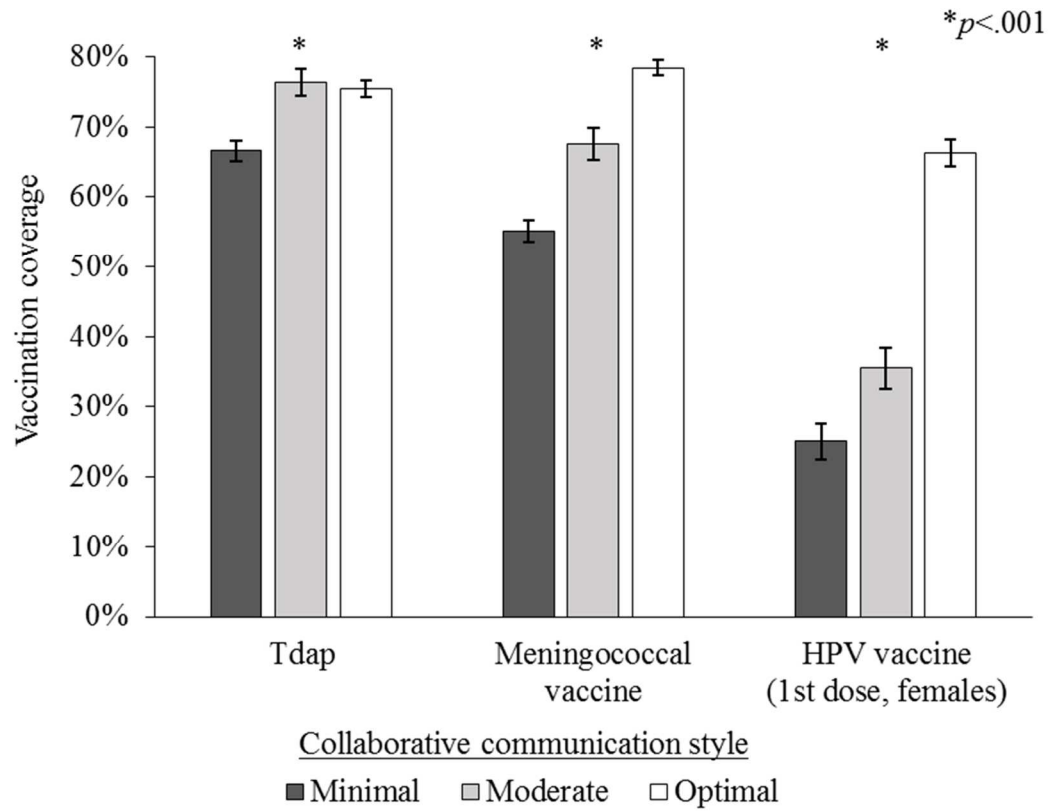
Note. Analyses controlled for adolescent age, insurance status, and receipt of a provider recommendation. Tdap = tetanus, diphtheria, and pertussis booster; HPV = human papillomavirus vaccine. The estimates for relationships with HPV vaccination differ from those presented in Table 8 because the model controls for the interaction terms (which were excluded in the main table).

¹First dose among female adolescents only.

**p*<.001.

Figure 12. Association of collaborative communication style with adolescent vaccination coverage.

Error bars show standard errors.



CHAPTER 8: DISCUSSION

In the three studies that I present in this dissertation, I evaluated how school entry requirements changed the context for adolescent vaccination, particularly through concomitant administration. Although the studies were about three vaccines recommended for routine administration to 11- and 12-year-old adolescents (i.e., Tdap booster, meningococcal vaccine, and HPV vaccine), my focus was on HPV vaccination, given its low coverage¹¹⁸ and resulting missed potential for cancer prevention.¹¹⁰ In Chapters 5 and 6 (Aim 1), I found that coverage for each adolescent vaccine, both singly and concomitantly, increased dramatically in the summer months compared to the rest of the calendar year. These increases partially explained the relationship between vaccination school entry requirements and coverage for both the vaccines targeted by those requirements as well as spillover onto other vaccines. In Chapter 7 (Aim 2), I found that vaccination school entry requirements and collaborative communication between patients and providers were both independently, positively associated with uptake of adolescent vaccines. Next, I describe overarching themes across these chapters, future directions for research, and strengths and limitations of these studies.

