2016

Disparities in Arkansas Mandated Immunization Coverage Among Natural Home and Foster-Care Adolescents

Jerome Essono Ngundue
Walden University

Walden University

College of Health Sciences

This is to certify that the doctoral dissertation by

Jerome Ngundue

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. Chinaro Kennedy, Committee Chairperson, Public Health Faculty
Dr. Angela Prehn, Committee Member, Public Health Faculty
Dr. Kimberly Brownley, University Reviewer, Public Health Faculty

Chief Academic Officer
Eric Riedel, Ph.D.

Walden University
2016

Abstract

Disparities in Arkansas Mandated Immunization Coverage Among Natural Home and Foster-Care Adolescents

by

Jerome E. Ngundue

MHSA, University of Arkansas, Little Rock, Arkansas, 2001

BS, Nuclear Medicine Technology, University of Arkansas for Medical Sciences, 1987

BS, Biology, University of Arkansas, Little Rock, 1987

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health

Walden University

November 2016

Abstract

Anecdotal evidence indicated vaccine coverage disparities among foster-care (FCA) and natural-home adolescents (NHA). Arkansas laws require 5 vaccines for school entry (FVSE) to prevent 9 common childhood diseases. The study problem was that Pulaski County, Arkansas adolescent birth cohort (PCABC) immunization rates were low compared to U.S. adolescents for these FVSE. This study examined the extent to which (1) PCABC immunization rates were significantly different from those estimated for U.S. adolescents in 2006–2008, (2) NHA and FCA immunization rates were different in 2003–2008; (3) sociodemographic variables mediate associations between home of residence (HOR), NHA or FCA, and up to date (UTD) status for FVSE; and (4) vaccination game theory (VGT) estimated deaths differ between individual-equilibrium and group-optimum behaviors. The methodologies applied were direct standardization, χ^2, multiple logistic regressions, and VGT to analyze PCABC retrospective secondary data from the Arkansas immunization registry. The results revealed that U.S. adjusted UTD coverage rates for Hepatitis B, measles-mumps-rubella, and varicella were greater than those for PCABC. Race-adjusted FCA immunization rates were 120% higher than for NHA. Race mediated the association between HOR and UTD FVSE status, and African Americans had 80% greater odds of being UTD with FVSE compared to Caucasians. Group-optimum behavior was associated with fewer estimated deaths than individual equilibrium; thus, it is protective against disease outbreaks. Positive social change may occur among the PCABC when healthcare providers include these results in communications with parents at FCA and NHA community health clinics. Parental vaccine acceptance for their children may increase vaccinations and improve PCABC health and wellness.

Disparities in Arkansas Mandated Immunization Coverage Among Natural Home and Foster-Care Adolescents

by

Jerome E. Ngundue

MHSA, University of Arkansas, Little Rock, Arkansas, 2001

BS, Nuclear Medicine Technology, University of Arkansas for Medical Sciences, 1987

BS, Biology, University of Arkansas, Little Rock, 1987

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Philosophy

Public Health

Walden University

November 2016

Dedication

This dissertation is dedicated to my Almighty God and Creator for his gifts, talents, and blessings that lifted me throughout this scholastic journey.

To Jesus Christ, my Lord for His guidance, endurance, and mercies, that allowed me to grow and become a servant leader.

To my father, who for his tireless work and contributions, educated and inspired young minds.

I am extremely grateful to my father, Justin Ngundue, and mother, Justina Ngundue, for the life they gave me and instilled the value of knowledge and education at an early age.

I want to thank my family for their unconditional love, and prayers.

To my wife, Sarah, who provided encouragement, selfless patience, love, kindness, and understanding. To my children: To Bijoux Comfort, who always reminded me to stay the course with hope and faith and commitment. To George Akama and Edward Moki, who devoted their time, service, research support, loyalty, and focused discussion. To Elizabeth and Cassandra who dedicated their graces, faith, and prayers. To my granddaughter, Cecelia Rose, who is our hope, joy, and gift. I warmly appreciate their generosity, kindness, commitment, and dedication to the success of this scholastic work.

It is with humble acceptance that we progress with the endurance of Jesus Christ who replenishes us every day.

Acknowledgments

I wish to humbly express my profound appreciation to everyone who contributed to this destination, for this journey made us one journey. I owe my gratitude to all these dedicated colleagues, friends, parishioners, and family who have made this dissertation possible in every way imaginable. This was a journey of many in several stages for the support of the single name that appears on the cover of this dissertation. So many voluntarily and patiently gave much dedicated work and time.

I humbly and graciously express my pietistic gratitude to Dr. Chinaro M. Kennedy (fondly referred to as Dr. K), who encouraged, lifted my spirits, and kept a sense of scholarly dedicated humor when I had lost mine. Dr. K devotedly had faith in my abilities and raised the standards beyond the limits of my endurance. Dr. K's selfless time and care were always all that kept me focused during every phase of my work. I sincerely thank my committee member, Dr. Angela W. Prehn, for seraphic, constructive reviews, feedback, and guidance in developing my dissertation and academic authority. I express appreciation to Dr. Kimberly Brownley, who rigorously reviewed this research and offered precise additional contributions. So many professors patiently gave a great deal of dedicated work; especially my devoted dissertation committee chair, Dr. Kennedy, and committee member, Dr. Prehn.

I especially express my heart-felt gratitude to Dr. Leonard Mukasa, Dr. Haytham Safi, and Dr. Barbara Fuhrman who closely worked with and inspired me during the entire dissertation journey. I wish to thank Dr. Dirk Haselow for his guidance through the science advisory committee and institutional review board process at Arkansas Department of Health. I am thankful to Dr. Gary Wheeler who shared his experiences and

publications. I acknowledge Dr. Joseph Bates, chairperson, Dr. Nate Smith, Dr. William Mason, Dr. Namvar Zohoori, Dr. Gary Wheeler, and the entire science advisory committee members of the Arkansas Department of Health.

I wish to thank LaTonya Bynum, Sabra Miller, Ms. Tsai Mei Lin Tsai, Dr. Howraa Al-Mousawi, Dr. McGehee, and Dr. Morgan for their guidance in the health records and vital statistics data-link process. I want to express my gratitude to Dr. Sherri Tucker, who reviewed several drafts of Chapter 2 of my dissertation. I thank Ms. Greta Kilmer for helpful reviews, advice, suggestions, and comments on the statistical analyses.

I am also indebted and thankful to my pastor, Rev. Monsignor Malone, for his spiritual counsel; Dr. Greenway, and the deacons for their moral and spiritual advice. I also want to thank my church community and several special parishioners including Ms. Lydia Antonez, Ms. Terry Crow, and Dr. Maryelle Vonlantha who always tirelessly prayed during my difficult times. I could not have completed the doctoral program without their generous moral encouragement and support. I offer profound appreciation to Ms. Ernestine Russ-Williams and Dr. Raymond Ortega for their approval of financial support from the Veterans Administration. The approval funded part of this dissertation to completion when my student loan funds were exhausted.

Finally, I warmly appreciate the generosity, commitment, and understanding of my family, extended family, friends, and colleagues for all their encouragement.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction to the Study

Introduction

This dissertation examined the association between adolescent home of residence (HOR) and vaccination coverage uptake among the 1990 birth cohort in Pulaski County, Arkansas (PCA). In this study, adolescent vaccination behavior and disparity in vaccine coverage uptake were important and significant links in the resurgence and outbreaks of previously controlled or eradicated childhood vaccine-preventable diseases (VPDs; Centers for Disease Control and Prevention [CDC], 1999b; Immunization Action Coalition [IAC], 2012). Immunization rates for adolescents aged 13 to 19 years were low compared to childhood and adult immunization rates (CDC, 2008a; Mahon, Shea, Dougherty, & Loughlin, 2008). Adolescent vaccine coverage uptakes were also below coverage levels for those vaccines administered routinely in childhood (CDC, 2010a; IAC, 2011). I used vaccination game theory (VGT) to further explore and identify risk factors that influenced the five school-entry vaccine coverage uptakes among the 1990 birth cohort in PCA.

The five vaccines for school entry (FVSE) examined in this dissertation are tetanus-diphtheria/tetanus-diphtheria-acellular pertussis (Td/Tdap), hepatitis B (Hep B), measles-mumps-rubella (MMR), poliomyelitis (OPV/IPV), and varicella (VAR, chickenpox). FVSE in Arkansas are required and mandated by Arkansas law (Arkansas Department of Health [ADH], 2008; Jackson, 1969). The Arkansas immunization registry (AIR) is the legal repository for reporting every administered vaccine from birth to age 22 years in Arkansas (ADH, 1995). Several counties in Arkansas reported that adolescent vaccine-coverage levels, especially for the FVSE, tended to be lower than the national

average (Safi et al., 2012). For example, PCA evidence showed that adolescent vaccine-coverage levels for FVSE were lower than the national average. It was unclear whether coverage levels were lower among certain groups of adolescents or whether they were lower among all age groups.

Differences emerged in vaccine coverage among adolescents in previous studies. For example, evidence suggested that children raised in nonparental-home settings were less likely to be up-to-date (UTD) on their preventive healthcare services compared to children in their natural home (Chu, Barker, & Smith, 2004; Darden, Gustafson, Nietert, & Jacobson, 2011). Immunization coverage is one preventive-health service that differed between foster-care and natural-home children (Chu et al., 2004; Darden et al., 2011). This dissertation further examined the vaccine UTD status of adolescents in the 1990 PCA birth cohort from 1990 to 2008.

Increased numbers of cases of vaccine-preventable disease among adolescents in Arkansas were a public health burden and concern. VPD outbreaks and resurgences in Arkansas aligned with underimmunization and low-immunization coverage (Haselow, 2014). These VPD outbreaks among adolescents continued to increase in several counties in Arkansas between 2012 and 2014 including Pulaski, Faulkner, Lonoke, Saline, and White Counties (Haselow, 2014). In 2012, 248 pertussis cases emerged compared to 467 pertussis cases in 2013. Similarly, 237 VAR cases emerged in 2012 compared to 249 VAR cases in 2013 (Haselow, 2014). Thus, given the resurgence of previously controlled (Chiappini, Stival, Galli, & Martino, 2013) or eradicated childhood diseases, it is important to examine whether vaccination coverage levels for the FVSE are at or below

coverage levels in PCA between two groups of adolescents: natural-home adolescents (NHAs) and foster-care adolescents (FCAs).

This dissertation has five major sections. The first section includes the background, purpose, significance, assumptions, delimitations, and social change implications of this dissertation. The second section is the literature review, which describes evidence from recent research studies on adolescent immunization coverage and factors that influenced vaccine-coverage levels. The focus in Chapter 3 is the dissertation methodology, whereas Chapter 4 presents data analysis and results. Finally, Chapter 5 of this dissertation presents the implications of the findings as well as recommendations.

Background

Measles-, mumps-, pertussis-, and VAR-outbreak resurgences continue to occur every year in the United States (CDC, 1998a; 2011a, 2011d, 2012g, 2015; Cherry, 2013; Gould et al., 2009; L. E. Lee et al., 2008; Lopez et al., 2006; Vitek, Aduddell, Brinton, Hoffman, & Redd, 1999; Wheeler, 2012). Counties in the southern portion of the United States have disproportionally high rates of VPD resurgence. Outbreaks of VPD negatively impacted public health departments' resources and contributed to societal burdens (California Department of Public Health Immunization Branch, 2012; Wheeler et al., 2004). Examples of societal burdens include economic stress from lost work productivity, school absenteeism, hospitalization, and outbreak-investigation resources and costs (Gould et al., 2009; Parker et al., 2006; Safi et al., 2012; Thompson et al., 2007; Wheeler et al., 2004).

Adolescent immunization rates are appropriate measures of societal burdens (Byrd, Santibanez, & Chaves, 2011; Safi et al., 2012; Thompson et al., 2007). These metrics emerge through declining shifts in public trust, parental attitudes toward immunizations, and resurgence of VPD (Atwell et al., 2013; Darden et al., 2013; Dorell, Jain, & Yankey, 2011). Although vaccines have contributed to an overall decline in morbidity and mortality in society (CDC, 1998b, 1999b, 2007a), immunization rates among adolescents in PCA are consistently below nationally established immunization indicators (IAC, 2010; U.S. Department of Health and Human Services [USDHHS], 2010c).

The 1990 birth cohort PCA study determined differences among NHA and FCA immunization rates for FVSE. Arkansas immunization laws (AILs) require adolescents to complete all dose series of FVSE prior to age 18 years or before completing high school (ADH, 1993, 2004a; Bugenske, Stokley, Kennedy, & Dorell, 2012). Evidence from peer-reviewed research indicated that adolescents in their natural-home environments are more likely to be UTD on their vaccination status compared to adolescents in foster care (Chu et al., 2004; Darden et al., 2011). Thus, in Arkansas, where universal vaccination coverage averaged lower than national coverage (CDC, 2011d), it was important to determine whether disparities in vaccination coverage existed between NHA and FCA children.

The importance of calculated differences in immunization rates between the two groups established evidence for school-entry immunization-focused compliance interventions. Access to health care, insurance status (Smith, Stevenson, & Chu, 2006), immunization fragmentation of services, multiple providers, and sociodemographic

factors contributed to differences that affected immunization coverage in both groups (Smith, Singleton, & National Center for Immunization and Respiratory Diseases, 2011). I calculated immunization rates for each group and compared results to identify any differences in FVSE immunization rates and UTD status between NHA and FCA among adolescents in PCA.

Arkansas Department of Health (ADH) and Advisory Committee on Immunization Practices (ACIP) criteria established cohort immunization-coverage rates for NHA and FCA. The Arkansas Department of Human Services (ADHS) required immunization for all children in foster care as part of FCA-mandated medical care under Medicaid regulations (ADHS, 2007, 2013). The criteria used to determine the percentage of adolescents with complete vaccination UTD status for FVSE were based on Arkansas Adolescent Immunization Rules and Regulations (see Appendix A, Table A1). Finally, I compared the calculated immunization rates for the 1990 birth cohort for the FVSE to U.S. national adjusted adolescent immunization rates for the same FVSE.

Purpose

This quantitative study had three main purposes. First was to examine differences in vaccine coverage for FVSE between PCA and their corresponding birth cohort in the United States. The second purpose was to examine differences in adolescent vaccine coverage for FVSE between NHA and FCA. Third, I calculated the costs and risks associated with vaccine payoff for the FVSE for individual and group behavior choices for the 1990 birth cohort, modeled on VGT (Bauch & Earn, 2004). This study was one of the few studies focused exclusively on an FCA and NHA birth cohort in PCA adolescent immunization rates.

Parental attitudes, environmental factors, social distancing, and clinical reasons emerged as risk factors that adversely impacted immunization rates in this study. Parental attitudes (Omer, Richards, Ward, & Bednarczyk, 2012; Opel et al., 2013) and clinical reasons arose for adolescent disease prevention (CDC, 2009a). Adolescent immunization behaviors related to social distancing (Reluga, 2010; Sawyer, Carbone, Searle, & Robinson, 2007). Social-congregating impacted resurgence of VPDs including pertussis (Wheeler et al., 2004) and VAR (Gould et al., 2009) in Arkansas. Understanding immunization rates in a cohort supported compliance strategies to achieve 90% protective coverage in herd immunity (CDC, 2009b; McElligott et al., 2012). It was important to establish evidence to increase or maintain immunization rates required by Arkansas law in compliance with public health and safety.

Arkansas vaccination-compliance expectation was that school administrators and school nurses would gain an understanding of the magnitude of adolescent immunization-rate disparity in PCA. I analyzed 1990 birth cohort records in the Arkansas immunization registry database (AIRD) quantitatively and established differences among the 1990 cohort immunization-rates uptake coverage and UTD status. The study design focused on FVSE disparities among adolescents based on HOR—NHA and FCA—gender, race, and ethnicity in the 1990 birth cohort for PCA. The positive social impact of improved immunization coverage and UTD status were increased life expectancy (CDC, 1999c) and reduced burden of hospitalization, disability, and deaths from VPD outbreak and resurgence (Cooper, Larson, & Katz, 2008).

Significance

The significance of this study was the ability to examine and establish differences in adolescent vaccination-coverage level between two groups of adolescents—NHA and FCA—living in PCA. Second, the study predicted estimated risks in payoff deaths associated with vaccine behavior among NHAs and FCAs in the 1990 birth cohort in PCA. Given evidence that vaccine coverage levels tend to be higher among NHAs compared to FCAs (Smith, Santoli, Chu, Ochoa, & Rodewald, 2005), it was important to examine whether this disparity also existed in PCA. Further analysis also explained whether HOR was a driving force behind disparities in adolescent vaccine-coverage levels for FVSE in PCA.

The importance of examining disparities in vaccination coverage between NHAs and FCAs relates to primary prevention and the benefits of improved childhood and adolescent wellness (CDC, 1999d, 1999g; Shefer et al., 1999; USDHHS, 2009). Improvements in immunization coverage between NHAs and FCAs helps maintain good health, extend life expectancy, and reduce risk and exposure to VPDs. School absenteeism and poor student performance align with disease outbreaks (Davis, King, Moag, Cummings, & Magder, 2008). Immunization rate, vaccine coverage, and UTD status are national health indicators and surveillance tools for community health (CDC, 2006a; USDHHS, 2010d). Immunization UTD status is a preventive health behavior (Bauch, Galvani, & Earn, 2003). Being current on vaccines aligns with the conduct of other clinical preventive services in a community (USDHHS, 2009), and helps measure the robustness of a preventive clinical healthcare system (Rodewald et al., 1999).

Immunization UTD status was the main outcome variable in this analysis to establish immunization rates among the 1990 birth cohort in PCA.

Problem Statement

The research problem was that reported immunization rates and uptake coverage for the routinely required FVSE among adolescents in PCA were persistently low compared to the U.S. average (CDC, 2012e). For example, PCA immunization rates were 20–40% lower compared to the U.S. national average for adolescents (CDC, 2010a). Why this difference existed was uncertain, especially because FVSE were mandatory in PCA. However, one reason this difference existed was adolescents' home setting. Differences in home setting partially explained this disparity (Zhao & Luman, 2010) in that preventive health services differed between adolescents who lived in the natural-care setting and those in foster care.

This study examined vaccine-coverage disparities between NHAs and FCAs. Vaccine-coverage disparities among adolescents aligned with fragmentation of immunization services (Darden et al., 2011). Adolescents who lived in stable parental-care environments and had a single medical home (Smith, Santoli, et al., 2005) had less fragmentation in immunization services (Darden et al., 2011). High-risk adolescents, such as FCAs, often resided in group-home environments. These high-risk adolescents had multiple providers and multiple facility types for their immunization services (Darden et al., 2011; Smith et al., 2011). Adolescent group homes included behavior-treatment facilities, juvenile correctional facilities, incarcerated housed adolescents, homes for persons experiencing homelessness, and institutionalized juveniles (Smith et al., 2011). In this study, FCAs were preidentified among the 1990 birth cohort for PCA.