Cycles in Adolescent Vaccination Matter

Single and concomitant uptake of adolescent vaccines was 3 to 10 times as common at the peaks of the vaccination cycles compared to their troughs, using the ratio of highest to lowest incidence (see Chapter 5). These seasonal cycles were larger than other well-

recognized patterns such as suicide (2 times as common in the summer as in the winter)⁵³ or interest in smoking cessation (1.25 times as common on Mondays as the rest of the week).⁵⁵

These cycles have important implications for the timing of vaccine promotion interventions. Programs that are relatively brief, such as disseminating educational vaccination messages through radio spots, should occur in the late spring or early summer. These programs could impact recipients by the beginning of the summer increase in vaccination yet still be novel enough to be effective. In contrast, for programs that are more durable, such as altering a clinic's electronic health record system, researchers should time their activities to occur earlier, perhaps in the winter or early spring, to ensure full adoption and sorting out implementation challenges well before the summer.

Of particular interest to the study of HPV vaccination are the cycles of concomitant vaccination for HPV vaccine alongside either Tdap or meningococcal vaccine. Recently, Stokley and colleagues¹⁰⁹ illustrated the untapped potential of concomitant uptake for increasing HPV vaccination coverage: They found that if all the girls in the 2000 birth cohort received HPV vaccine during a healthcare visit in which they received another vaccine, HPV vaccine initiation would have surpassed 90%. Little is known about how families make decisions about concomitant vaccination, but previous studies have found that some parents are reluctant to consent to their children receiving more than one vaccine in a day.^{137,138} I reported in Chapter 6 that states with higher proportions of concomitant vaccination in the summer compared to the entire year had higher HPV vaccination coverage rates. If interventions that educate parents about the efficacy^{31,139} and safety^{15,109,139} of concomitant vaccination take place in the spring, they may lead to improvements in concomitant

vaccination among adolescents who are already seeking Tdap or meningococcal vaccination during the summer.

School Entry Requirements Increase Targeted and Spillover Vaccination

As demonstrated in Chapter 6 and in preliminary studies,^{47,51,52,112} state policies that required adolescent students to receive vaccines before a certain school year were associated with increases in coverage for the targeted vaccines, and the effect spilled over onto coverage for non-targeted vaccines. These states also had more pronounced summer increases in vaccination coverage than other states. However, in all states, regardless of whether or not they had school entry requirements, vaccination peaked in the summer. Alternative explanations beyond school entry requirements must account for some of the observed increases. One of the most likely explanations is that in summer months, when most children do not attend school, parents could more easily take their children to primary care clinics for preventive healthcare services than other times of the year. Future research should examine cycles in vaccination for adolescents who attend schools with non-traditional formats, such as year-round schools or home schools.

School entry requirements may frame uptake of targeted vaccines as a default behavior.⁴⁸ The default effect may increase behavioral engagement through at least three mechanisms: effort, or the burden associated with pursuing an alternative to the default behavior; norms, or the implied recommendation from policymakers and the descriptive and injunctive social norms about the behavior; and loss aversion, which makes the default seem more appealing.⁴⁸

In states with school entry requirements, the phenomenon of parents more easily seeking preventive care for adolescents in the summer months was likely compounded by the

effort explanation for default effects. That is, to the extent that school entry requirements situate vaccination as a behavioral default, the effort needed to seek an exemption discouraged parents and adolescents from non-participation. In parents' decision making about vaccination, the ease of seeking care in the summer and the anticipated effort of seeking an exemption from a school entry requirement may have reinforced one another, thereby exaggerating the summer peaks in uptake of targeted vaccines. Alternatively, parents may have little time in the brief period at the start of the school year when school administrators are more available to complete the requirements for opting out of the school entry requirement.

Additionally, summer peaks may vary by the ease of states' exemption policies. For example, previous studies have examined the complexity of seeking a non-medical exemption from vaccination requirements, which can range from simply signing a waiver to reading online educational material to speaking with a healthcare provider to obtain a signature.^{123,140} If parents view receiving education from a healthcare provider as effortful and signing a waiver as not very effortful, they may be more likely to seek an exemption in the states with less effortful exemption procedures, leading to reductions in summer peaks in vaccination, a topic for future research to examine.

For the increases in coverage for vaccines not targeted by school entry requirements, the norms explanation may account for more of the effect than the effort explanation.⁴⁸ School entry requirements carry an implied recommendation to vaccinate from policymakers.⁴⁸ In addition, as vaccination becomes more common in a population, descriptive and injunctive norms around receipt of adolescent vaccines may become more positive. These pro-vaccination norms may generalize to the non-targeted vaccines. The

combination of these norms, along with the ease of getting a second (or third) vaccine during the same healthcare visit as the one targeted by a school entry requirement, may explain the elevated concomitant vaccination in the summer months observed in this dissertation. Future studies should parse out the explanations for the success of school entry requirements (e.g., effort, norms, and loss aversion), particularly in increasing the magnitude of summer peaks in adolescent vaccination coverage.

Given the strong, positive relationships between vaccination school entry requirements and coverage, a next step to support HPV vaccination might be to encourage states to adopt more vaccination requirements for Tdap or meningococcal vaccine. However, as of Fall 2014, 47 states had adopted Tdap vaccination requirements and 20 had adopted meningococcal vaccination requirements.³⁷ Very few states can institute new Tdap vaccination requirements, but even instituting a new meningococcal vaccination requirement may not be desirable for HPV vaccination. Interestingly, the possibility exists that states with school entry requirements for both Tdap and meningococcal vaccination may experience relative reductions in HPV vaccine coverage. That is, if adolescents must receive Tdap and meningococcal vaccines but HPV vaccine is optional, families may choose to only receive the two required doses and opt out of receiving HPV vaccine. I will continue to investigate the possibility of this phenomenon in the current dataset by testing the interaction between Tdap and meningococcal vaccination requirements. As a result, future possibilities for expanding on vaccination school entry requirements may involve focusing on enforcement of existing policies^{34,119,141} or in adopting HPV vaccine requirements.^{42,43,142}

Provider Communication Style Correlates with Adolescent Vaccination

In cross-sectional analyses, adolescents who received vaccines recalled that their providers used a more collaborative communication style than unvaccinated adolescents. This association held true regardless of the vaccination school entry requirements in the state where the adolescents lived. These findings are consistent with recommendations for collaborative patient-provider communication.^{100,134} Collaborative communication can offer parents and adolescents the opportunity to learn about vaccines (or the diseases they protect against). Parents commonly report needing more information as a reason that they do not have their adolescents vaccinated with HPV vaccine.^{91,143-145} However, to facilitate collaborative communication, healthcare providers need to be comfortable discussing HPV vaccination. Previous studies have demonstrated that providers are reluctant to bring up HPV vaccine,^{146,147} either due to unfamiliarity with the disease, anticipation of parental resistance, or hesitance in discussing sexual activity. Experimental trials are needed to understand both the optimal communication techniques for providers discussing adolescent vaccines and the best ways to teach providers to use these techniques.

These results also have implications for the ethical literature around communication and decision making in primary care. Providers cannot administer adolescent vaccines without at least bringing them up to parents and patients,¹²⁸ but the degree of collaboration is flexible. Many ethicists have suggested that collaborative communication is unnecessary for decisions involving healthcare interventions that (1) have considerable support among clinicians, (2) are safe, and (3) do not have alternatives that could accomplish the same protection.^{131,132,135} Generally, vaccinations fall in to this category, and one previous study demonstrated quite dramatic benefits of directive communication for uptake of childhood

vaccines.¹⁰⁸ However, we found in this study that recollections of collaborative communication were positively associated with uptake, even in states with vaccination requirements. So although collaborative communication about vaccines may be unnecessary, I found that it was associated with vaccination outcomes, over and above the effects of vaccination school entry requirements.