I calculated and reported the 1990 birth cohort immunization rates for PCA in this study. Since 2006, Arkansas adolescents' reported immunization rates have been 15–20% lower than U.S. national averages for FVSE (CDC, 2012e). Adolescent immunization rates of 90% or greater were essential to reduce risk of diseases (Glanz et al., 2010; Healthy People 2010, 2011; USDHHS, 2010c). Community immunity was maintained through immunization rates greater than 90% uptake coverage, as established in Healthy People 2020 (McCauley, Stokley, Stevenson, & Fishbein, 2008; USDHHS, 2010a). I compared calculated immunization rates for the 1990 PCA birth cohort to Healthy People 2020 immunization standards to determine compliance or disparity.

Research Questions and Hypotheses

RQ1: Are the calculated 2006–2008 adolescent percent vaccination uptake (VCU) rates for FVSE among the 1990 birth cohort in PCA (PCABC) significantly different from the reported FVSE 2006–2008 U.S. national adolescent estimated immunization rates?

H_o1: There is no difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent national immunization teen (NIS-Teen) estimated percent VCU for the FVSE.

H_a1: There is a difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent NIS-Teen estimated percent VCU for the FVSE.

RQ2: Are there differences in percentage of FVSE vaccine coverage uptake between NHA and FCA among adolescents in the 2003–2008 PCABC?

H_o2: There is no significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

H_a2: There is a significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

RQ3: Is the association between HOR, defined as NHA and FCA, and UTD FVSE coverage mediated through sociodemographic characteristics, which include age, race, ethnicity, and gender in PCABC?

H_o3: The associations between HOR, defined as NHA or FCA, and UTD FVSE in PCABC is not mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

H_a3: The associations between HOR, defined as NHA or FCA, and UTD FVSE in PCABC is mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

RQ4: Will differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, affect group interest, measured by deaths as a result of nonvaccination for the FVSE among the 1990 PCABC?

H_o4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will not affect group interest, measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

H_a4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will affect group interest,

measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

Theoretical Construct

Theory of games (TOG; von Neumann & Morgenstern, 1944), as used in this study, enhanced understanding of how individual vaccine behavior affected the group interest. I used the TOG to model individual decisions to receive vaccination and its impact on the group interest. One feature of this vaccine-modeling construct was to examine how the impact of vaccine uptake related to vaccine payoff deaths (Bauch et al., 2003). The TOG (von Neumann & Morgenstern, 1944) and VGT application (Bauch et al., 2003) offered important modeling for adolescent immunization actions, choices, or behaviors to maximize or minimize payoffs (Jackson, Leyton-Brown, & Shoham, 2015). The hallmark of the TOG (von Neumann & Morgenstern, 1944) and VGT application (Bauch et al., 2003) was to use mathematical models to predict how an individual's decision to receive vaccine affected and compared to the outcome of group interests. Appendix B contains tables with VGT equations and calculations. Immunization acronyms are defined in Appendix C. In this study, 1990 PCABC immunization rates predicted outcomes. In the 1990 birth cohort, mathematical models determined how individuals' self-interest decisions to vaccinate, called individual equilibrium in the model, affected the group's altruistic interest, and called group optimum. I calculated the group interest as the cost of individuals who preemptively received vaccination and measured the cost by the number of adolescents in the cohort who were expected to die due to the failure of individuals to receive vaccination.

Another important feature of the game-theory construct was its relationship to community or herd immunity and the payoff from not receiving vaccination. If a community had immunity as a population, then theoretically, the ability of that disease-causing agent to cause disease diminished because the agent was no longer active or present in the population (Baguelin et al., 2013). Community or herd immunity in a community increased through population decisions to vaccinate (Barclay et al., 2014; Domenech de Cellès, Riolo, Magpantay, Rohani, & King, 2014; Shim, Kochin, & Galvani, 2010; Shim, Meyers, & Galvani, 2011), thereby improving disease prevention and minimizing deaths associated with VPDs (Arinaminpathy et al., 2012; Blackwood, Cummings, Broutin, Iamsirithaworn, & Rohani, 2013). Likewise, herd immunity could impact an individual's decision to receive vaccination. I examined this notion when I applied the mathematical constructs in the data analysis derived from VGT.

Nature of the Study

This cross-sectional study used quantitative methods to examine differences in adolescent vaccine coverage rates between NHAs and FCAs using the 1990 birth cohort immunization records in PCA. Additionally, I modeled individual vaccine uptake behaviors for the FVSE among NHAs and FCAs, and its impact on the group interest.

Definitions

The 1990 birth cohort defined all children born between January 1, 1990 and December 31, 1990 in PCA. I subdivided this 1990 birth cohort into a control group, NHA, and a research group, FCA. The NHAs were never under Arkansas child protective services as wards of the State of Arkansas mandated by judicial court orders. FCAs were wards of the State of Arkansas, mandated by judicial court orders until age 18. The age of

18 years was a significant factor because this was the cut-off age for enrollment in foster-care services, graduation from high school, and adolescent status for immunization.

Age-appropriate vaccine status: The correct age in months or years at which a specific vaccine must be administered (Dombkowski, Harrington, Hanauer, Kennedy, & Clark, 2012; Schempf, Minkovitz, Strobino, & Guyer, 2007).

Arkansas immunization laws: Mandated age, grade, and specific types of vaccines are defined in Table II of the Arkansas Immunization Rules and Regulations (AIRR) established by Arkansas Board of Health (ADH, 2008).

Arkansas immunization registry (AIR): Mandated by AIL in 1995; AIR is the legal repository for all reported and administered vaccines for all children in Arkansas (Arkansas Legislative Branch [ALB], 1995a).

Five vaccines for school entry (FVSE): The FVSE were Td/Tdap, Hep B, MMR, OPV/IPV, and VAR (ADH, 2008).

Foster-care adolescent (FCA): An adolescent up to age 18 years who does not live in their natural or adoptive parents' residence and is under court-ordered judicial protective care, supported through ADHS control (ADHS, 2010).

Group optimum: The group optimum is the level of maximum vaccine coverage that is best to protect the entire population against a VPD (Bauch et al., 2003).

Immunization disparity: Deficiency in a specific type and specific number of doses for vaccines that fail to achieve 90% uptake of a routinely recommended vaccine dose, established in Healthy People 2020 (USDHHS, 2010a).

Immunization rate: The proportion of vaccines in a dose series received by children, as prescribed in ACIP immunization schedules (CDC, 2007b, 2012k).

Individual equilibrium: Individual equilibrium focuses on maximizing self-interest benefits from an outcome and minimizing the probability of the associated cost of the outcome (Bauch & Earn, 2004; Bauch et al., 2003; von Neumann & Morgenstern, 1944).

Natural-home adolescent (NHA): Adolescents who live with their natural or adoptive parents, have never been in child protective services, and attended public schools from 1996 to 2008 in PCA (ADHS, 2010).

Payoffs: The benefit of receiving a vaccine, quantified by the number of deaths prevented by vaccine receipt.

Routinely recommended vaccines: U.S. Food and Drug Administration licensed vaccines recommended by ACIP (CDC, 1999c; CDC, 2007c).

Strategy: Strategies, which include vaccination, delayed vaccination, or no vaccination, are deliberate choices, actions, behaviors, or decisions employed by individuals or groups to achieve a desired outcome or payoff (Bauch et al., 2003; Chaves et al., 2008; Meyer, Seward, Jumaan, & Wharton, 2000; Reluga & Galvani, 2011; Shim, Chapman, & Galvani, 2010).

Up-to-date status (UTD): The current vaccination-series completion of actual specific vaccine types and total number of doses in the series received at a given age and calendar date. The UTD is important for vaccine-series next-dose administration, disease exposure, and risk at time of an outbreak (Dombkowski, Lantz, & Freed, 2004b).

Vaccination status: The recommended specific vaccine type and total number of doses received up to a particular given age (CDC, 2008b; Hinman, Orenstein, & Schuchat, 2011).

Assumptions

This study retained four assumptions based on Arkansas vaccine requirements:

- Assumption 1: Each child received all age-appropriate vaccines, from birth to age 18 years, and required vaccines during each school-grade milestone. Children who received childhood doses could not have completed the vaccine-dose series or received the booster dose. Adolescents refused vaccine and immunization exemptions based on philosophical, religious, or personal reasons (ADH, 2003; Arkansas State Board of Health, 2003).
- Assumption 2: Students were 6 years old in the first grade in 1996 and progressed regularly each year to the 12th grade. Further, Assumption 2 included that a fourth-grade student was 10 years old in 2000 and progressed to seventh grade at the age of 13 in 2003.
- Assumption 3: NHAs and FCAs progressed equally through similar public school systems in PCA and graduated from high school in 2008.
- Assumption 4: NHAs' and FCAs' school attendance data were collected by October 15th each year from all school districts and systems in PCA. The 1990 cohort school-attendance data were reported annually to the Arkansas Department of Education (ADE). For example, in 2002, PCA had 4,134 adolescents aged 12 in the sixth grade in all public schools. This study examined the cohort as they progressed to the next grade until age 18 years as a unit block (FCA enrollment appears in Appendix A, Table A5).

Scope and Delimitations

The scope of this study was adolescent immunization status in a 1990 birth cohort of all children born between January 1, 1990, and December 31, 1990, in PCA. The study's delimitation also includes all children who attended public schools from kindergarten through 12th grade between 1996 and 2008 (ADE, 2009). Delimitations in this study included those aged 13 to 18 years, defined as adolescence, the population size of the study population, school attendance, parental control, and geography in PCA. I subdivided the age of adolescents in the 1990 birth cohort into the control group, NHA, and the study group, FCA. The delimitation focus was adolescents who were 13 years old in 2003 and born in PCA. The focus followed each year for vaccines received and reported to the AIR until age 18 years, in 2008 or upon graduation.

The study population size and study population denominator consisted of five inclusion criteria in the 1990 birth cohort. These criteria were (a) FCAs enrolled under ADHS control under judicial court orders; (b) NHAs who lived with their parents; (c) types of vaccines, all five vaccines with number of doses with documented records in the AIR; (d) attended public schools in PCA; and (e) in the geographic contiguous borders and zip codes in PCA.

Limitations

AIR data contained several internal validity issues associated with many types of errors and reporting of immunization information. I excluded incomplete or mismatched records from the data analysis to minimize internal-validity limitations and unreliable results. Duplicate doses of the same vaccine were not included in immunization-rate calculations, based on the criteria delineated in Appendix A, Table A1. Incomplete

transmission of immunization records during reporting to the registry are common limitations in immunization-registry data (Stevenson et al., 2000). Electronic records and hard-paper reporting systems have limitations in transmission, formatting, standardization of documentation, and legibility of documents (CDC, 2000b; Stevenson et al., 2000).

The registry data was built from health-provider documented and reported immunization histories of individually administered vaccines (CDC, 2001; Khare et al., 2000). Consequently, the accuracy and completeness of the immunization histories and eliminating significant errors in child's name, date of birth, vaccine types, no data reported, and overall duplicate records are important in calculating coverage estimates (Khare et al., 2000). Early enrollment of children into the registry from birth, when Hep B globulin was administered, enhances accuracy of the registry data. The CDC (2000c) recommended early enrollment, within 2 months of birth for each newborn child.

PCA adolescent immunization-result generalizability is significant to the external validity of this immunization study. Adolescent immunization results from this study are generalized and limited to PCA, and did not include the entire Arkansas population or other populations. Researchers and future users may draw inferences to influence policy, awareness, knowledge, and social-marketing campaigns. However, my interpretations of the results are applicable and specific to adolescents in PCA.

Social-Change Implication

The social-change implication relates to primary prevention of VPD among adolescents (CDC, 1999c; Shefer et al., 1999). The social-change impact of understanding adolescent immunization uptake is valuable in public health functions. Improving immunization coverage among NHAs, FCAs, or other adolescents will

enhance their quality of life and life expectancy (CDC, 1999c) and reduce frequency of VPD outbreaks (Schaffer, Gillette, Hedberg, & Cieslak, 2006). The outcome of this study may influence five societal levels of social change: individual, institutional, organizational, community, and policy.

Parents and adolescents of PCA constitute the individual level and are the primary target for social change. Because of results from this study, evidence of change in this group includes increased immunization knowledge, awareness, and positive attitudes toward immunization uptake. The second societal level likely to be impacted by findings from this study is the institutional level, comprised of school nurses in public schools in PCA whose focus is immunization compliance of FVSE. I include physicians and public health agencies in the organizational level, as their health practices influence adolescent behavior and access to immunization services. Community-level supports are cultural norms, attitudes, and availability of professionals and organizations that provide immunization services.

The final level that findings from this study impact is the policymaker level. Policy-level change influences financing and eligibility criteria, as well as rules and regulations associated with adolescent immunization coverage. Arkansas' major policy stakeholders include the Arkansas Departments of Education, Health, and Human services. The specific role of these departments influences policy change.

Findings from this study potentially will benefit parents through increased immunization awareness and will support compliance with school-entry laws. This positive immunization chain effect could also benefit future populations through increased herd or community immunity. Results from this study identified disparities

among vaccines with low coverage among adolescents in the 1990 PCABC. The identified immunization disparity data stimulated innovative communication methods in the community to address parental vaccine safety and efficacy concerns in PCA.

Summary

Four research questions were cogent to examine whether disparities in FVSE vaccination coverage existed among a birth cohort in the archival AIRD. The first research question was pertinent to determine if a difference ensued between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent NIS-Teen estimated percent VCU for the FVSE. In the second research question, I examined if differences emerged in percentage of FVSE vaccine coverage uptake between NHAs and FCAs in the 2003–2008 PCABC. Third, I examined if the association between HOR, defined as NHA and FCA, and UTD FVSE coverage mediated through the sociodemographic characteristics of age, race, ethnicity, and gender in PCABC. With the fourth research question, I examined game-theory mathematical models to determine if individuals' decisions to receive vaccine for the FVSE affected the group interest.

The social-change implications maintain or improve awareness and understanding of FVSE vaccination coverage among NHAs and FCAs in PCA. Vaccines align with benefits of improved childhood, adolescent wellness, and public health (CDC, 1999c; Shefer et al., 1999). For this quantitative study, I used a cross-sectional study design, analyzed archival AIRD, and examined disparities in vaccine coverage for FVSE among NHAs and FCAs in PCA.

The next section is the literature review in Chapter 2. The literature review contributes detailed focus on published research on vaccination coverage, providing information on how vaccinations influenced disease elimination, resurgence, outbreaks, prevention, and control. The literature review further probes the theoretical basis for relationships between immunization behavior and negative consequences of low-immunization rates. The key sections in this literature review included the search methods as well as the identification of gaps in the literature. Specific issues discussed in the literature review that relate to gaps in the literature include the economic burden associated with disease outbreaks, loss of workdays, school closings, and disability and mortality related to VPD.

Chapter 2: Literature Review

Introduction

Immunization rates among adolescents in Arkansas were disproportionately lower than the U.S. national average for routinely recommended vaccines and FVSE required for adolescents (ADH, 2014a; CDC, 2010d). The adolescent-vaccination-coverage uptake was a significant component in this study. The purpose of this cross-sectional study was to establish quantitative vaccine UTD status for the FVSE among the 1990 PCABC of NHAs and FCAs. The literature review focused on peer-reviewed articles, textbooks, and publications on the TOG, immunization rates, adolescent-vaccinations uptakes, laws, disparities, disease outbreaks, and resurgence.

Literature-Search Strategy

I accessed and retrieved published research articles from physical library and online databases. Peer-reviewed journals, reports, and bulletins from online databases accounted for more than 90% of the information used in this study. Examples of these databases included PubMed, Clinic Trials.gov, Cochran Library, Healthy People, The Community Guide, World Health Organization (WHO), and Global Health. The search strategy consisted of key words, databases, search engines, and retrieved articles from more than 5,000 published articles dated during the 5 years between 2008 and 2013. These key words included *names of nine communicable and childhood diseases; Diphtheria, hepatitis B, measles, mumps, pertussis, poliomyelitis, rubella, tetanus, and varicella, vaccines, adolescents, immunization, vaccine rates, schedules, vaccine preventable diseases, disease outbreaks, resurgence and prevention, foster care*

adolescents and health, natural home adolescents and health, school entry laws, vaccine rules, regulations, adverse events, Pulaski County, Arkansas, and *immunization registry*.

The second search strategy of databases and search engines included the ALB, ADH, CDC, WHO, and Pub-Med indexed publications. Searches included public and private universities, the legislature, professional associations, and industry websites using immunization categories such as articles, reports, policies, press releases, and bulletins. Other databases were accessible through their websites with registered authorization, user identification, and a password. The ALB (2012) website yielded legislative reports and 34 immunization laws enacted between 1987 and 2009. The third search strategy required physical access to documents at the ALB library and Arkansas State Board of Health archives. Immunization laws enacted before 1987 were not initially available on the ALB website. I physically accessed and retrieved pre-1987 immunization laws from bounded legislative historic archives at the Arkansas State Capitol in Little Rock, Arkansas. These pre-1987 immunization laws were significant foundations for AILs that affected 1990 birth-cohort-immunization rates. Arkansas immunization laws relevant to this study were enacted between 1987 and 2009 and are listed in Appendix A., Table A2. I also physically accessed and retrieved other Arkansas historic immunizations reports and State Board of Health documents archived at ADH headquarters in Little Rock, Arkansas. Archived records from Arkansas Board of Health meetings provided important information on childhood- and adolescent immunization rates.

Background

School-entry vaccine mandates were one of the six key areas of concern identified in 2008 National Vaccine Advisory Committee (NVAC) recommendations. NVAC

(2008) recommendations addressed challenges in adolescent immunization. Immunization rates among adolescents in the 1990 PCABC were lower compared to adolescents nationally (ADH, 2012c; CDC, 2010c). The major focus areas within the scope of this study included coverage uptake rate and UTD status among adolescents in the 1990 PCABC and FVSE. Immunization barriers, behavior risk factors, parental knowledge, and access to vaccines were challenges that contributed to low adolescent-vaccine-coverage uptake (CDC, 2005b; Washington State Department of Health, 2012). Similar immunization challenges persisted among adolescents in the 1990 PCABC, in spite of 2008 NVAC (2009) recommendations and the 1977 National Childhood Immunization Initiative. These challenges were in five key areas: venues for vaccine-administration consent for immunization, communication, financing, surveillance, and the potential for school mandates (CDC, 2011f; NVAC, 2008, 2014; Stokley et al., 2009). The U.S. national goal for minimum vaccination achievement has been 90% for all children since 1977 (CDC, 1982, 2009d). School-entry vaccine mandates contributed and aligned with increased high childhood-vaccination-coverage rates and low rates of VPDs (Hinman, Orenstein, Williamson, & Darrington, 2002; Orenstein & Hinman, 1999). Vaccine contributions and achievements of public health, concepts of routine vaccination for children (Hamborsky, Kroger, & Wolfe, 2015), and continued outbreaks of VPD in recent years accounted for three significant and relevant challenge areas related to adolescent immunization coverage uptake.

Vaccination and Public Achievements

Vaccinations were one of the 10 greatest public health achievements during the 20th century and the first decade of the 21st century (CDC, 1999h, 2011k). Vaccines

were fundamental cornerstones in preventing mortality from disease outbreaks (Schaffer et al., 2006), and increasing life expectancy (CDC, 1999c). During the 1950s, infant-mortality rates improved in the United States, decreasing from 29.2 deaths per 1,000 live births to 7.1 deaths per 1,000 live births (CDC, 1999c). For example, in 1950, 33,300 polio cases and 1,904 deaths ensued, compared to six cases and no deaths in 1990 (CDC, 2011e). Vaccine-uptake coverage increased during the 20th century, eradicating smallpox in 1971 in the United States, and globally in 1980 (IAC, 2012). The trend in increased immunization rates among children and adolescents during the 20th century contributed to elimination of four major childhood diseases: measles (CDC, 2009e, 2009f; WHO, 2013), neonatal tetanus, OPV/IPV (CDC, 200g), and rubella congenital syndrome (CDC, 1999e; USDHHS, 2010e).

Routine Vaccination for Children

Childhood vaccines were cost effective in disease prevention, reducing the burden of morbidity (ADH, 2014b), infant mortalities, and disabilities associated with diseases such as poliomyelitis (CDC, 2009c; Salk, 1955a). Public support for vaccination increased during the 1950s when VPD outbreaks (Santoli et al., 2004; Washington State Department of Health, 2012) and epidemics caused high rates of infant mortality (CDC, 1999e). Since 1967, AILs required vaccination against these highly communicable diseases including diphtheria, measles, pertussis, poliomyelitis, varicella, and more than nine childhood diseases from birth to age 22 years (ALB, 1967; CDC, 2010e, 2011g; Marin, Guris, Chaves, Schmid, S., & Seward, 2007; Vitek et al., 1999). School-entry regulations and immunization laws in Arkansas intended to increase immunization rates based on UTD requirements, shown in AIRR Table II (ADH, 2008).

Vaccine compliance for school-entry requirements prevented diseases and protected all children in daycare facilities, kindergarten to 12th grade, and college students (ADH, 1997, 2008). Similarly, immunization was a national health objective established by Healthy People 2000, 2010, and 2020 to increase childhood and adolescent immunization rates to reach the 90% threshold indicator (USDHHS, 2012). Furthermore, the ACIP annually updated immunization recommendations (Broder et al., 2006; CDC, 1991a, 2005a, 2006c, 2007c, 2008b) and schedules, ensured adequate UTD, increased immunization rates, standardized national immunization policies, and encouraged practices to prevent disease resurgence and outbreaks (CDC, 1991b, 1998c, 1999f, 2011h, 2013).

Access to Immunization

Given the potential disparity in vaccine coverage between NHAs and FCAs, it was important to examine access to immunization as a potential contributor to this disparity. The individual decision to vaccinate relates to self-interest (Galvani, Reluga, & Chapman, 2007; Ibuka, Li, Vietri, Chapman, & Galvani, 2014), actions of others (Hilbe, Nowak, & Sigmund, 2013; Meszaros et al., 1996), risk of infections, the perceived costs and benefits (Basu, Chapman, & Galvani, 2008), ethnicity and language preference (Haviland, Elliott,, & Hambarsoomian, 2011), and primary immunization access. Parents of adolescents who decided to vaccinate experienced lack of access to vaccines as another contributing immunization-barrier factor.

The Vaccine for Children's (VFC) program was a federal program intended to improve access to immunization for all eligible children (CDC, 1998d, 2011o, 2012c, 2012m; Lee et al., 2007). The VFC improved child and adolescent UTD status based on

ACIP recommendations, access to vaccines, and medical home (Smith, Santoli, et al., 2005) for vaccine. ACIP recommended children's UTD coverage (2012a) include more than four doses of Td/Tdap (Broder et al., 2006), more than three doses of OPV/IPV, more than one dose of MMR, more than three doses of haemophilus influenza type b (Hib), and more than three doses of Hep B (CDC, 2005a; Salk, 1955b; Salmon et al., 2009). Adolescents required two doses of VAR vaccine for school enrollment to improve waned immunity and reduce disease outbreaks (CDC, 2005b; Lopez et al., 2006).

Barriers to Immunization

Immunization barriers offered opportunities and challenges to vaccinated adolescents. Barriers included risk factors that contributed to potential challenges of low-immunization rates (Kaplan, 2010), and low coverage for the FVSE among children and adolescents. I based adolescent immunization barriers described in this study on the TOG construct (von Neumann & Morgenstern, 1944), and how decisions to vaccinate influenced coverage uptake of individuals and groups (Bauch & Earn, 2004). TOG constructs compared immunization costs and benefits related to self-interest, minimized costs, and group-interest maximized-payoffs deaths. These constructs were central to the comprehension of other important barriers to immunization. The seven important barriers to immunization from the literature review comprised adolescent risky behaviors; parental factors; physicians; healthcare providers; clinicians; cultural and societal practices; and finance, policy, regulations, and laws.

The great proportion of immunization barriers aligned with parental concerns. Parental immunization concerns (Daley et al., 2010; Dorell et al., 2011) and immunization barriers contributed to low immunization rates. Some studies listed these

four categories among other parental vaccine concerns: safety, effectiveness, adverse events, and efficacy (CDC, 2012f; Baxter et al., 2013; Freed, Clark, Butchart, Singer, & Davis, 2011; Hall & Jolley, 2011; Offit et al., 2002; Slade et al., 2009). Two studies listed knowledge and awareness as parental concerns (Caskey, Lindau, & Alexander, 2009; Shapiro et al., 2011) and two studies defined attitudes and beliefs as parental concerns (Gust, Darling, Kennedy, & Schwartz, 2008; Kennedy, Basket, & Sheedy, 2011a). Some studies about parental concerns and vaccinations provided information based on medical, philosophical, and religious beliefs (Klein et al., 2012; Safi et al., 2012; Thompson et al., 2007). Vaccine exemptions for FVSE contributed to suboptimal and low immunization coverage (Diekema et al., 2005; Imdad et al., 2013). For example, high religious-exemption counties had 33.1 per 100,000 pertussis incidence compared to 20.1 per 100,000 pertussis incidences, $p < .001$, in low religious-exemption counties (Imdad et al., 2013). Vaccines are safe, effective, and efficacious (CDC, 2012i, Civen et al., 2008; Lopez et al., 2006; Seward, Marin, & Vázquez, 2008; Shapiro et al., 2011). However, parental perceptions and attitudes were risk factors associated with immunization barriers such as vaccine hesitancy (Salmon, Dudley, Glanz, & Omer, 2015), vaccine refusal to immunize children against VPD such as pertussis (Civen et al., 2008; Dorell, Yankey, & Strasser, 2011; Dredze, Broniatowski, Smith, & Hilyard, 2015; Lopez et al., 2006; Seward et al., 2008; Shapiro et al., 2011). Children of parents who refused to immunize their children had a 23-fold risk of contracting pertussis compared to children of parents who had them vaccinated (Glanz et al., 2010).

Five clinician-immunization-barrier risk factors were clinician decision support (Fiks et al., 2013; Hughes, Jones, Feemster, & Fiks, 2011; Szilagyi et al., 2006), clinical

practice (Fiks et al., 2013; Rand et al., 2011a; Rosenthal et al., 2008; Vadaparampil et al., 2011), missed opportunities (Ladak, Gjelsvik, Feller, Rosenthal, & Montague, 2012; Lee et al., 2008), attitudes (M. M. Davis et al., 2006; Humiston et al., 2009), and electronic health records (EHR; Fiks et al., 2012; Shojania et al., 2009; Suh et al., 2012). Clinician-decision support systems contributed to increased vaccination coverage through audit of health records in physicians' practices, education materials (vaccine information statements), and physician education. The clinician-decision support system enhanced clinicians' justifications to recommend adolescent vaccines during wellness visits (Fiks et al., 2013). EHRs effectively improved immunization rates in clinical practice, alerting physicians, families, and adolescents about their next visit and vaccine UTD status. For example, EHR immunization recall/reminder systems encouraged parents and adolescents to receive recommended vaccines during their next wellness visit (Smith, Lindley, Shefer, & Rodewald, 2009; Suh et al., 2012). Physician EHR systems alerted providers when the next adolescent vaccine dose was due (CDC, 2012j; Fiks et al., 2013). EHR systems also provided current clinical history evidence and minimized any lost opportunity to vaccinate adolescents in their medical homes or nonpediatric clinics, school athletic health physicals, and gynecological visits (Shojania et al., 2009; Smith, Jain, Stevenson, Männikkö, & Molina, 2009).

Vaccinated adolescents reduced morbidity and mortality from VPD to protective levels. For example, morbidity from VAR reported cases in PCA declined to 11 cases in 2010, compared to 46 VAR cases in 2006 (Lopez et al., 2006) before the 2007 ACIP second-dose policy. The initial varicella vaccine one dose was licensed and introduced in 1995 (CDC, 1999a). In PCA in 2007, of 808 VAR cases among all ages, the county saw

172 cases (21.3%) among children and adolescents 10–18 years (ADH, 2012a). In 2001, PCA had 194 pertussis cases compared to 21 pertussis cases in 2011 in PCA (ADH, 2012a).

Barriers to immunization were significant risk factors that threatened public health and safety. These significant risk factors aligned with low immunization rates among adolescents (Dorell, Yankey, Kennedy, & Stokley, 2013). Since 2006, public school-entry vaccines required for adolescents in seventh grade included a Hep B series of three doses; an MMR two-dose series; a one-dose booster Tdap, and a two-dose series of VAR. Disease resurgences and outbreaks aligned with low immunization rates, unvaccinated adolescents, and imports of VPD (Glanz et al., 2010). Vaccination policies exempted adolescents from private or parochial schools (ADH, 2011b).

Vaccine Preventable Disease Outbreaks in Recent Years

In Arkansas, VPD resurgence and outbreaks had increased from 2005 to 2012 (CDC, 2012h). For example, U.S. reported resurgence and outbreaks included measles (ADH, 2012b; Lopez et al., 2006; Vitek et al., 1999; J. G. Wheeler, 2012), mumps (ADH, 2006; CDC, 2006c, 2010f), pertussis (ADH, 2012a; Wheeler et al., 2004), and VAR (Gould et al., 2009). These resurgences and outbreaks were attributable to unvaccinated adolescents, vaccine hesitancy (Salmon et al., 2015), low immunizations, and disease imports from endemic countries (CDC, 2011c).

During the last 2 decades of the 20th century, VPD reported cases declined to historically low numbers for diphtheria, measles, mumps (CDC,1998c;WHO, 2013), pertussis(CDC, 2010g, 2011b), poliomyelitis (paralytic), rubella, VAR, and tetanus (CDC, 2006d, 2011j; Seward et al., 2008; WHO, 2011a, 2011b). However, significant

barriers to immunization contributed to low adolescent immunization rates (Klein et al., 2012; Stokley et al., 2011). These new immunization barriers included religious exemptions (Imdad et al., 2013), immunization laws and policies (Safi et al., 2012; Thompson et al., 2007), parental attitudes and knowledge (Gust et al., 2008), and vaccine adverse events (Institute of Medicine, 2011a, 2011b).

Significance of Immunization Barriers and Solutions

VPD outbreaks resulted from immunization barriers. Disease outbreaks associated with unvaccinated persons increased in 2012 for all reported cases of Hep B (10 cases), measles (four cases Arkansas wide), pertussis (63 cases), and VAR (14 cases) in PCA (ADH, 2014a). Measles was an example of a disease eliminated in the United States in 2000 (CDC, 2006b, 2011g). Other VPDs, including mumps, rubella, and VAR, were controlled to less than 200 cases per year (CDC, 2012b). Examples of the significance of immunization barriers were VPD outbreaks and resurgences that occurred annually during the past 5 years (CDC, 2012d). The largest VPD outbreaks and immunization barrier to date (2016) was the pertussis epidemic outbreak in Washington State in 2012 (CDC, 2012g). This pertussis outbreak aligned with unvaccinated children and high immunization-exemption rates, providing another example of an immunization barrier.

The potential immunization solutions defined in this study explained published research that illustrated increases in immunization rates and each level of individual or group optimum described in VGT (Bauch et al., 2003). Low-immunization rates increased the risk of disease outbreaks. The impacts of barriers to immunization to society consisted of negative outcomes, social and financial burdens to society, missed school and work days, and costs to public health resources (Wheeler et al., 2004). These

research-based attributable risk factors of immunization barriers included awareness and knowledge (Gust et al., 2008), parental attitudes, cultural and social beliefs, religious, philosophical, and medical beliefs (Thompson et al., 2007), parental refusal (Glanz et al., 2009), vaccine safety (Institute of Medicine, 2012, 2013; NVAC, 2005), socioeconomic factors (Wooten, Luman, & Barker, 2007), insurance, and access.

These immunization barriers were expressed as choices or behaviors to either preemptively vaccinate, delay, or refuse vaccination. The importance of vaccinated adolescents relates to costs such as disability, death, disease, infection, and recovery (Bauch et al., 2003). Bauch and Earn (2004) measured individual equilibrium and group-optimum coverage-uptake levels based on archival immunization data collected in the AIRD. Differences in levels of vaccination associated with immunization barriers were influenced by differences in interest between individuals and groups (Bauch & Earn, 2004).

Public-health-agency and institution-implemented innovative strategies to increase immunization rates have also reduced VPD population risk and controlled disease exposure. Federal public health insurance programs, VFC, State Medicaid eligibility plans, school-entry laws, and healthcare-provider influence were effective vaccine-uptake strategies. In addition, adolescent and childhood immunization rates increased from 85% to 92% for certain vaccines (CDC, 2009b, 2012m). Although U.S. adolescent immunization rates improved, challenges persisted for achieved and desired 90% immunization-rate indicators in Healthy People 2020 objectives (CDC, 2010b).

Parental awareness and knowledge are essential for parental consent to immunize children and adolescents. Federal immunization laws encourage parents to receive

informed knowledge about the risks and benefits of vaccination. In addition, the National Childhood Vaccine Injury Act, section 2126 of the Public Health Service Act (USDHHS, 1996) required healthcare-provider immunization information to educate parents and children during preventive and wellness visits. Federal law also mandates that parents receive vaccine-information statements (VIS) and other vaccine information before healthcare providers administer any vaccines to children or adolescents. All VIS and educational materials provide specific and relevant vaccine information that enhances parental awareness and knowledge. Parental knowledge and awareness influences positive vaccine perceptions and attitudes associated with parental vaccine acceptance for children and adolescents (Dorell, Yankey, Byrd, & Murphy, 2012; Glanz et al., 2010; Klein et al., 2012). Healthcare-provider information is important and influenced 89.7% of positive parental vaccination decisions (Kennedy et al., 2011). Physicians routinely recommend and administer MMR, OPV/IPV, and Td/Tdap childhood and adolescent vaccines.

Underimmunizations

Underimmunization was a significant finding in this dissertation, confirming previous research. Significant associations arose for underimmunizations (Smith, Chu, & Barker, 2004), with race, income, parental marital status, education, and number of children in the household (Kesselsa et al., 2012; Salmon et al., 2009). Similarly, children of parents who participated in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) were more likely to not have completed a vaccine-dose series compared to parents who did not participate in the program (CDC, 2014c; Salmon et al., 2009; Shefer, Webb, & Wilmoth, 2000).

Adolescent-Vaccine Access

Immunization registries functioned as official repositories of quantifiable evidence of adolescent-vaccine access. Immunization coverage for adolescents aged 10 to 18 years in the United States lagged behind childhood rates for 19- to 35-month-old children and adults 65 years and older (CDC, 2010b). Adolescent catch-up vaccine doses improved in the NIS-Teen 2008 (CDC, 2009b). Vaccination data collection was through national immunization surveys (Smith, Hoaglin, Battaglia, Khare, & Barker, 2005), immunization-patient records from providers (Broder, Cohn, Schwartz, & Working Group on Adolescent Prevention Priorities, 2008), state and local immunization registries, immunization information systems, the Arkansas Children's Network, and NIS-Teen (CDC, 2010b; Children's Reporting and Information System [CHRIS], 2013). Immunization registries are confidential, population-based, computerized information systems that attempt to collect vaccination data about all children in a geographic area (CDC, 2010c, p. 5). Local immunization registries focus on their geographic catchment area, thereby providing tools for monitored immunization assessment and surveillance. Healthy People 2020 objectives for adolescent immunization are difficult to achieve. The challenges and associated risk factors include vaccine safety (Baggs et al., 2011), access to immunization, and provider-practice guidelines. In studies, health providers' influence accounted for 21.5% of risk factors; parental attitudes included mistrust of safety of vaccines at 5.7%. Parental reluctance or refusal also contributed as challenges (Cooper et al., 2008; Glanz et al., 2009; Smith, Kennedy, Wooten, Gust, & Pickering, 2006).

Arkansas immunization rates reported in the immunization-information-systems data for children between 19 and 35 months declined from 78% UTD (CDC, 2008a) to

71.4% UTD coverage (CDC, 2010b, p. 10). The UTD criteria were four or more doses of Td/Tdap; three or more doses of OPV/IPV; one or more doses of meningococcal conjugate vaccine; three or more doses of Hib; and three or more doses Hep B vaccine (for 4:3:1:3:3). The vaccination 4:3:1:3:3:1:4 dose series has additional four or more doses of pneumococcal conjugate vaccine (CDC, 2010b, p. 17).

Adolescent Vaccine Coverage: Reducing Disease Recurrence and Outbreak

Key public health contributions to social change with the implementation of viable vaccine strategies included reduction in morbidity, disability, and death from vaccine-preventable infectious diseases. The effect of middle school-entry requirements positively impacted adolescent vaccine coverage. Coverage rates for Hep B vaccines increased among adolescents (91%) in states with school-entry requirements (CDC, 2011m; Wilson, Fishbein, Ellis, & Edlavitch, 2005) compared to (58%), $p > .001$ in states without school-entry vaccine requirements (CDC, 2011n, 2012b; Jacobs & Meyerhoff, 2004).