I used the Charles and Gafni framework for collaborative patient-provider communication in primary care^{100,101,133} to organize my analysis of communication and vaccination. This framework suggests that collaborative communication includes joint efforts from patients and providers in information exchange, deliberation, and decision about a particular healthcare option. I found that, most commonly, parents recalled that they engaged in all three of these processes with providers in discussions about adolescent vaccines (“optimal” collaboration: Tdap: 46%; meningococcal vaccine: 40%; HPV vaccine: 53%). Yet the second most common communication type involved minimal collaboration (Tdap: 34%; meningococcal vaccine: 46%; HPV vaccine: 23%). That the bulk of vaccination conversations fell into the two extremes of the communication continuum may reflect the genuine uncertainty that exists regarding the style that promotes vaccination. They may also reflect the differing conditions under which clinicians recommend vaccination: directive approaches may work well with patients seen for many years, but a collaborative approach may more often be necessary when meeting with new patients. Although collaborative communication has become popular in medical practice in the past decades, directive communication may be more efficient and effective. Resolving this uncertainty is important for supporting clinicians in delivering adolescent vaccinations.

In addition, the Charles and Gafni framework (as well as most other models of communication in primary care) may be insufficient for understanding healthcare decisions that involve more than two people. That is, current theories do not account for the influence of patient, parent, and provider in communication and decision making, instead focusing only on the parent and provider. Although parents are the primary decision makers in healthcare for their children, the adolescent can still influence the ultimate outcomes. Most providers would not vaccinate adolescents against their will, even with parents' consent.¹⁴⁸ Though adolescents often feel removed from parent and provider conversations around healthcare options,^{69,95,104} most adolescents reported that they did not want to make decisions about vaccinations without their parents.⁹³ Indeed, half of parents indicated that their daughters were involved in HPV vaccination decisions either a moderate amount or a lot.¹⁴⁹ In my own research, I have found that parents and adolescent sons share similar attitudes and beliefs about HPV vaccine, but they have some distinct motivations for actually receiving the vaccine (manuscript under review). The decision-making process among these three actors, i.e., the patient, parent, and provider, is complex, and additional theoretical consideration about the interplay of their beliefs and actions would provide valuable guidance in future analyses of communication and adolescent vaccination.

Despite these findings, the retrospective, observational nature of these data does not allow me to make conclusions about the direction of the relationship between communication and vaccination. On the one hand, collaborative communication may increase receipt of vaccines by allowing providers to persuade parents of the value of vaccination. On the other hand, parents who consent to vaccination may have different recollections of the

communication techniques their providers used. More research is needed to discern the direction of this relationship.

Strengths and Limitations

Study strengths include the use of a large, high-quality data source. The National Immunization Survey (NIS)-Teen contains five years of data about almost 100,000 adolescents across the United States.⁶¹ It is a nationally representative dataset that the CDC uses to calculate its official estimates of vaccination coverage and that the U.S. Department of Health and Human Services uses to measure progress toward the Healthy People 2020 goals.²⁷ NIS-Teen includes provider verification of adolescent vaccination status, increasing the reliability and validity of the measures of vaccination under study. Provider verification is crucial for studying HPV vaccination, because self-reported measures often underestimate actual uptake.¹⁵⁰ NIS-Teen contains data for the entire period because the Advisory Committee on Immunization Practices introduced Tdap, meningococcal vaccine, and HPV vaccine.¹⁵ In my analyses, I used sampling weights to account for non-equal probability of selection into the survey and thus increase the generalizability of results to the entire population of U.S. adolescents.