Disparities in Immunization Coverage between NHAs and FCAs

I identified three reasons adolescents are placed in foster-care services: abuse, abandonment, and neglect from their birth parents (American Academy of Pediatrics [AAP], 2005). When adolescents were removed from their natural birth home to foster care, such actions caused difficult and stressful situations for the adolescent and the medical home. Adolescents displaced from their birth family and foster parent(s) must be assured they will receive the best possible emotional and physical care (AAP, 2005; CDC, 2014c; Leathers, 2005). Because many FCAs were affected by emotional or developmental problems, foster parents often face the unfortunate choice of either

tackling any psychological issues or obtaining routine preventive health services, such as immunization, often to the demise of the latter (AAP, 2005; Leathers, 2005).

Another barrier to preventive health services FCAs often face is that birth parents retain authority to provide consent for all health and medical procedures (American Academy of Child and Adolescent Psychiatry [AACAP], 2005; Freundlich, 2003; Humiston et al., 2013). These health and medical procedures include immunizations, reproductive health, sexually transmitted diseases, HIV testing, and substance abuse (AACAP, 2005). The birth parent's consent often wanes, given the contentious situation that result in the removal of the adolescent from the home. Unlike FCAs, those in the natural-home setting are unlikely to face these barriers. Barring particular circumstances such as lack of health insurance preventing access to preventive health services, most adolescents in the natural-home setting adhered to prescribed preventive health services (AACAP, 2005; Freundlich, 2003).

Arkansas Immunization Laws

Arkansas Immunization Laws for School Enrollment Grades K–12

Arkansas legislators enacted more than 12 immunization-important laws and amendments since 1987 (ALB, 1987). Five of these laws were significant immunization laws that grounded the relevance of this study. These five significant AILs were enacted in 1987, 1989, 1993, 1995, and 1997, and appear in Table A3 of Appendix A. These five immunization laws relate to five critical immunization areas in the scope of this study: child care and school-entry vaccine requirements; immunization access, financing, and schedules; a statewide immunization registry in Arkansas; adequate minimum percent levels of immunization coverage, specific required number of vaccine doses for each

series, and vaccine types; disease prevention (ALB, 1995b); and outbreak control. The 2003 immunization laws had one major societal development: authorizing exemptions for medical, personal, religious, and philosophical beliefs (ALB, 2003). Arkansas legislative Act 141 of 1987 authorized the Arkansas State Board of Health to mandate proof of measles, rubella, and other disease immunization prior to enrollment in daycare facilities and schools (ALB, 1973) and Arkansas colleges and universities.

The Arkansas 1987 immunization law stated two purposes, required proof of immunity, and alleviated the potential for an outbreak of communicable diseases (ALB, 1987). Arkansas legislative Act 387 of 1989 committed to achieving and maintaining adequate immunization levels for all children in Arkansas. The minimum required immunization levels established by law were 95% of children in public and private schools and above 90% of children in childcare facilities (ALB, 1989).

Arkansas legislative ACT 591 of 1993 addressed availability, adequacy, promotion, and use of immunization programs for infants and preschool children in Arkansas. These legal provisions also enhanced achievement of minimum immunization levels of 95% of children in public and private schools and above 90% of children in childcare facilities (ALB, 1989). Two Arkansas laws, Act 432 and 685 of 1995, promoted the efficiency and effectiveness of immunization services and coverage for all children in Arkansas.

ACT 685 of 1995 mandated coverage of children's preventive health care (ALB, 1995a) from birth through the age of 18, with periodic preventive-care visits (ALB, 1995b), and appropriate immunizations. ACT 685 funded immunization services under the Medicaid program in the State of Arkansas and eased the financial burden for low-

income, uninsured children through benefits for recommended immunization services. The law also provided exemptions for eligible children from any copayment, coinsurance, deductible, or dollar-limit provisions in the health-insurance policy.

ACT 432 of 1995 established the Arkansas statewide childhood-immunization registry. The AIR serves three functions: The AIR provides information on childhood-immunization status from birth to 22 years to parents, guardians, and providers. Second, AIL ACT 432 requires physicians and health providers to register and report all vaccines administered to children and adolescents from birth to 22 years (ALB, 1995a). Third, AIL ACT 432 imposed a penalty of $25 dollars on all providers who do not report administered vaccines to the registry (ALB, 1995a).

In 1997, two AILs, ACT 870 of 1997 and ACT 871 of 1997, mandated immunization prior to school enrollment and required specific vaccines for all children (ALB, 1997a, 1997b). These two laws impacted the 1990 birth-cohort school enrollment. These students were the first adolescent-age cohort to comply with FVSE requirements. The law required immunizations for students in kindergarten through 12th grade who attended Arkansas schools (ALB, 1997a). AILs also authorized the ADH and Arkansas Department of Education to impose penalties for violation.

Arkansas Act 871 of 1997 also placed compliance enforcement responsibilities on school boards, superintendents, and principals of all schools. In PCA, school nurses have direct responsibility to verify immunization records and require each student to receive all age-appropriate vaccines (ALB, 1987). AIL ACT 870 of 1997 authorized the Arkansas State Board of Health to require school-children receive immunization prior to enrollment in public or private school from kindergarten through 12th grade, or childcare

facilities, and for other purposes. Similarly, ACT 871 required age-appropriate immunization of children with OPV/IPV, Td/Tdap, red (rubeola) measles, rubella, and other diseases designated by the State Board of Health.

Arkansas Immunization Exemptions

ACT 999 of the 2003 Arkansas legislative regular session authorized immunization exemptions based on philosophical, religious, and personal beliefs. The ADH is the only legal authority to approve and grant exemptions each year (ALB, 2003). Several researchers suggested associations among immunization exemptions, immunization coverage, and immunization rates. In Arkansas, requests for immunization exemptions increased following 2003 (Safi et al., 2012; Thompson et al., 2007). However, no published studies exist on specific associations between immunization rates and exemptions. In addition, no published studies exist on 1990 PCABC adolescent immunization rates, based on analysis of AIR data in the literature.

Changes in Arkansas Rules and Regulations 1990–2012

AIRR changes were consistent with ACIP adolescent-vaccine routine recommendations. Arkansas school-entry vaccine requirements were limited to five vaccines, tetanus and diphtheria toxoids, and Tdap (CDC, 2013). The human papillomavirus and meningococcal conjugate vaccine were also recommended for adolescents (CDC, 2013). The ADH increased VAR-dose requirements to two dose series in AIRR in 2006 due to the resurgence of VAR in Arkansas (Lopez et al., 2006).

Childhood and adolescent vaccines recommended against 11 childhood diseases in the United States since 1900 are Hep B, Td/Tdap; measles, mumps (CDC, 2012d), congenital rubella syndrome CRS, Hib, OPV/IPV (Salk, 1955b), smallpox, and VAR

(CDC, 1999d). These 11 vaccines, except for smallpox, were required for school entry in Arkansas and established in Table II immunization regulations for children attending kindergarten through 12th grades (ADH, 2008). Adolescent immunization changes applicable to this study are changes in the number of vaccine doses and schedules implemented between 2003 and 2008. Extensive cohort vaccine changes appear in Appendix A., Table A2.

Arkansas adolescent immunization rates were persistently low, compared to national immunization indicators established in Healthy People 2020 (2012). Arkansas immunization rates ranked lower compared to other states in the region with similar demographics and rural populations. The Arkansas 1995 immunization law required vaccine compliance and immunization reporting for enrollment in daycare facilities, Grades K–12, colleges, universities, military, and for state employees (ADH, 2008; ALB, 1995a). The 1995 immunization law directly improved adolescent immunization rates and indirectly reduced immunization disparities among adolescents.

Evaluating Changes in Arkansas Rules and Regulations 2000–2008

Evaluation changes in Arkansas rules enhanced school-entry immunization requirements. Arkansas rules and regulations pertaining to changes in vaccine types, number of doses, and vaccine administration from 2000 to 2008 were important in compliance with school-entry immunization requirements. Immunization relationships or correlations existed between changes in adolescent immunization rates and changes in Arkansas and national requirements (Kroger, Sumaya, Pickering, & Atkinson, 2011). Arkansas State mandated immunization rules and regulations, influenced changes in quantitative variables such as number of doses required for completion of vaccine series,

age-appropriate doses, and vaccine UTD coverage. This evaluation of changes in adolescent immunization regulations facilitated assessment and determination of any relationships or correlations to changes in immunization rates and changes in state-mandated immunizations.

Change emphases were on vaccine doses because no changes had occurred in AIRR since 1995 (see Appendix A, Table A2; ADH, 2008). The 2000 Table II of AIRR requirements were limited to adolescents spanning seventh through 12th grades. A second criterion was age-appropriate completion of required immunization for children aged 13 to 18. Adolescent students in the seventh grade UTD required three doses of Tdap, three doses of Hep B vaccine, two doses of a measles-containing vaccine (usually MMR), three doses of OPV/IPV vaccine, and one dose of VAR vaccine (ADH, 2000). Adolescent transfer students from seventh grade through 12th grade received similar UTD requirements (ADH, 2000). The chronological list of the immunization rules and regulations between 2001 and 2008 follows from Table II of the 2001 AIRR.

In 2001 and 2002, no new changes or additions accrued for adolescents who began seventh through 12th grades. In 2003, AIL authorized exemptions for medical, religious, and philosophical beliefs (ADH, 2003). AIL made no changes in 2004 and 2005 for adolescents. In 2006, Table II included recommendations for the addition of a second dose of VAR for adolescents (CDC, 2006a) in seventh grade through 12th grades (ADH, 2006). No changes accrued in 2007 or 2008.

Solution to Low Adolescent Immunization

Adolescent immunization solutions to low-immunization rates were implemented at policy and individual levels. The Healthy People 2000 national health promotion

identified immunization as a national health priority (USDHHS, 1999). Federal solutions to low-immunization rates (Kalies, Redel, Varga, Tauscher, & von Kries, 2008) since 1994 included funding eligibility insurance programs, Medicaid, and the VFC program (CDC, 2012l; Zhou, Santoli, et al., 2005). Federal law required VIS sheets for each vaccine. A VIS was an immunization strategy and a national policy (USDHHS, 1987) that targeted education of adolescents, parents, and physicians on vaccine safety and adverse events. Healthcare providers educated parents, adolescents, and children before administering vaccines. These health-promotion strategies and mechanisms targeted multiple levels that influenced individual health behaviors at the interpersonal, community, organization, and policy levels.

The individual immunization health-behavior-change approaches contributed to increases in adolescent immunization rates (Stokley et al., 2011). The parental-influence approach targeted interpersonal increases in knowledge, awareness, and attitudes, and provided potential solutions that addressed parental reasons for not immunizing adolescents (Darden et al., 2011). Individual health-behavior change for parents involved multiple mechanisms of influence that incorporated social networks, organization, and policy influences. Parents who refused to vaccinate their adolescents had to sign and document the informed refusal of consent to vaccinate (Burns & Zimmerman, 2005). WIC and VFC programs improved parental awareness (Kennedy, Stokley, Curtis, & Gust, 2011) and knowledge of the benefits of vaccines, contributing to increases in childhood and adolescent access to vaccines and immunization rates.

Community solutions included clinical decision support and maximized opportunities to immunize adolescents during each wellness visit (Schaffer et al., 2008;

Szilagyi et al., 2008). Solutions included immunization standing orders and EHR immunization audits to minimize missed opportunities and increase immunization rates (Burns & Zimmerman, 2005). The implemented reminder/recall systems were time and cost intensive (Burns & Zimmerman, 2005); however, direct immunization communication between providers and vaccine recipients or parents of recipients were effective and increased immunization rates (T. C. Davis et al., 2001). Healthcare providers who used EHR recall/reminder systems improved adolescent immunization rates (Clark, Butchart, Kennedy, & Dombkowski, 2011; Fiks et al., 2013; Hambidge, Phibbs, Chandramouli, Fairclough, & Steiner, 2009; Szilagyi et al., 2002). Pharmacists' additional roles as vaccinators also increased immunizations in inner-city, rural, and nontraditional sites beyond local county health units (Hogue, Grabenstein, Foster, & Rothholz, 2006; Ndiaye et al., 2003; Neuhauser, Wiley, Simpson, & Garey, 2004).

Policy solutions included school-entry laws (ALB, 1967; Omer, Salmon, Orenstein, deHart, & Halsey, 2009; Orenstein & Hinman, 1999), access to immunization in Arkansas (ALB, 1967) through federal and state eligibility programs such as VFC, Medicaid, and supplemental children's insurance (ARKIDS) programs in Arkansas (ADHS, 2011c). Legislative actions of immunization laws and school-entry requirements influenced societal and environmental levels. School-based immunization clinic practices aligned with increased adolescent immunization coverage (Allison et al., 2007; Daley et al., 2009; Federico, Abrams, Everhart, Melinkovich, & Hambidge, 2010; McNall, Lichty, & Mavis, 2010).

The central concept of adolescent immunization health was individual behavior change related to specific health, contributing large social-change impacts and beneficial

economic gains (Lee, Feaver, Miller, Hedberg, & Ehresmann, 2004). Commensurate health gains decreased childhood disease and deaths and increased life expectancy. Adolescent immunization contributed to several other great achievements of vaccinations in the 20th century and the first 2 decades of the 21st century (CDC, 1999c).

The specific health problems of unvaccinated adolescents related to individual behavior change were VPD resurgence, outbreaks, disease transmissions, and importations of measles, mumps, pertussis, and VAR (CDC, 2006b, 2006e, 2012d). Other effective solutions that increased immunization rates included reduced adolescent-crowd opportunities, minimized proximal interaction between disease carriers and exposed unvaccinated or underimmunized individuals, increased social distancing, and school closings during outbreaks (Glass & Barnes, 2007; C. Jackson, Vynnycky, Hawker, Olowokure, & Mangtani, 2013; Miller et al., 2010). During the prevaccine era of the 19th and 20th centuries, childhood diseases and mortality were prevalent (CDC, 1999a). Since vaccines were licensed and introduced as part of a health-promotion strategy, childhood diseases have significantly decreased and mortality has declined (CDC, 2000a). For example, approximately 4 million people were infected annually with measles during the 1963 measles prevaccine era (Zhou et al., 2004).

Vaccines contributed to personal high economic costs (Lee et al., 2004; Zhou, Harpaz, Jumaan, Winston, & Shefer, 2005) and societal costs (Shapiro et al., 2011), and provided communitywide and societal protection from disease morbidity and mortality (Zhou et al., 2004). Parental delayed vaccination of their children as a consequence of vaccine hesitation, resistance, and refusal at the individual level increased the risk of resurgence of diseases (Opel et al., 2011). Disease risks were greater during the

predominant host-agent-environment models of disease experienced during the prevaccine era of societal and environmental outbreaks, epidemics, and pandemics (Opel et al., 2011).

The relevance of adolescent immunization is more important today than in the 20th century as a result of narrow social distancing (Reluga, 2010). In addition, adolescent immunizations are relevant because of the frequency of disease transmission facilitated by global travel, the availability of cost-effective vaccines (Whitney, Zhou, Singleton, & Schuchat, 2014), and increased parental objection and refusal of vaccines (Diekema, 2012; WHO, 2011a). Experiences ranging from immunization resistance to global poliomyelitis eradication initiatives aligned with parental health-behavior influences in Afghanistan, India, Nigeria, and Pakistan (CDC, 2009g; WHO, 2011b). Increased use of vaccines provided effective defenses in environments where global disease transmissions were facilitated by factors related to individual, community, and societal behaviors.

Theoretical Foundation

The Theory of Games

The theoretical foundation used in this study was the TOG (von Neumann & Morgenstern, 1944). I applied TOG constructs as a mathematical model to measure individual vaccine behavior (Bauch & Earn, 2004; Bauch et al., 2003), called individual equilibrium, because the FVSE affects the group's interest, known as the group optimum. Individual equilibrium examines the probability and cost of delayed vaccination among a population, whereas the group optimum examines the probability of preemptive vaccination coverage and minimum payoff death or disability from VPD, for which there

is routine vaccination among a population. If the proportion of preemptively vaccinated individuals in the group is significantly large and the disease is sparsely distributed across the population, then community or herd immunity exists in the group. Thus, community or herd immunity mitigates the payoff for preemptive vaccination in the group, to avoid or minimize death or disability. Individuals with self-interest behavior therefore choose not to become vaccinated.

Framework for Modeling

TOG was an important framework used to model an individuals' probability of vaccination, calculated for the 1990 PCABC. I also calculated the group payoff deaths for preemptive vaccination coverage. Vaccination payoff deaths references the cost associated with VPDs if individuals with self-interest in the group were not vaccinated. The TOG construct predicted individual and group vaccine behavior. This predictive function was essential and significant in preemptive vaccination calculations (Bauch et al., 2003) for public health interventions of disease resurgence, outbreaks, epidemics, and pandemics. Participants' strategies, individual self-interest adolescent actions, and group altruistic action are key constructs of the TOG (Bauch et al., 2003).

The TOG was also useful in evaluating vaccine policy and assessing advantages of vaccination self-interest and group utilitarian optimization (Galvani et al., 2007). The probability, proportion, frequency, and immunization outcome of UTD variables aligned with the key predictive payoff death functions in this quantitative study. These immunization outcome UTD variables were vaccine-coverage rates for FVSEs for school entry (ADH, 2008).

Social-Change Implications

The social-change impact of adolescent immunization-uptake prediction is valuable to public health functions. The TOG application in immunization quantitative analysis incorporated in several research studies included vaccine uptake among adolescents (Reluga, Bauch, & Galvani, 2006), immunization rates (Niccolai & Hansen, 2015; Skoff & Martin, 2016), UTD predictors, and uptake coverage (Ibuka, Chapman, Meyers, Li, & Galvani, 2010). The TOG was an effective model used in this study to investigate and describe risk factors associated with health outcomes (Bauch et al., 2003). The low-immunization rates among populations explained the individual and group-equilibrium framework (Bauch et al., 2003). For example, VGT explained how self-interest, altruistic decisions, and maximization and minimization of payoff concepts or frameworks (Bauch & Earn, 2004) influenced immunization policy (Bauch et al., 2003). I applied TOG constructs and determined how individuals' decisions or actions related to immunization uptakes and coverage rates probabilities (Bauch & Earn, 2004). Similarly, Arkansas immunization policy influenced school-entry vaccine requirements (ADH, 2008) and contributed to increased immunization rates for specific vaccines (Morita, Ramirez, & Trick, 2008).

The TOG was important in understanding, investigating, and developing solutions for health problems with multilevel risk factors such as immunization (Bauch & Bhattacharyya, 2012; Bauch et al., 2003). The TOG framework was also applicable to significant determinants and predictors of vaccine uptake (Bauch, 2005) during acute events such as smallpox outbreaks that occurred in several developing nations (Bauch et al., 2003).

Summary and Conclusion

Summary

This study determined how HOR aligned with vaccination coverage UTD. This associative concept was significant in vaccine-coverage improvements and interventions. Increased adolescent immunization rates contribute to community health and prevention of VPD outbreaks. Individual decisions to vaccinate often relate to self-interest (Ibuka et al., 2014). VPD outbreaks among school children and index cases are more likely to occur among unvaccinated children compared to vaccinated children with waned immunity (Skoff, Cohn, Clark, Messonnier, & Martin, 2012; Sugerman et al., 2010). VPD outbreaks are also common among highly vaccinated populations that were underimmunized and only received one dose in a vaccine series (Lopez et al., 2006; Sugerman et al., 2010).

Outbreaks of VPDs reported in Arkansas included pertussis in 2001 (Wheeler et al., 2004) and VAR in 2005 (Lopez et al., 2006). Disease outbreaks such as pertussis associated with pneumonia, encephalitis complications, hospitalization, and deaths reported during the California pertussis outbreak (California Department of Public Health, 2010). School outbreaks of VPDs frequently disrupt educational activities, increase absenteeism due to illness (King et al., 2006), and lead to hospitalization and school closure (M. M. Davis et al., 2008). VPDs such as VAR are highly contagious and easily transmitted (CDC, 1999c) by airborne and contact between persons (Ross, 1962; Schmid & Jumaan, 2010). Control of VPD outbreaks is financially costly and a public health burden (Wheeler et al., 2004).

Societal and individual health costs were consequences of unassured full immunization coverage among at-risk populations. At the societal level, these costs include disease transition among socially congregating adolescents at public venues and events. The outcomes of congregating groups at sports events, church activities, and shopping complexes often results in increased illness and hospitalization in the community (Reynolds et al., 2008). At the individual level, costs associated with lost productivity and wages often occurs when parents or guardians stay home to care for affected children (M. M. Davis et al., 2008).

Conclusion

For this study, I analyzed data from the AIRD to establish vaccine UTD status for the 1990 PCABC. Differences emerged in vaccine-coverage uptake between NHAs and FCAs among the PCABC. PCABC FVSE immunization rates were included in the four main outcomes. A literature review gap emerged in that peer-reviewed studies on disparities of vaccination coverage for the FVSE among NHAs and FCAs in the 1990 PCABC were not found or did not exist. The AIRD analysis implemented in this study quantitatively addressed this gap in the literature. Several peer-reviewed studies previously addressed components of immunization in Arkansas, including infant and childhood coverage rates, VPD outbreaks, vaccine exemptions, school-enrollment requirements, immunization policies, and state-mandated immunization laws. However, these studies did not apply quantitative analysis of immunization-registry data, nor did they focus on NHAs and FCAs in the 1990 PCABC to establish immunization-coverage rates for the FVSE. The NIS-Teen coverage rates reported for adolescents in Arkansas (CDC, 2008a; Darden et al., 2013; Jain, Singleton, Montgomery, & Skalland, 2009;

Stokley et al., 2011) were based on a random-digit dialing survey (RDDS) of sampled households. RDDS consents were corroborated with consent from participants to use provider-based immunization data. In contrast, this study was an archival cohort analysis, and consent from participants was not required to access deidentified registry data. I satisfied all institutional review board (IRB) requirements and gained approved for this study.

The next chapter of this dissertation, Chapter 3, includes the research methodology. Key sections of Chapter 3 consist of the study design, research questions, and hypotheses, sample frames and sample sizes, data analysis, and ethical considerations.

Chapter 3: Research Method

Study Purpose

I achieved four main purposes in this quantitative study. The first was to calculate and compare adolescent immunization rates between the 1990 adolescent PCABC adolescent and the U.S. national adolescent immunization data from 2003 and 2008. The second purpose of the study was to identify whether an association emerged between HOR, defined as NHA or FCA, and the UTD status of FVSE. The third purpose was to determine whether disparities in immunization rates existed based on sociodemographic risk factors that included age, gender, race, and ethnicity in PCAs. The fourth purpose, based on the TOG, was to develop mathematical models to illustrate how an individual's decision to receive vaccination for the FVSE affected the group interest.

Research Design and Rationale

Research Design

I used the cross-sectional study design to conduct this quantitative inquiry. Because information on vaccine coverage and HOR were captured at a single point in time, the cross-sectional design was the ideal study design; however, no feasible methods could account for temporality. Although other quantitative study designs were useful, the inability to account for temporal order made their utility in this instance inappropriate.

Design Rationale

The cross-sectional study design was an appropriate design to explain the problem statement and answer the four research questions in this study. I analyzed the individual immunization registry data to establish immunization rates, vaccines with low uptake, and UTD status for NHAs and FCAs, all collected at a single point in time. The cohort

independent variable was the HOR, defined as NHA and FCAs. The dependent variables were five vaccines required by AIL for school entry: diphtheria, Hep B, MMR, OPV/IPV, and VAR. The individual immunization records were coded with unique identification criteria and formulae for specific recommended vaccines for school entry (ADH, 2008).

Operationalization of the Theoretical Construct

Operationalizing Game Theory

The TOG (von Neumann & Morgenstern, 1944) theoretical construct was operationalized using several steps. First, the variables that corresponded to TOG constructs included individual equilibrium and group optimum, identified for each FVSE. Next, I developed mathematical models to examine individual equilibrium and group optimum for each of the FVSE in the 1990 PCABC. Because county data reported to the CDC does not distinguish NHA and FCA, I calculated overall probabilities. Additionally, if county data for PCA were incomplete in the national database, I used a representative sample of the 1990 U.S. birth cohort to calculate attack rates.

I measured individual health behavior using the frequency function of all vaccine doses recorded for that type of vaccine. Appropriate individual immunization was the maximum number of doses required, according to recommendations of the CDC for that specific vaccine to complete the dose series (CDC, 1999c). For example, Tdap vaccine had a maximum of four doses to complete the vaccine series compared to MMR or VAR, which required a maximum of two doses to complete the vaccine series. The frequency of completed vaccine series used to determine probabilities needed in the calculation of the individual equilibrium and group optimum was equal to the total number of individuals

with completed vaccine series in the study population. The frequency function was a statistical tool that predicted vaccination proportions and probabilities (Bauch, 2005) for a given TOG individual equilibrium and group optimum construct. Bauch and Earn (2004) used the TOG to explain how individual behavior contributed to adolescent immunization coverage rates.

The Theory of Games Constructs

The two constructs used as part of the TOG in this study were individual equilibrium and group optimum. The payoff calculations used in both mathematical models were based on data obtained from the AIR and from the CDC's immunization database, which compiled national immunization rates.

The following parameters defined the equations to express the individual equilibrium and the group-optimum equation:

- C = optimum cost;
- E_{vac} = the efficacy of vaccination for an individual who receives the vaccine;
- d_v = the probability of death of the individual from vaccination;
- p_{eff} = the proportion effectively vaccinated;
- p = the proportion of individuals preemptively vaccinated;
- r = the risk of attack from a VPD after an outbreak;
- $\phi_s(p)$ = the probability that a delayer becomes infected with disease after an outbreak;
- d_s = the probability of death due to a VPD;

- $\phi_v(p)$ = the probability that a delayer is vaccinated successfully after an outbreak;
- N = the population size.

The population size was equal to N adolescents in the 1990 PCABC and was based on U.S. population census data. The importance of adolescent vaccination is the cost of vaccination in terms of death. The cost equals the total number of deaths where $E_{vac} = -d_v$ and is the probability outcome (Q; Bauch et al., 2003). The group optimum cost ($C(p)$) is the vaccine coverage level needed to avert deaths due to VPD.

Assumptions

I noted several assumptions in the calculation of individual equilibrium and group optimum. First, the risk of attack from a VPD after an outbreak, r, was based on a priori knowledge found in the literature. Additionally, the $\phi_s(p)$, probability that a delayer became infected after an outbreak, as well as the d_s, probability of death due to a VPD, was based on a priori knowledge found in the literature. The $\phi_v(p)$, probability that a delayer was vaccinated successfully after an outbreak was based on the number of available vaccine series available in PCA. I assumed enough vaccine existed for any of the FVSE, available for all unvaccinated adolescents. I based all other probabilities on information obtained from the AIR.

Constructs Used in the Theory of Game

Individual equilibrium. I used the individual-equilibrium equation to examine the relationship between those who preemptively received vaccination and those who delayed vaccination for each of the FVSE. The payoff for an individual who received vaccination can be expressed as $E_{vac} = -d_v$ where d_v is the probability of death from

vaccination. Because the probability of death due to vaccination was usually small, d_v was usually ignored in the equation; therefore, E_{vac} was usually assumed to be 100%, or 1 when expressed as a probability. I therefore focused on the effect of an individual delayed vaccination and the risk of the disease if an outbreak occurred, $E_{del}(p)$. The equation examined vaccine delay and the payoff associated with delay was

$$E_{del}(p) = -r[\phi_s(p)d_s + \phi_v(p)d_v],$$

where $E_{del}(p)$ calculates the payoff to an individual who chose to delay vaccination; r is the risk of attack from a VPD after an outbreak, calculated as number of people likely to become infected if there were no vaccine protection divided by total population at risk of becoming infected; $\phi_s(p)$ is the probability that a delayer becomes infected with disease after an outbreak, calculated as the total number of eligible unvaccinated people divided by the total population at risk of becoming infected; d_s is the probability of death due to a VPD, calculated as the total number of deaths among those who were unvaccinated from VPD divided by the total population at risk of becoming infected; $\phi_v(p)$ is the probability that a delayer is vaccinated successfully after an outbreak, calculated as the total number of disabilities among delayers receiving the vaccination divided by total number of delayers who received vaccination; and d_v is the probability of death of an individual from vaccination, calculated as the total number of deaths due to the vaccination divided by the total number of those who received the vaccine.

Because the goal of individual equilibrium, P_{ind}, is to examine the relationship between E_{vac} and E_{del}, one would expect to see a maximized payoff from receiving vaccines, where $E_{vac} = 1$ or 100% vaccine efficacy, no deaths from vaccination, and a minimized payoff of delaying vaccination where $E_{del} = 0$ or no payoff for delaying

vaccination. Therefore the association expected was $E_{vac} > E_{del}$. If $E_{vac} \leq E_{del}$; then the individual equilibrium, $P_{ind,}$ may approach zero where, although the vaccine is effective, the payoff for delaying vaccination may not pose any additional risk of harm (Bauch et al., 2003). Under such circumstances, individuals may choose not to be vaccinated, thereby eliminating individual equilibrium, P_{ind}. An important assumption to make when calculating the individual equilibrium is that individuals will act to increase survival from a VPD when vaccines are readily available. See Table 1 on how I identified each construct.

Table 1

Theory of Game Parameters, Definition, and Sources

Parameter	Definition	Source
r	Risk of attack from a vaccine preventable disease for an individual	CDC's U.S. morbidity national data published in the *Morbidity and Mortality Weekly Report*
d_s	Probability of death from a vaccine-preventable disease for an individual	CDC's U.S. mortality national data published in the *Morbidity and Mortality Weekly Report*
$\phi_s(p)$	Probability an individual delayer becomes infected after an outbreak	CDC's U.S. morbidity national data published in the *Morbidity and Mortality Weekly Report*
$\phi_v(p)$	Probability an individual delayer is successfully vaccinated after an outbreak	Arkansas vaccine stockpile information. CDC national vaccine stockpile information.
N	Population size	2000 U.S. census data, for PCA

Note. Adapted from "Group Interest Versus Self-Interest in Smallpox Vaccination Policy," by C. T. Bauch, A. P. Galvani, and D. J. D. Earn, 2003, *Proceedings of the National Academy of Sciences, 100* for Pulaski County, Arkansas, Birth Cohort Analysis, 2015.

The group optimum. For the group interest, it was important to minimize the total number of deaths due to vaccination and infection if an outbreak of a VPD occurred. Thus, to examine group optimum, I applied the equation

$$C(p) = pd_v + r(1 - p)[(d_s - d_v)\phi_s(p) + d_v],$$

where $C(p)$ was measured as a probability between zero, and 1 was the coverage level that would have to be imposed to minimize the total expected number of deaths due to a VPD. All other variables are the same as those described for individual equilibrium and reported in Table 1.

Research Methodology

Immunization Registry Archival Data

The initial process began with a cover letter and an attached summary of the project proposal sent to the deputy director of health programs and state epidemiologist at ADH. I sent a request letter to the ADH director for permission to examine official archived State Board of Health minutes from 1980 to 2012. These minutes provided gainful understanding of background knowledge on the history, policy, and practices of immunizations in Arkansas.

From April 2011 to August 2012 the ADH Immunization and Communicable Disease Branch offered me an unpaid graduate internship to work on special projects. I initiated the process to request immunization data access during this period. Another access-to-data requirement was a memorandum of understanding between ADH and ADHS to acquire a foster-care identification roster of Datalink immunization records. I sent numerous e-mails and letters of request to ADHS leadership for permission to acquire the foster-care identification roster. The ADH Scientific Advisory Committee (SAC) has legal authority to release the data. I obtained the study data from AIRD through SAC.

Roadmap to Data Merge

To obtain the initial list of the 1990 PCABC, I used the Arkansas Department of Public Health Vital Statistics database to extract the name, date of birth, gender, race, and ethnicity of all children born in 1990 in PCA. The individual birth-record information is publicly available when requested. To extract information on children who enrolled in the public school system, the list of children born in 1990 was sent to the Arkansas Board of Education. Once I obtained the list of identified children who enrolled in public school from the Board of Education, this list was sent to the AIR to obtain the immunization history of children born in 1990 in PCA who attended public school.

FCA and NHA data were combined in the immunization-registry data, as required by Arkansas law (ALB, 1995a). FCA and NHA data were coded by registry staff—0 = FCA and 1 = NHA—then reviewed by a senior epidemiologist before being released to me. However, the data were deidentified to protect minors, in accordance with Arkansas law (ALB, 1995a).

The final list obtained from the immunization registry included the patient unique identifier, date of birth, age, gender, race, and ethnicity of only cohort children. Figure 1 illustrates the topography of Arkansas immunization linkage databases.

Deterministic Data Linkage

The Arkansas vital-statistics database and the AIRD were large databases that contained similar important PCABC unique identifiers and demographic variables (Lin, 2003). I used these identifiers and variables to develop an optimal file-linkage algorithm that yielded quality matched immunization records (Lin, 2011). I performed all linkages under close advisement and guidance of the senior statistician at the ADH. I used the

algorithm shown in Figures 1 and 2 in the linkage process. The constructed optimal file-linkage algorithm required three types of data files: birth-certificate data, immunization data, and a gold-standard file (Lin, 2011). The birth-certificate-file variables included social security number and demographic data (Lin, 2003). The immunization data included social security number, date of birth, vaccine type, number of doses, date of vaccine administration, and specific demographic data.

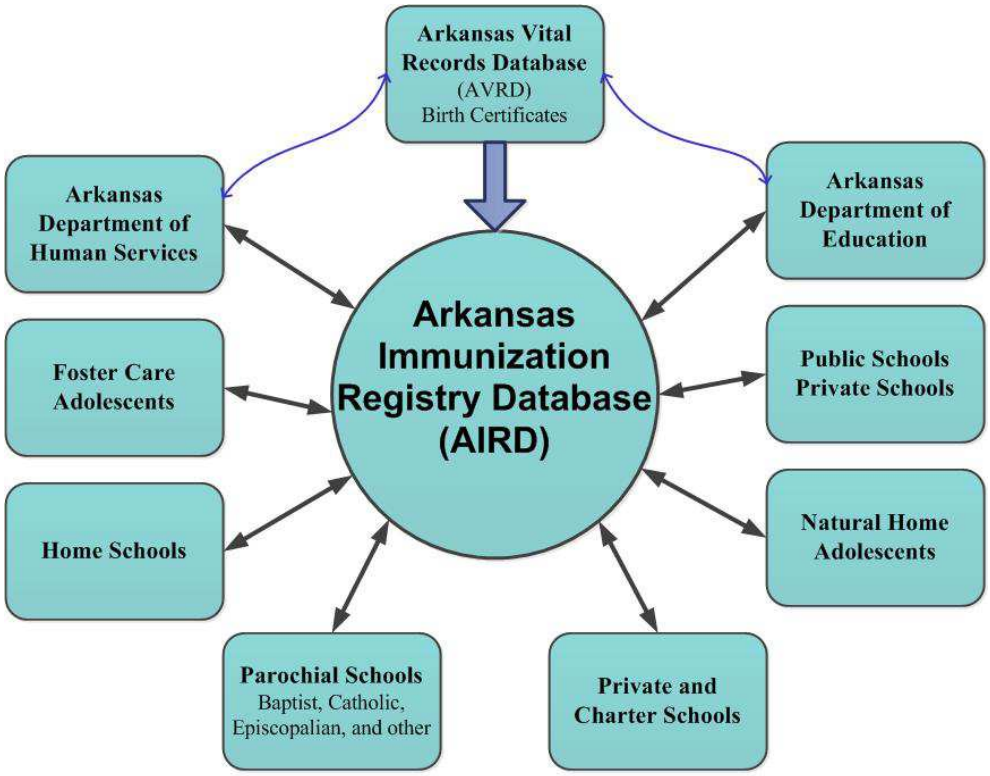

Figure 1. Arkansas immunization linkage database.

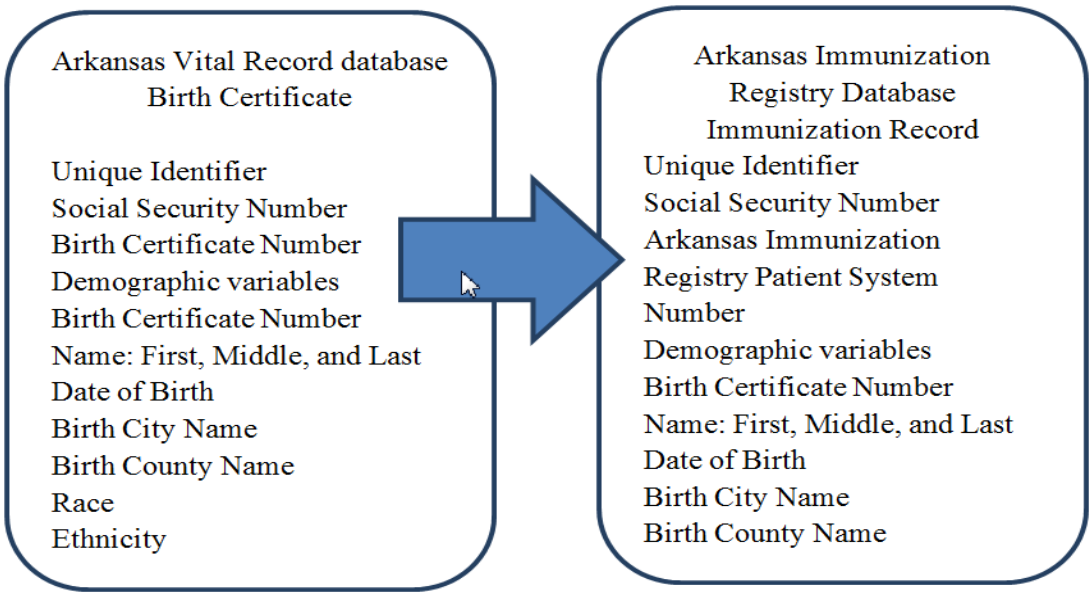

Figure 2. Optical file linkage algorithm.
Note. Adapted from "Designing the optimal file linkage algorithm," by T. M. Lin, 2003, retrieved from Retrieved from http://webcast.hrsa.gov/conferences/mchb/cdc/mchepi2003/index .htm, and "Designing the optimal file linkage algorithm OFLA," by T. M. Lin, 2004, retrieved from http://www.lexjansen.com/scsug/2004/Lin%20-%20Designing%20the%20Optimal %20File%20Linkage%20Algorithm.pdf.