A second strength of these studies is the use of strong interdisciplinary methods to examine the phenomena of interest. Chapter 5 uses the Edwards method, an approach borrowed from demography that is the most commonly used technique for analyzing seasonality.^{56,68} I selected this method by reviewing the variety of analytic techniques used in studies of cyclical effects.^{56,151} Several possible techniques emerged, including the Lorenz curve, the Edwards method, Cave and Freedman's approach, decomposition, or simultaneous modeling (e.g., ARIMA). I was able to eliminate some of these options based on the

constraints of the data (i.e., observations available for only 60 time points, which precluded analysis with decomposition or simultaneous modeling) and expectations about the form of the cyclical effects based on the pilot data from North Carolina (i.e., a curve with only one maximum and one minimum per year, which precluded analysis with Cave and Freedman's approach). Of the remaining options, I discovered that the Edwards approach was not only the canonical technique for this sort of analysis but it would also provide me with rich data on the magnitude and timing of cyclical effects. Taken together, these advantages convinced me that the Edwards approach was the ideal analytic technique for examining cyclical patterns in adolescent vaccination.

I used bootstrapping to test for mediated effects in Chapter 6, a cutting-edge technique recommended by methodologists.¹²⁴ Bootstrapping is preferred over techniques such as the Sobel test or the Baron and Kenny approach to examining mediation because it has the most statistical power and it reduces the possibility of Type I errors.¹²⁴ In addition, theories and frameworks informed the analytic plans, contributing to the larger body of scientific knowledge around default effects, patient-provider communication, and interactions across levels of the socioecological framework.

A third strength that cuts across these studies is their novelty. Although concomitant vaccination is an incredibly important behavior for public health,¹⁰⁹ very few empirical studies have investigated it. By describing some of the processes supporting concomitant adolescent vaccination, these studies will support future interventionists in developing programs to promote this behavior. In addition, Chapters 5 and 6 use longitudinal techniques to expand on previous studies of adolescent vaccination that mostly have implemented cross-sectional study designs. My research helps disentangle the temporality of the relationships

between school entry requirements, seasonal patterns in vaccination, and population-level vaccination coverage.

In terms of limitations, in all of the studies I was able to observe states' vaccination school entry requirements. Although my longitudinal studies (i.e., Chapters 5 and 6) examined temporality in the study relationships, third variables such as norms may drive the observed effects. For example, Rhode Island is in the process of adopting a school entry requirement for HPV vaccine, but it already has the highest rates of HPV vaccination among all U.S. states.¹¹⁸ Because HPV vaccine enjoys wide acceptance among people living in Rhode Island, adopting a school entry requirement was possible, while in other states, adopting such a policy may not be feasible. Because states do not randomly determine whether they should adopt a vaccination school entry requirement, I could not eliminate non-spuriousness in these relationships. A related limitation pertaining to school entry requirements was that I could not assess whether adolescents had moved to a different state in the time between vaccination and participation in NIS-Teen; although I evaluated school entry requirements in adolescents' state of residence at the time of survey participation, surely the requirements in the state where adolescents lived at the time of vaccination would be more salient to the processes under study.

A second limitation was reduced statistical power. Although the overall sample was quite large, analysis of monthly vaccination, within years and within states, was precluded by small cell sizes, especially for analyses of concomitant vaccination (which is by definition less common than uptake of individual vaccines). Dividing the sample among that many units posed too great a threat of deductive disclosure, and the National Center for Health Statistics (who reviewed my study plans and output) prohibited this analysis. As the NIS-

Teen sample accumulates, in future years I may be able to conduct the Edwards analysis in individual states and years for concomitant vaccination.

Third, the response rate for NIS-Teen is adequate but not optimal. Across the five study years, 73–85% of eligible households contacted by survey staff participated in the telephone interview. Of participating parents in these households, 72–77% consented to have NIS-Teen staff contact their adolescents' healthcare providers. Providers returned mailed questionnaires for 76–85% of adolescents. Altogether, 44–49% of contacted eligible households had complete, provider-verified data on participating adolescents. NIS-Teen staff attempted to ameliorate biases introduced by non-response by releasing survey weights for the subset of adolescents with provider-verified data (these were the weights I used in weighted analyses), but some possibility of bias remains.