The deterministic linkage algorithm achieved accuracy and true positive matches of linked records from the independent databases (Lin, 2011). I achieved true positive matches of linked records when I combined unique identifiers such as social security numbers with gender, name, and birth date variable fields (Grannis, Overhage, & McDonald, 2002; Lin, 2011). The deterministic linkage algorithm was accurate for matched records, achieved high sensitivity of 90–92%, and maintained 100% specificity of linked records (Grannis et al., 2002). Therefore, the deterministic-linkage-algorithm method was appropriate to link birth records with immunization records in this study.

The deterministic method of data linkage was important and matched records from the vital records and immunization database (Lin, 2003). The data-linkage process

has potential problems associated with errors such false negatives, false positives, and duplicate records when matching data sets or records (Bohensky et al., 2010; Lin, 2003). Therefore, I matched a proportion of records and a proportion remained unmatched (Bohensky et al., 2010). New parameters included the addition of race, gender, and ethnicity, assimilated in the linkage to match all unmatched records (Grannis et al., 2002; Lin, 2003).

IRB Approvals

I completed all ADH IRB requirements, which included Health Insurance Portability and Accountability Act (HIPAA) compliance, confidentiality, and privacy trainings. This was the required regulatory process to obtain archival data from the ADH. I obtained IRB approvals from ADH and Walden University (03-17-15-0137370) and eventually obtained the data from ADH, after the dissertation committee approved the draft proposal and after Walden University IRB approved the IRB application to conduct this study. The Walden approval number for this study is 03-17-15-0137370.

Instrumentation

I did not require a study instrument to establish a calculated adolescent immunization rate. I used archival data from the AIRD to obtain information on immunization rates for the 1990 birth cohort, PCA (ADH, 2008). I obtained archival data for the 1990 PCABC upon approval of the ADH SAC. This archival data contained immunization histories and records of all children born in PCA between January 1, 1990 and December 31, 1990. Each individual immunization record contained a history of vaccine type, date of administration, demographic, and a deidentified number instead of a name. The registry data combined FCA and NHA data, as required by law. The registry

staff coded FCA and NHA data; then senior epidemiologists reviewed the coding before releasing the data to me. This process ensured protection of minors in accordance with Arkansas law. All 1990 cohort names were in the registry. The deidentified data were coded as 0 for FCA and 1 for NHA.

Target Population

The target population was adolescents in the 1990 PCABC, and had three inclusion criteria: (a) adolescents aged 13–18, born between January 1 and December 31, 1990 in PCA; (b) attended public schools in PCA from 1996 to 2008; and (c) had immunization records in the AIRD. The 1990 cohort PCA was stratified in two groups: NHA and FCA. FCA represented the high-risk group because of their social status as wards of the state. The cohort demographic distribution was by gender; race including Caucasian, African American, and other; and age, assumed to be constant because of their identical birth year 1990.

Target-Population Approximate Size

The ADH reported 9,102 births in PCA in 1990 (ADH, 2015). The targeted analyzed population of adolescents born in 1990 in PCA was limited to the universe of individuals who were 13 years old in 2003, attended public school, and had vaccine records in the AIRD.

Foster-Care Sample Size

The average annual enrollment of FCAs in the ADHS system from 2000 to 2008 was 83.11 per year. The largest foster-care enrollment was 164 adolescents in 2006. The estimated annual sample-size range was 83 to 164 adolescents (ADHS, 2010). The sample size was less than the cohort population due to a proportion who attended private

school, immigration and emigration, relocation, mortality, and loss to follow up. Several other factors influenced the FCA sample size such as social family structure, domestic violence, family social disruption, and judicial actions due to child abuse and maltreatment (ADHS, 2010).

The AIR data were coded for FCA and NHA as zero and 1, respectively. The foster-care sample size was based on the total number of adolescents coded as foster care in the 1990 PCABC. The AIR received all reported immunization histories, provided confirmation, and verified compliance with immunizations for school enrollment (ALB, 1995a). The AIRD incorporated functions to match the name and unique identification roster of adolescents with their immunization histories, for analysis that determined 1990 PCABC immunization rates.

Sampling and Sampling Procedure

Sampling Strategy

The study sample was drawn from census data of 5,257 births, registered in ADH vital statistics, for PCA (ADH, 2015) and from AIRD. All records with date of birth, location, date of vaccination, dose, lot number, and type of vaccine administered were in the sample and analyzed. Physicians, healthcare providers, and all facilities that administered vaccines were required to report the name, date of birth, location, date of vaccination, dose, vaccine lot number, and type of vaccine administered to all children and adolescents within 30 days to the AIRD (ALB, 1995a).

Sampling frame

The sampling frame was based on population and I used the HL7 form for the entire cohort population data collection. Healthcare providers are required to use the HL7

form to report individually administered immunizations to the registry (ALB, 1993). The sampling frame in this study was not a predetermined sample of selected households.

Inclusion criteria. This study had four inclusion eligibility criteria: vaccine types, date of birth and geographic location, specific year interval, and education. The four eligibility criteria were (a) children with health-provider-reported immunization records for five routinely recommended vaccines required for school entry; (b) children with birth dates between January 1, 1990 and December 31, 1990 who were born in PCA, (c) eligible cohort children who attended public schools in PCA between 1996 and 2008, and (d) vaccine records in the AIR.

Exclusion criteria. Children who did not attain the four inclusion eligibility criteria defined in the cohort period were excluded from the study analysis. The first criterion was date of birth. The second criterion was geographic criterion and was limited to the contiguous residential zip codes in PCA. The third exclusion criterion in this study was school attendance. I excluded adolescents born in 1990 who were not enrolled in public schools in PCA. The fourth exclusion criterion was children who did not have vaccine records in the AIR. For example homeschooled or adolescents who attended private schools were excluded from this study because homeschooled children and students who did not attend public school are not required to comply with FVSE requirement.

Procedures for Recruitment, Participation, and Data Collection

This quantitative study design did not require recruitment, participants, or data collection. I analyzed archival immunization data from AIRD. I focused and obtained access to deidentified Arkansas adolescent immunization data from ADH and did not

require participant recruitment procedures. The data were limited to a 1990 birth cohort of all births between January 1, 1990 and December 31, 1990, recorded in PCA.

I sent two request letters to obtain access to data. I sent the AIRD request letter to the Chief of Immunization Branch, ADH to request permission to obtain and use deidentified AIRD data. I obtained coded immunization data on FCAs and NHAs. The AIR removed all names and social security numbers, and maintained confidentiality and privacy protection. The ADH is responsible for all immunization records in Arkansas (ALB, 1995a). The process to obtain access to deidentified 1990 birth cohort AIRD was a significant challenge, due to regulatory requirements.

Variable Measurements and Definitions

Measures of Immunization Status

Measures of immunization status analyzed in this study was FVSE UTD of specific rates for each of the FVSE defined in AIL (ADH, 2008).

Five vaccines for school entry and adolescent up-to-date status. For examination of the UTD of the FVSE, I examined each required vaccine. Table 2 outlines each vaccine, the number of doses needed, the interval between each administered dose, and the age at which the full vaccine is required. In this study, I examined the 1990 birth cohort; most adolescents in this cohort were 13 years of age at the time, and I expected that all childhood immunizations were completed. However, in some instances, this was not the case. Thus, an adolescent was considered not UTD if any of the following occurred:

1. Any one dose was missing among any of the FVSE;

2. The interval between the booster dose (the first dose) and any subsequent dose was more than 5 days of when the follow-up dose was expected;
3. An exception was noted to immunization due to religious or political reasons.

Thus, the analysis of UTD coverage was based on an all-and-on-time or nothing concept. For example, UTD was coded as 1 if the adolescent had all required vaccines in a series and these vaccines were given within the stated time. An adolescent was coded as 0 when doses of a given vaccine were missing or when the interval between the booster dose and the follow-up exceeded the maximum allowable time between vaccine series. All children who had a vaccine exemption were coded as 0 for their UTD.

Table 2

Vaccination Schedule for the FVSE

Vaccine	Minimum number doses in complete series	Minimum age at 1st dose schedule	Minimum age at 2nd dose schedule	Minimum age at 3rd dose schedule	Minimum age at 4th dose schedule	Minimum completion milestone age and school grade
Diphtheria, Pertussis, Tetanus	4	3–4 months	5–6 months or within 8 weeks of 1st dose	7–18 months or 8 weeks after 2nd dose	19–48 months or within 8 weeks after 3rd dose	11–13 years or 7th grade
Poliomyelitis	3	3–4 months	5–18 months or 8 weeks after 1st dose	19–48 months or 8 weeks after 2nd dose	N/A	11–13 years or 7th grade
Measles, Rubella, Mumps	2	13–48 months	49–72 months	N/A	N/A	11–13 years or 7th grade
Hepatitis B	3	3–4 months	5–12 months or 8 weeks after 1st dose	13–18 months or 8 weeks after 2nd dose	19–48 months or 8 weeks after 2nd dose	11–13 years or 7th grade
Varicella	2	13–18 months or history of diagnosed varicella	49–72 months or history of diagnosed varicella	N/A	N/A	11–13 years or 7th grade

Note. Adapted from "Arkansas State Board of Health: Rules and Regulations Pertaining to Immunization Requirements," by Arkansas Department of Health, 2008, Retrieved from http://www.healthy.arkansas.gov/Aboutadh/Rulesregs/Immunizationreporting.pdf.

Education grade and vaccine completion. Table II in AIL identified specific numbers of doses and vaccine types required and completed on or before attaining certain grade levels (ADH, 2008). The adolescent was unvaccinated if the dose series was not completed and documented or if an exemption was noted in the immunization-registry records.

Certain clinical criteria were based on the immunization schedule, such as age and interval since the last dose was received and before the next dose was administered. This

interval in time was the time between date of birth and the date when the specific vaccine was administered, reported in AIR. If the interval of days between vaccine doses was within ± 5 days of the maximum length of time required for the next recommended dose, those children was considered vaccinated (ADH, 2008; CDC, 2014a, 2014b). However, intervals greater than 5 days of the maximum length of time for any vaccine series requiring more than one dose meant I classified the adolescent as unvaccinated, if they did have a documented new series of completed vaccinations among those previously missed.

In addition to the age vaccine milestone, I also had a grade-appropriate vaccination requirement. The state mandated certain vaccine milestones for kindergarten, third grade, and seventh grade, to achieve school-entry requirements. Table 2 simplifies the recommended schedule and reflects the expected coverage for all children enrolled in public school (ADH, 2008). However, the observed immunization coverage varied and because of missed vaccine doses, inappropriate intervals sometimes accrued for immunization doses or immunization exemptions (LoMurray & Sander, 2011a).

Age-appropriate status. Age-appropriate status means the specific duration or optimal age to receive all vaccine doses in a series (Kim & Lee, 2011). For example, age-appropriate status for the first dose of Tdap vaccine was 12–15 months (CDC, 2011i). Age-appropriate status was expressed as an age-specific trend through measured parameters such as rates of vaccine coverage for age-specific groups: younger than 1 year, 1 to 10 years, and 11 to 18 years (Skoff et al., 2012). In these measurements, the numerator was the number of persons in the age-specific group who received the vaccine such as Tdap and the denominator was the total number of persons in the cohort who

were eligible to receive the vaccine (Lindley, Smith, & Rodewald, 2011). The cohort vital statistics data provided eligibility status. Eligibility-inclusion criteria were based on the cohort birth date, January 1, 1990 to December 31, 1990, county birth place of Pulaski, and valid vaccine doses administered between January 1, 1990 and December 31, 2008.

Measure of Home Status

The ADHS foster-care criteria were legal court and state-award assignment of children for social custody-protection services. Children assigned to ADHS social-protective services were registered in the CHRIS system as foster-care children eligible for adoption (ADHS, 2010). The CHRIS system was the source for FCA demographic information used by the registry to match vaccine records. The ADHS provided an identified FCA name roster to ADH. The ADH matched the FCA names with their corresponding vaccine records. All FCA and NHA vaccine records in AIRD were coded, deidentified with unique numbers, and then released to me. The ADH also processed NHA and FCA vaccine records to protect adolescents and maintain confidentiality and privacy. NHAs were individuals who were not wards of the state, never enrolled in ADHS, and were not identified in the CHRIS system.

Variable Definitions

Vaccination coverage uptake (VCU): The number of adolescents with FVSE-completed dose series divided by the number of adolescents in the 1990 birth cohort, PCA, and then multiplied by 100.

Immunization rate: The number of adolescents in the age group (1990 PCABC) who received FVSE in PCA divided by the number of adolescents in the target

population who were legally required to receive FVSE (ADH, 2008; ALB, 1993) multiplied by 100,000.

Age-specific immunization rate: The proportion of vaccines in a dose series received by children, as prescribed in ACIP immunization schedules (CDC, 2007d). For example, this category includes the number of adolescents of a specific age such as 13–15 years old in the 1990 PCABC who received a number of vaccine doses of FVSE divided by the total number of adolescent vaccine doses of FVSE in that target 13–15-year age group who are legally required to receive FVSE (ADH, 2008; ALB, 1993) multiplied by 100,000.

Five vaccines for school entry (FVSE): Four doses of Td/Tdap, three doses of Hep B, two doses of MMR, three doses of OPV/IPV, and two doses VAR (ADH, 2008).

Pulaski County, Arkansas birth cohort (PCABC): Adolescents born in PCA in the birth cohort between January 1, 1990 and December 31, 1990.

Natural-home adolescent (NHA): An adolescent who lives with their natural or adoptive parents, has never been in child-protective services, and attended public schools from 1996 to 2008 in PCA (ADHS, 2010).

Foster-care adolescent (FCA): An adolescent up to age 18 years who does not live in their natural or adoptive parents' residence and are under court-ordered judicial protective care supported through ADHS control (ADHS, 2010).

Potential Covariate Variables

Age, race, ethnicity, and gender were important covariates in which immunization coverage for the FVSE differed between groups, thereby confounding true associations. The specific race and ethnic codes I used appear in Table 3.

Table 3

Covariate Codes, Pulaski County, Arkansas, 1990 Birth Cohort

Covariates	Codes
Caucasian	W
African American	AA
Other	O
Hispanic	H
Not Hispanic	NH
Female	F
Male	M

Data-Analysis Plan

Variable Calculations

Immunization-completion calculation. I calculated the total number of doses per vaccine recommended for FVSE based on adolescent-age distribution in Appendix A, Table A1, adopted from tables in AIRR (ADH, 2008). Each vaccine dose series had a maximum number of doses required to complete the vaccine series. I based the vaccine-completion calculation on addition of all valid doses at appropriately administered intervals established in the ACIP vaccine schedules (CDC, 2008b).

Independent and dependent variables. The independent variable was HOR, defined as NHA or FCA in the 1990 PCABC. The dependent variables were UTD and age-appropriate UTD FVSE. Potential covariates included gender, race, and ethnicity.

Descriptive Statistics

Descriptive statistics were a descriptive quantitative analysis plan for normal-distribution archival-immunization data. The quantitative parametric test included

multivariate analysis and statistical central tendencies: frequencies. The specific cumulative vaccines required for school entry were Td/Tdap, Hep B, MMR, OPV/IPV, and VAR. I analyzed the 1990 PCABC archival-immunization data from AIRD with SAS 9.3 software (Cary, North Carolina, USA).

I counted duplicate vaccine doses for the same vaccine series administered at spaced interval as valid doses in the numerator. I corrected multiple different immunization dates for the same vaccine series based on the ACIP vaccine schedule (CDC, 2008b). I considered a vaccine series to have been completed if the total number of valid doses was equal to the number of doses for that vaccine type. I repeated this process for all FVSE and calculated the percent of immunization rates.

AIR built immunization-registry records from health-provider documented and reported immunization histories of individually administered vaccines (Khare et al., 2000). However, it was important to maintain the accuracy and completeness of the immunization histories and eliminate significant errors in children's names, dates of birth, vaccine types, no data reported, and overall duplicate records to calculate coverage accurately (Khare et al., 2000). Each unique identifier number accompanied vaccine type with doses administered. If the same vaccine dose was administered beyond the required maximum dose number, then I considered the rest to be duplicates and did not include them in the analysis. Thus, I defined excess doses as over-immunization.

The names of individual adolescents were not important in this analysis. ADH coded individual immunization records with a unique number and identified all FVSE vaccine doses received and documented in that record. I did not count or include the

vaccine doses that fell outside the defined ACIP vaccine schedule (CDC, 2008b) in the analysis as valid doses for that vaccine series.

Research Questions and Hypotheses

Four Research Questions and Data-Analysis Plan

This data analysis plan addressed four research questions.

RQ1: Are the calculated 2006–2008 adolescent percent vaccination uptake (VCU) for FVSE among the 1990 Birth cohort in PCA (PCABC) significantly different from the FVSE reported 2006–2008 U.S. national adolescent estimated immunization rates?

H_o1: There is no difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent national immunization teen (NIS-Teen) estimated percent VCU for the FVSE.

H_a1: There is a difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent NIS-Teen estimated percent VCU for the FVSE.

Research Question 1 analysis plan. To compare rates in the PCABC and the United States, I conducted direct standardization, standardizing the rates by age. The standardization accounted for any mixing of a third factor, age, and vaccine coverage uptake. The goal of the standardized rates was to account for any mixing of a third factor and multiple other factors with the primary association of interest. I then performed the *t*-test statistical analysis to compare differences between PCABC and the United States for test significance.

Direct-standardization statistical tool. I standardized the PCA birth cohort PCABC vaccine UTD to the 2010 U.S. Census to compare adjusted rates between PCABC and U.S. NIS-Teen. I determined the total population census for 2010 for the United States, Arkansas, and PCA from the U.S. Census Bureau for 2010. An example of direct standardization steps and Table 4 illustrate how I adjusted immunization rates. I extracted the age distributions total census for 16, 17, and 18 years from the U.S. Census Bureau to determine the weighted factor (*w*) for each age group. The number of PCA adolescents was the numerator. The number of U.S. adolescents in the U.S. Census 2010 was the denominator. The numerator divided by the denominator equaled the weighted factor. The weighted factor is the fraction of PCA adolescents for each age group, 13–18 years, depending on the years 2003–2008, based on U.S. Census adolescents for that year. I determined the weighted factor for each age group (13–16 years for 2006) for PCABC and U.S. NIS-Teen. I converted the vaccine percentage from SAS frequency analysis to fractions (*m*) for each vaccine for each year 2003–2008. I multiplied the *m* value by the *w* for each age stratum for that year. Then *m***w* yielded the adjusted UTD for that age. I repeated this multiplication for ages 13–16 years (if 2006), then summed to obtain the vaccine-adjusted rate for that year.

Table 4

Calculations Direct Standardization Vaccination Rates: Age Standardized to 2010 U.S. Population

	Arkansas 2006 PCABC	Standard population 2010 census			U.S. 2006 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	x	b	xb	13	x	b	Xb
14	x	b	xb	14	x	b	Xb
15	x	b	xb	15	x	b	Xb
16	x	b	xb	16	x	b	Xb
		sum(*m***w*)	CT.00%			sum(*m***w*)	CT.00%

Note. PCABC = Pulaski County Arkansas birth cohort; NIS = national immunization surveys.

Direct standardization steps.

1. U.S. 2010 total census came from the U.S. Census Bureau
2. Arkansas population 2010
3. Total number of adolescents each year 16, 17, and 18 years
4. PCA number of age specific 16, 17, and 18 years
5. Vaccine percentages for each year 2006, 2007, and 2008
6. Immunization rates from the SAS frequency for each vaccine for each year 2003–2008: 2003 represents age 13. Next, I determined PCABC and U.S. NIS-Teen percentages for UTD all vaccines Td/Tdap, Hep B, MMR, OPV/IPV, and VAR. The vaccine UTD is the *m* value in the equation to determine the adjusted vaccine UTD for 2010
7. The weighted factor *w* was the percent of PCA based on U.S. Census adolescents for that year.

8. *m***w* yielded the adjusted UTD for that age. I repeated these multiplications for 13–16 years for 2006 because in 2006 the cohort was 16 years old. I summed *m***w* to obtain the 2006 UTD for each vaccine.
9. *D* and *P* were the confidence-interval-value minimum and maximum ranges.

RQ2: Are there differences in percentage of FVSE vaccine coverage uptake between NHA and FCA among adolescents in the 2003–2008 PCABC?

H_o2: There is no significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

H_a2: There is a significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

Research Question 2 analysis plan. I dichotomized FVSE as yes, UTD for all five vaccines, or no, not UTD, even if one vaccine was missing. I conducted chi square analysis to examine whether an association emerged between UTD FVSE and HOR: NHA or FCA. A significant association existed; I then conducted multiple logistic regressions to determine the odds of being UTD for FVSE for an NHA versus an FCA. I conducted multiple logistic regressions to control for the confounding effects of age, race, ethnicity, and gender.

Chi square test statistic and confounding analysis.

- I calculated the chi-square test (χ^2) and reported *p*-values in Chapter 4.
- I used the chi-square test (χ^2) to test the association between NHA/FCA HOR and the vaccine UTD dependent variable.

- I found that confounding variables distorted the strength of the relationship between the independent variable HOR (NHA or FCA) specific stratum and the UTD outcome variable.
- I calculated and compared five-vaccine UTD rates among NHA/FCA-specific stratum related to a covariate variable (race, gender, and ethnicity).
- I compared NHA and FCA stratum-specific association significance with vaccine UTD-specific stratum when controlling or adjusting for race, gender, and ethnicity.
- For example, NHA or FCA had a stratum for race (African American, Caucasian, and other); gender (male or female); and ethnicity (Hispanic and non-Hispanic).
- The criteria for significant association was *p*-value ($p < .05$) when I included a confounder stratum (race, gender, and ethnicity) in the logistic regression model, based on test statistics of *p*-value ($p < .05$) and the odds ratio (OR) likely associated value (if the OR has a positive or negative value). Caucasian adolescent was the reference (1) in the race covariate.
- I performed the chi-square test (χ^2) analysis, OR calculations in SAS applications. I controlled and eliminated the confounding variable to establish a clearer relationship between the NHA/FCA and UTD.
- I performed manual calculations of the chi-square test vaccine UTD.
- $\chi^2 = (o - e)^2/e$; observed (o), expected (e).

RQ3: Is the association between HOR, defined as NHA and FCA, and UTD of FVSE coverage mediated through sociodemographic characteristics, which include age, race, ethnicity, and gender in PCABC?

H_o3: The associations between HOR, as defined as NHA or FCA, and UTD FVSE in PCABC is not mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

H_a3: The associations between HOR, defined as NHA or FCA, and UTD FVSE in PCABC is mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

RQ3 analysis plan. I examined the statistically significant effect mediation by sociodemographic characteristics on the main-effect association, association between HOR, and UTD FVSE (see Figure 3). I conducted multiple logistic regression analyses by including interaction terms in the model. I performed bivariate logistic regression to examine the association between FVSE and HOR while controlling for covariates race, gender, and ethnicity. I report the results in Chapter 4.

Multiple logistic regression model to account for mediated variables.

- I tested if the mediating variable has a significant direct or indirect effect on the relationship between NHA/FCA (*X* variable) and vaccine UTD (*Y* variable).
- I tested the effect significance-based calculated OR and $p < .05$ in the regression model to determine if the mediator variable *p*-value estimates increased or decreased.

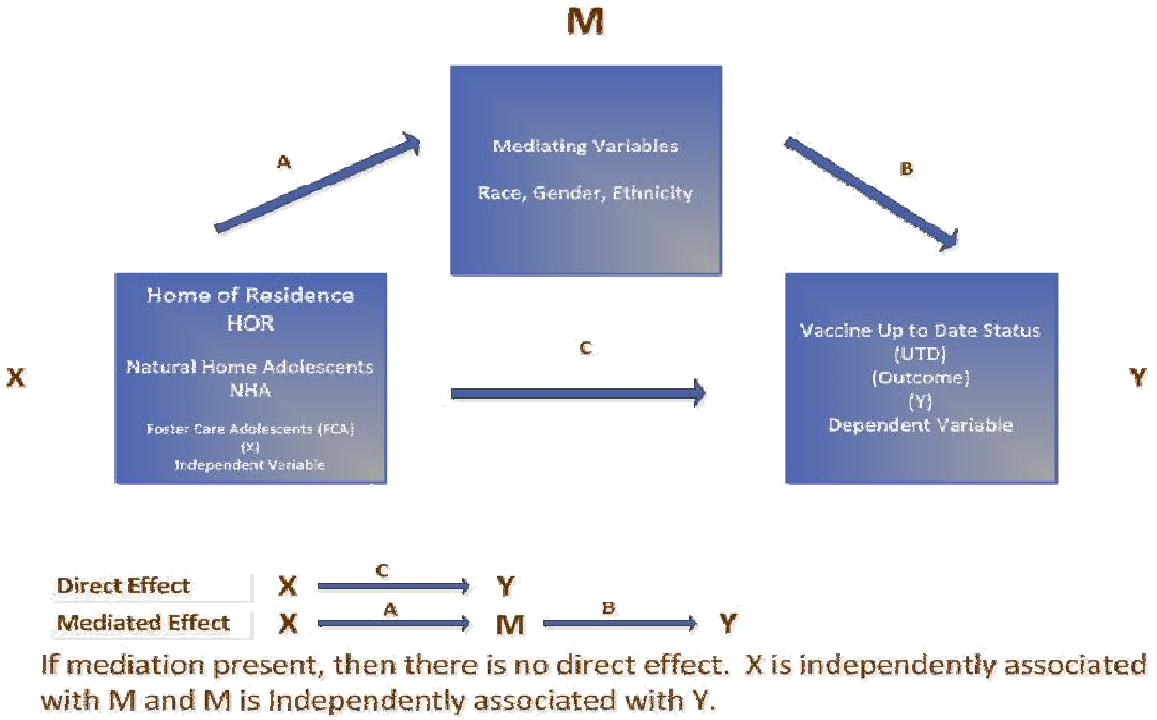

Figure 3. Mediating effect diagram.

Three outcomes.

- I gained a better understanding of the overall relationship between NHA/FCA (*X* variable), vaccine UTD (*Y* variable), and covariates.
- I performed a bivariate logistic regression to examine mediation from covariables.
- The mediator explains the *X*–*Y* relationship when a significant association emerged with or without the mediator. If the *X* and *Y* variables and covariates aligned or related because of a mediator (*M*) variable such as gender, race, and ethnicity, then *M* facilitated the association between *X* and *Y*. Changes in OR and $p < .05$ without *M* yielded no association between *X* and *Y*. Thus, *X* –> *M* –> *Y*.

- I measured the association and mediation bases estimates of OR and $p < .05$; p-value significance was based on $p < .05$.

I measured three outcomes using estimates of p-value based on $p < .05$.

- Mediation present: The calculated p-value diminished to near zero (.0001), a direct effect is not significant, and the mediator is present. The effect of X on the mediator is significant and the effect of the mediator on Y is significant.
- Partial mediation: The direct effect of X to Y is borderline significant when the mediator is absent.
- No mediation: The direct effect from X to the mediator is insignificant and the Mediator to Y is insignificant.

Accounting for mediated variables will increase understanding of three potential outcomes when the mediating variable is included in the multiple logistics model.

Determining mediation. A variable must satisfy three criteria before it is deemed a mediator. It must align with the main outcome variable; it must align with the exposure variable; and it must be in the causal pathway between the exposure variable and the outcome variable. I conducted bivariate analyses to determine whether each covariate satisfied these criteria. Each variable that was not associated with the outcome variable and the exposure variable was not a mediator. Further testing prevented Type II error, incorrectly concluding that mediation does not exist. These bivariate regression processes detected simple mediation (Preacher & Hayes, 2008) and identified any differences in direct and indirect mediation (Preacher & Hayes, 2004). The additional examination decomposed any causal association to expose the contribution of each variable (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). This process ensured

exhaustive and complete testing (MacKinnon et al., 2002) of all variables in the bivariate logistic regression analysis, examining the association between FVSE and HOR and mediating variables (Baron & Kenny, 1986; MacKinnon, Krull, & Lockwood, 2000). The extent and strength of the association revealed and explained, for each variable, the effect of that variable on the outcome (Preacher & Hayes, 2004).

RQ4: Will differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, affect group interest, measured by deaths as a result of nonvaccination for the FVSE among the PCA?

H_o4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will not affect group interest, measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

H_a4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will affect group interest, measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

Research Question 4 analysis plan. I operationalized the vaccination TOG equation parameters and developed a model for payoffs. I then applied the individual equilibrium equation and group optimum equation to calculate payoffs. The *r* (attack rate) parameter was significant in the two equations:

- The attack rate [*r*] for a VPD was the number of persons in the age group with the VPD divided by the number of persons in the age group, then multiplied by 100.

- The individual strategy was the delayer strategy: The goal was to delay vaccine maximized protection-benefit payoff, reduce risk from VPD attack, and diminish death from vaccine.
- I used the attack rate *r* in the individual equilibrium equation to calculate the probability of death due to VPD or vaccine.
- The group optimum is a preemptive strategy: The payoff outcome minimizes the expected cost of vaccination, which is death from VPD.
- I used the attack rate *r* in the group optimum equation to calculate the expected cost of vaccination: the level of vaccine coverage to minimize death due to VPD or vaccine.

The individual-equilibrium equation. I used the individual-equilibrium equation to examine the relationship between those who preemptively received vaccination and those who delayed vaccination for each of the FVSE. The payoff for an individual receiving vaccination can be expressed as $E_{vac} = -d_v$ where d_v is the probability of death from vaccination. Because the probability of death due to vaccination was usually small, I usually ignored d_v in the equation; therefore, I usually assumed E_{vac} was 100%, or 1 when expressed as a probability. Therefore the focus was on the effect of an individual who delayed vaccination and the risk of acquired disease when an outbreak occurred. $E_{del}(p)$ was the equation to examine vaccine delay and the payoff associated with delay:

$$E_{del}(p) = -r[\phi_s(p)d_s + \phi_v(p)d_v],$$

where, $E_{del}(p)$ calculated payoff when an individual chose to delay vaccination; *r* is the risk of attack from a VPD after an outbreak occurred, calculated as the number likely to

become infected when no vaccine protection was divided by total population at the risk of becoming infected. $\phi_s(p)$ is the probability that a delayer becomes infected with the disease after an outbreak; calculated as the total number of eligible unvaccinated divided by the total population at risk of becoming infected. d_s is the probability of death due to a VPD; calculated as the total number of deaths among those who are unvaccinated from VPD divided by the total population at risk of becoming infected. $\phi_v(p)$ is the probability that a delayer was vaccinated successfully after an outbreak; calculated as the total number of disabilities among delayers receiving the vaccination divided by the total number of delayers who received vaccination. d_v is the probability of death of the individual from vaccination; calculated as the total number of deaths due to the vaccination divided by total number of those receiving the vaccine.

Because the goal of the individual equilibrium, P_{ind} was the examined relationship between E_{vac} and E_{del}, the mathematical model for a maximized payoff of receiving a vaccine was significant. In the model where $E_{vac} = 1$ or 100% vaccine efficacy, no deaths from vaccination occurred, and a minimized payoff of delayed vaccination where $E_{del} = 0$ had no payoff for delayed vaccine. Therefore, the expected association was $E_{vac} > E_{del}$. When $E_{vac} \leq E_{del}$ then the individual equilibrium, $P_{ind,}$ may approach zero, where, although an effective vaccine existed, the payoff for delayed vaccine did not pose any additional harm (Bauch et al., 2003). Under such circumstances, individuals chose not to be vaccinated, thereby zeroing out the individual equilibrium, P_{ind}. An important assumption when calculating individual equilibrium was that individual behaviors would increase survival from VPDs when vaccines were readily available.

The group optimum. The group interest and importance was to minimize the total number of deaths due to vaccination and infection when an outbreak of a VPD occurred. Thus, I examined the group optimum and applied the equation

$$C(p) = pd_v + r(1 - p)[(d_s - d_v)\phi_s(p) + d_v],$$

where $C(p)$ was measured as a probability between zero and one. This was the coverage level required and imposed to minimize the total expected number of deaths due to a VPD. All other parameters in the group-optimum equation and variables were the same as those described in the individual equilibrium.

Threats to Validity

External Validity

The results of this study were drawn from a sample of children born in a 1990 PCABC. External validity was the ability to generalize results of this study from a sample to the general population (Trochim, 2006). The results are generalizable to the population of all children born in 1990 in PCA who attended public schools between the ages of 6 and 18 years from 1996 to 2008.

Extrapolating results of the study to other adolescent populations threatens the validity of the study. External factors during the data periods influenced certain causal relations between variables. Such influencing factors had the same effect when the results were generalized to another population. For example, in 2003 Arkansas state law allowed immunization exemptions based on medical, philosophical, religious, and personal beliefs (ADH, 2003). The effect of the law influenced immunization rates for vaccines such as exemptions from Hep B, VAR, and Tdap at the time and age when the vaccine was to be

administered. During 2003, adolescents in the 1990 birth cohort were 13 years old, eligible, and required to receive these seventh-grade vaccines.

The methods and analysis of registry data were replicable when I defined immunization parameters, variables, and outcomes. Dissemination of research results is important for future research (Steckler & McLeroy, 2007). These results provide evidence-based immunization rates and may support strategies to prevent disease, hospitalization, and mortality among adolescents in PCA.

Internal Validity

This study had four significant internal validly threats: immunization enrollment and reporting (Stevenson et al., 2000), no vaccine history or missing records, immunization data-quality assurance (American Immunization Registry Association, 2008), and duplicate records (American Immunization Registry Association, 2006). Errors in vaccine administration included documentation of date of birth and vaccination dates (Khare et al., 2000). These threats contributed to incorrect reported results. Therefore, individual-history record completeness and correctness of variables in immunization data were essential in maintaining the accuracy of the reported outcomes.

Incomplete vaccine-records data were due to passive reporting to AIR and provider delays beyond the allowed 30-day reporting period. Another problem with record accuracy was duplicate records (American Immunization Registry Association, 2006). Immunization-record duplication occurred when transposing name order, date of birth, wrongly coded vaccines, incorrect vaccine type, errors in documented dose series number, errors in lot numbers, and incorrect reported date of immunization. Vaccine-history data were lost, not reported, or incomplete due to electronic transmittal, or used

incompatible electronic formats or software. The HL7 2.x data-exchange format was the compatible standard that used an open architecture and facilitated effective immunization data transfer between healthcare providers and AIR (ADH, 2011a).

The research focus was to examine each record for duplicate vaccine doses and invalid doses. The unique identifier-number feature aggregated all vaccine records associated with the unique number. Therefore, documentation of the same vaccine type administered with the same date of administration indicated duplication. I included only one dose of that specific vaccine, administered on the same day, in UTD calculations and completion of that vaccine dose series. I matched an individual's date of birth with interval dates of vaccine administration to enhance outcome accuracy and minimize internal-validity threats. I verified complete vaccine-dose series and birth-date matches with established ACIP schedules for vaccine series completion for childhood- and adolescent immunization schedules. Standardized EHR with compatible HL7 2.x exchange software increased accuracy in Datalink between provider offices and the AIR. Use of handwritten reports exacerbated errors. Bar-code systems used in scanning patient records and vaccine vitals at point of vaccine administration further eliminated any clerical documentation errors (Khare et al., 2000). This efficient system linked to the registry, thereby eliminating delays in passive reporting. Also, computerized systems improved individual vaccine-records documentation and retrieval. Duplicate records were minimized and points of delivery enhanced through documentation of correct names, dates of birth, vaccine types, and dates of administration, thereby minimizing records.

Ethical Procedures

Confidentiality, privacy, and personal protected information were ensured through deidentification of all immunization data for FCA and NHA. I recruited no participants for this study; therefore I had no ethical concerns related to recruitment materials, processes, and plans to address them. I completed the ADH ethical-research requirements, Walden University IRB application, and the National Institutes of Health certification course. ADH ethical-research requirements consisted of understanding the Health Insurance Portability Accountability Act, confidentiality, and privacy training. I obtained the data-use agreements from ADH and ADHS to enable access to research data.