In addition, the communication analysis faced additional limitations. Because of the retrospective, observational nature of the data, causal inference about the observed associations was not possible. I was not able to assess other beliefs or attitudes that may be pertinent to communication and vaccination such as vaccine hesitancy. Finally, the items under study did not assess whether more than one healthcare provider talked to parents about the adolescent vaccines, and thus I could not assess how these multiple conversations may have impacted vaccination.

Future Directions for Research

This dissertation research has inspired at least three lines of future research: delving deeper into factors that support concomitant vaccination, conducting more fine-grained analyses of the effects of different types of vaccine policies, and refining the study of communication style and vaccination. First, given the dearth of research on concomitant

vaccination, I am interested in evaluating the factors that predispose adolescents to this behavior. A preliminary step would be to establish the sociodemographic and healthcare correlates of receiving vaccines concomitantly, a study I could undertake with the NIS-Teen data. A next step would be to examine the influence of theoretically-informed constructs on concomitant vaccination (e.g., perceived likelihood of contracting a vaccine-preventable disease, a construct from the Health Belief Model that is associated with HPV vaccine acceptability⁸⁶). These studies would support the development of interventions designed to promote concomitant vaccination and increase overall levels of coverage.

Second, I am interested in exploring the variations in states' vaccination policies and their implications for both patient-provider communication and cycles in vaccination. I used a dichotomous measure to capture the presence of states' vaccination school entry requirements in Chapters 6 and 7, but other options exist, including measures of (1) attempted legislation, i.e., proposed vaccination policies that state legislatures may have opted not to adopt;³⁸ (2) policies requiring schools to educate parents on vaccination but do not require vaccine uptake;⁵² (3) enforcement of vaccination requirements, given that in policy and in practice consequences for violating the requirement vary across states;^{34,119,141} and (4) ease of exempting out of a vaccination requirement.^{123,140} All of these policies could have different effects on patient-provider communication and vaccination cycles.

Third, I hope to update the study of patient-provider communication style and vaccination in Chapter 7. Given that these data came from 2010, when vaccination rates were lower than in 2015 and the Advisory Committee on Immunization Practices had not yet recommended routine HPV vaccination for adolescent males,¹⁵ these relationships may have changed. In addition, primary prospective data collection would have greatly strengthened

this study. The items used in this analysis did not match perfectly the theoretical constructs under study, and they did not create a conceptually distinct reference category. Parents responded to these items by recollecting healthcare encounters that could have occurred up to four years prior to the NIS-Teen interview (from 2006, when ACIP introduced Tdap,¹⁵ to 2010, when data collection occurred). Revising and updating that study could provide more valid inferences about the effects of collaborative patient-provider communication on adolescent vaccination.

Conclusion

Concomitant adolescent vaccination has the potential to vastly improve coverage with vaccines that protect against tetanus, diphtheria, and pertussis; meningitis; and genital warts and cancers caused by human papillomavirus. In Chapters 5 and 6 (Aim 1), I demonstrated the large annual cycles in uptake of individual adolescent vaccines and in concomitant vaccination. These cycles existed across the United States, within states, and for each of the past several years, and they were even more dramatic in states with vaccination school entry requirements. Further, these summertime increases in vaccination were associated with improved vaccination coverage. In Chapter 7 (Aim 2), I reported that parents' recollections of collaborative communication with providers in discussions about adolescent vaccines were associated with a higher likelihood of uptake regardless of states' vaccination school entry requirements. Through this dissertation, I also pointed to potential future methods for increasing adolescent vaccination coverage, particularly through promoting concomitant administration. By anticipating and preparing for annual increases in vaccination during the summer months and exploring further the effects of providers' communication styles when

discussing adolescent vaccines with patients and their parents, clinicians and public health researchers can make progress towards achieving widespread coverage with these vaccines.

Footnote

The research in this dissertation was conducted while the author was a Special Sworn Status researcher of the U.S. Census Bureau at the Center for Economic Studies. Research results and conclusions expressed are those of the author and do not necessarily reflect the views of the Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed.

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