Institutional Review Board Application

I submitted an IRB application to the ADH with clear declaration that this study did not involve or require any human subjects or participants. The IRB application was required because information for this study involved confidentiality of individual health-protected information. The name and identifiable individual information for each immunization record was blinded to me as assurance of the confidentiality of minors involved in this adolescent-cohort immunization study. I signed a memorandum of understanding that the registry data were deidentified in that all names, social security numbers, and any identifiable information were removed prior to receiving the data sets from the ADH.

The ADH SAC and Walden University received IRB-request applications. I obtained IRB approvals from each board before receiving any AIRD data. I submitted a

certificate of completion of the National Institute of Health course on Protecting Human Research Participants as part of the IRB-application process.

Ethical Concerns in Archival Data

Risk/benefit assessment. No risk or probability and magnitude of harm or discomfort was imposed on any participant in this study. This research was limited to immunization archival data. All personal information was deidentified and the ADH did not release participants' names to me. Although primary data collection was not part of this study, data collected by the AIR met scientific standards for research data, as prescribed by federal law under section 45 CFR 46.102(h)(i)).

Benefit assessment. This immunization research has potential health-related impacts and benefit for future policy, campaigns, or interventions. Any identified vaccines with low coverage offered benefits to future adolescents through the implementation of intervention or policies that target increased immunization coverage. High-immunization rates lower the risk of disease among individuals (Glanz et al., 2010). Any vaccine that achieved an immunization rate of 90% or greater, as established by the Healthy People 2020 indicator, contributed community protection through herd immunity (National Network for Immunization Information, 2006; Schlenker, Bain, Baughman, & Hadler, 1992). Immunization rates of 90% and greater for populations were protective over time and reduced the risk of VPD outbreaks such as varicella (Lee et al., 2008; Vázquez et al., 2004). The risk of disease greatly diminished when populations achieved critical immunization coverage thresholds. For example, coverage thresholds occurred at levels as low as 85% for diphtheria, measles, rubella, and smallpox, and at 94% for pertussis (National Network for Immunization Information, 2006).

Summary

I used a cross-sectional study design to conduct this quantitative inquiry. The cross-sectional design was appropriate because I analyzed and compared archival data on PCABC NHA and FCA immunization rates for FVSE. The methodology was a quantitative analysis of four research questions and commensurate hypotheses. The outcomes measured in this inquiry included UTD for FVSE and percent vaccine coverage uptake among PCABC. Study results were generalized to PCABC. The theoretical foundation in this study was the TOG construct (von Neumann & Morgenstern, 1944).

This cross-sectional-design study employed a retrospective secondary analysis of data collected through the AIR between 1990 and 2008 for the PCABC. The statistical analyses were frequency, chi square, direct standardization, bivariate, and multiple logistic regressions, determining that immunization-rate differences and disparities existed among groups. The four findings from this quantitative analysis of the AIR data contributed justification for immunization campaigns and public health interventions. First, I calculated direct standardization adolescent-vaccination-coverage uptakes for FVSE. I compared the adjusted vaccines uptake rates for the 1990 PCABC to U.S. adolescent coverage uptakes from 2006 to 2008. Second, chi-square analysis identified and compared differences in vaccine coverage between NHAs and FCAs among the 1990 PCABC. Third, I evaluated strength of association between HOR with vaccine UTD with multiple and bivariate logistic regression analysis. For the 1990 PCABC, fourth, I used VGT with applied individual equilibrium and group optimum constructs, and mathematical-model equations that contributed to quantify payoff deaths associated with

vaccination decisions. The TOG posited that the decisions of a group influence individual behavior.

Analysis data were archival data from AIR for the 1990 PCABC. The analysis plan was operationalized based on the four research questions and hypotheses. I defined the independent variables, covariates, and dependent variables in the text along with descriptive quantitative statistical tools used in this study. The important outcomes were primary associations of HOR with immunization, vaccine UTD, and percent coverage uptake.

The analysis in this study answered four main research questions and hypotheses and compared FCA and NHA. This was important because the actions of a group influence individual immunization behavior (Bauch et al., 2003). The adolescent-vaccination coverage uptake was a significant component in this study because of the FVSE. I used the individual equilibrium construct of TOG to examine the probability of preemptive vaccination among individuals in the PCABC. If the proportion of population preemptively vaccinated was greater than the proportion of population who refused the vaccine, then the population achieved a herd immunity threshold.

The theoretical foundation for this study was the TOG. I used TOG constructs (von Neumann & Morgenstern, 1944) to explain individual and group decisions related to vaccination coverage uptake. Using the TOG framework, I calculated the threshold level of VCU (Bauch & Earn, 2004) in a population herd immunity required to prevent disease and minimize the total number of deaths (Baguelin et al., 2013) from vaccination delay or refusal.

The adolescent-vaccination coverage uptake was a significant component in this study. I used the TOG construct (von Neumann & Morgenstern, 1944) to explain vaccination decisions related to coverage uptake. The factors that affected individual decisions to vaccinate related to self-interest (Ibuka et al., 2014), actions of others (Meszaros et al., 1996), risk of infections, and perceived costs and benefits (Basu et al., 2008; Whitney et al., 2014) associated with primary immunization-access factors.

The TOG (von Neumann & Morgenstern, 1944) offered an important modeling framework for adolescent immunization actions, choices, or behaviors to maximize or minimize payoffs. The "game" was a social situation that required behavior, choice, actions, and payoff. The payoffs were quantifiable consequences associated with a particular event, action, or behavior of each participant (M. C. Jackson et al., 2015). The modeling included probabilities, proportions, and frequencies of immunization actions, choices, or behaviors.

The importance of game theory and vaccination was the cost or payoffs associated with adolescent immunization actions, choices, or behaviors. For example, group equilibrium was the decision to immunize and the consequences of that immunization (protection, disease, or death). The probability, frequencies, and proportion were quantifiable actions performed by participants. I calculated the uncertainty actions of participants to predict or forecast adolescent immunization behavior. The social-change impact of predicting adolescent immunization uptake was valuable for public health functions.

Three positive social-change implications accrued from this study. First, results impact parents, community stakeholders, and legislative policymakers, providing

awareness, knowledge, and understanding of the FVSE VCU-coverage quantifiable evidence. The second positive social change was the ability to make informed decisions to vaccinate (Shim, Kochin et al., 2010) associated with VCU coverage, vaccine UTD, and disease outbreaks (Anderson & May, 1985). Another positive social change from this study is the ability to calculate the minimum number of total deaths from not vaccinating adolescents (Bauch & Earn, 2004) against infections from each of the five required adolescent vaccines among the 1990 PCABC. The research focus of Chapter 4 was the data analysis, interpretation, and presentation of results.

Chapter 4: Results

Study Purpose

This cross-sectional study had four main purposes. The first purpose was to calculate and compare adolescent immunization rates between the 1990 PCABC and the U.S. national adolescent immunization survey from 2003 and 2008. The second purpose was to assess whether an association would emerge between HOR, defined as NHA or FCA, and UTD status of FVSE. The study's third purpose was to determine if the associations between HOR and UTD FVSE in PCABC were mediated by such sociodemographic risk factors as age, gender, race, and ethnicity. The fourth purpose was to test a mathematical model based on vaccination-coverage uptake and the TOG.

Data Collection

From January 1, 1990 to December 31, 1990, the PCA had 9,102 recorded live births. However, only 3,371 met the data-collection criteria. The four eligibility data collection criteria were (a) date of birth, (b) geographic criterion, (c) school attendance, and (d) vaccine records in the AIR registry. From the 3,371 children, 74,292 immunization observations were recorded between 1990 and 2008 that covered the FVSE. An observation was defined as each data point in the vaccine record. For example, date of birth in a record is an observation. Similarly, gender, race, date of vaccine administration, vaccine type, dose number in the vaccine series, and location are all observations in a record for a vaccine-dose administration for each visit. I evaluated the immunization records for all PCABC 1990 members based on established vaccine-dose criteria (ADH, 2008) to determine vaccination UTD status for FVSE.

From the extracted data, I was able to identify the demographic characteristics of the 3,371 adolescents born in PCA in 1990, based on demographic ethnicity, gender, and race. I defined ethnicity as Hispanic or not Hispanic, gender as male and female, race as African American, Caucasian, and Other (which included Asian, Native American, and Native Alaskan Islander). The HOR of the adolescent was the independent variable defined as NHA and FCA. The UTD status was the dependent variable and was calculated based on the ADH and CDC vaccination schedule for the FVSE, which included Td/Tdap, Hep B, MMR, OPV/IPV, and VAR. I used Microsoft Excel and SAS 9.3 software (SAS Institute, 2012) for data analysis.

Results

Demographic Characteristics

Of the 3,371 adolescents, 53.2% were African American, 30.7% were Caucasian, and 16.1% identified as Other. Adolescent females accounted for 54.9% of the birth cohort. The majority of the birth cohort was non-Hispanic (97.3%). Overall, only 527 of the adolescents (15.6%) were UTD for all FVSE. The UTD analysis for FVSE was reported for HOR, gender, ethnicity, and race. The total UTD status for FCA was 29.4% compared to 15.1% UTD for NHA. The PCABC overall UTD immunization rate for FVSE was 15.6%. PCABC females were 15.4% UTD, compared to 16.4% UTD for PCABC males. The UTD status for Hispanics was 16.5%, compared to 15.5% UTD for non-Hispanics.

Table 5 shows the overall cohort vaccine-coverage uptake for the FVSE. The VAR vaccine-coverage uptake among PCABC was 1.6 times lower than the FVSE coverage. Among the PCABC, none of the vaccines reached the 90% coverage

recommended by Healthy People 2020 for any race or ethnic group. However, an overall association between race and ethnicity and UTD status for FVSE did emerge in that African-American adolescents were more likely to be UTD than Caucasian and other-race adolescents (see Table 6).

Table 5

Pulaski County 1990 Birth Cohort Vaccine-Coverage Uptake, 2008

Vaccine	No		Yes	
	N	%	*N* (%)	%
Td/Tdap	570	16.9	2797	83.1
Hep B	1,099	32.6	2268	67.4
MMR	751	22.3	2616	77.7
OPV/IPV	522	15.5	2845	84.5
VAR	2,705	80.3	662	9.7
FVSE coverage	2843	84.4	524	15.6

Note. Td/Tdap = tetanus-diphtheria/tetanus-diphtheria-acellular pertussis; Hep B = hepatitis B; MMR = measles-mumps-rubella; OPV/IPV = poliomyelitis; VAR = varicella.

Table 6

Pulaski County, Arkansas 1990 Birth Cohort Population and Five Vaccines for School Entry FVSE Coverage Uptake By Race

	FVSE vaccine UTD status by race							
	Total		No		Yes			
Race	*N*	%	*N*	%	*N*	%	χ^2	*p*-value
Total	3,371	100.0	2,840	84.3	531	15.7	25.93	< .0001
African American	1,792	53.2	1,456	81.3	336	18.7		
Caucasian	1,036	30.7	907	87.5	129	12.5		
Other	543	16.1	477	87.8	66	12.2		

Note. Statistically significant, $p < .05$.

Research Question 1 and Hypothesis 1

RQ1: Are the calculated 2006–2008 adolescent percent vaccination uptake (VCU) rates for FVSE among the 1990 Birth cohort in PCA (PCABC) significantly different from the reported FVSE 2006–2008 U.S. national adolescent estimated immunization rates?

H_o1: There is no difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent national immunization teen (NIS-Teen) estimated percent VCU for the FVSE.

H_a1: There is a difference between the 2006–2008 PCABC calculated percent VCU for the FVSE and the reported 2006–2008 U.S. adolescent NIS-Teen estimated percent VCU for the FVSE.

Direct-Standardization Analysis

As shown in Table 7, I compared the PCABC adjusted UTD coverage rates to U.S. adjusted UTD coverage rates for 2006–2008 U.S. NIS-Teen. These results for adjusted vaccine percent UTD coverage rates were based on U.S. 2010 Census data. The U.S. NIS-Teen had a greater vaccine percentage of coverage uptakes for Hep B (12.0%), MMR (11.6%), and VAR (70.2%) compared to PCABC from 2006 to 2008. Except for Td/Tdap, PCABC had 16.4% vaccines coverage uptake greater than that of the United States for 2006–2008. I included no comparison for OPV/IPV because U.S. NIS-Teen has not collected polio data since 2000, when polio was eradicated in the United States. The greatest vaccine differences between the two groups emerged among the UTD coverage rates for the VAR vaccine.

Table 7

Adjusted Adolescent Vaccine Coverage Uptake Differences (as Percentages) Between Pulaski County, Arkansas Birth Cohort and United States, 2006–2008

	Pulaski County, AR. 1990 birth cohort				U.S. National Immunization Survey					
Vaccine	2006	2007	2008	Average	2006	2007	2008	Average	*t*-test	*p*-value
Td/Tdap	84.0	84.0	83.8	83.9	58.2	72.3	72.1	67.5	3.51	.025
Hep B	77.9	75.6	74.2	75.9	82.1	87.6	87.9	85.9	4.59	.01
MMR	77.7	77.7	77.7	77.7	87.1	88.9	89.3	88.4	15.86	.000009
OPV/IPV	86.2	86.0	82.8	85.0	N/A	N/A	N/A	NA	N/A	N/A
VAR	17.0	17.4	28.8	21.1	89.4	91.8	92.7	91.3	17.59	.000006

Note. Td/Tdap = tetanus-diphtheria/tetanus-diphtheria-acellular pertussis; Hep B = hepatitis B; MMR = measles-mumps-rubella; OPV/IPV = poliomyelitis; VAR = varicella; Pulaski County, AR birth cohort 1990 Data Analysis, $p < .05$ statistically significant; *Standardized to 2010 U.S. population.

Also shown in Table 7, I conducted a student's *t* test for each vaccine—Td/Tdap, Hep B (12.0%), MMR (11.6%), and VAR—to determine whether statistically significant differences arose in adjusted average VCU reported for PCABC and the United States. A statistically significant difference emerged for each vaccine—Td/Tdap, Hep B (12.0%), MMR (11.6%), and VAR at $p < .05$—between PCABC and the United States.

Figure 4 illustrates the vaccine trends from 2006 to 2008 for PCABC and the United States. The PCABC coverage declined 0.2% for Td/Tdap between 2006 and 2008 compared to U.S. adolescents' 14.1% Td/Tdap coverage increase from 2006 to 2007 and 0.2% decline from 2007 to 2008. Hep B coverage showed a 3.7% coverage decline in PCABC between 2006 and 2008. In contrast, U.S. adolescents had 5.8% increased coverage for Hep B between 2006 and 2008. MMR coverage showed a 2.2% coverage increase among U.S. adolescents between 2006 and 2008 compared to no coverage change in the PCABC. OPV/IPV coverage showed a 3.4% decline among the PCABC

between 2006 and 2008. In contrast, no U.S. data was available because the CDC discontinued its household polio survey after 2006 because polio was declared eradicated in the United States in 2000(CDC, 2011). The PCABC VAR vaccine coverage uptake increased by 11.4% between 2006 and 2008 compared to a 3.3% increase among U.S. adolescents.

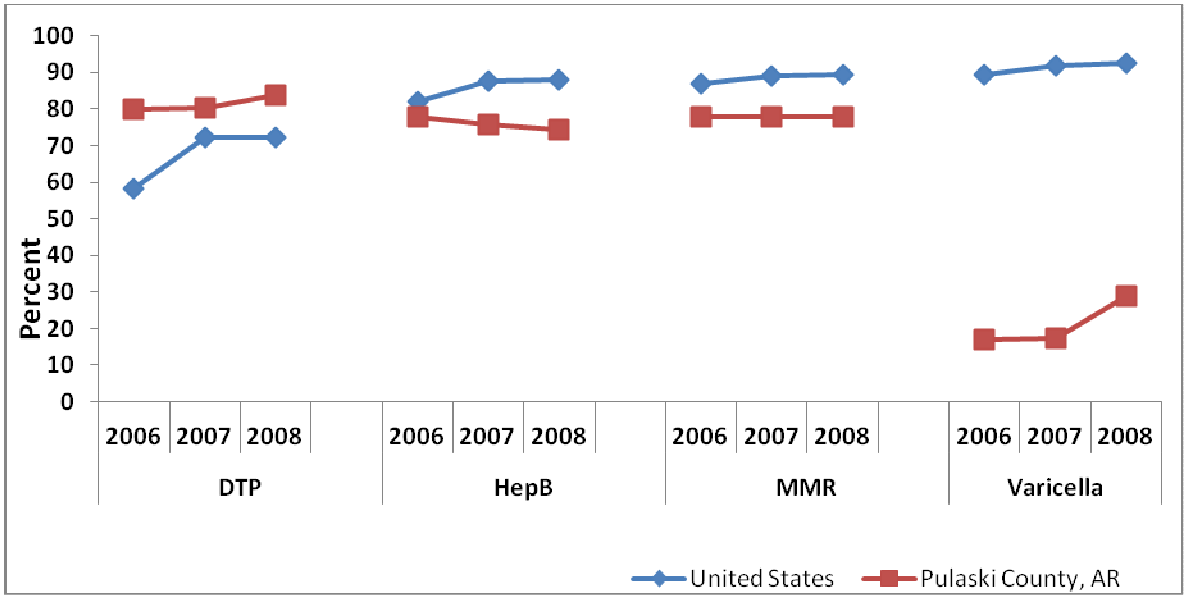

Figure 4. Adjusted adolescent vaccine-coverage rate trends, United States and Pulaski County, AR, 2006–2008.

Research Question 2 and Hypothesis 2

RQ2: Are there differences in percentage of FVSE vaccine coverage uptake between NHA and FCA among adolescents in the 2003–2008 PCABC?

H_o2: There is no significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

H_a2: There is a significant difference in FVSE coverage uptake between the HOR defined as NHA and FCA in the 2003–2008 PCABC.

The chi-square analysis (χ^2) results for RQ2 are in Table 8. An association arose between HOR and vaccine uptake for four of the FVSE. Only Td/Tdap was not associated with HOR and vaccine coverage. For all other individual vaccines, vaccine coverage was higher among FCA than NHA. These three vaccines—Hep B, MMR, and VAR—had strong positive associations with HOR. In contrast, OPV/IPV had weaker positive association with HOR compared to the Hep B, MMR, and VAR vaccines. Children in foster care, contrary to prior hypotheses, are no less likely to complete immunization requirements than children in natural-home settings.

Table 8

Home of Residence Vaccine Coverage Uptake Comparison, 1990 Pulaski County, Arkansas Birth Cohort

	Foster care				Natural home					
	N		%		*N*		%			
Vaccine	Yes	No	Yes	No	Yes	No	Yes	No	χ^2	*p*-value
Td/Tdap	103	15	87.3	12.7	2,694	555	82.9	17.1	1.55	.21
Hep B	96	22	81.4	18.6	2,172	1,077	66.9	33.1	10.89	.001
MMR	107	11	90.7	9.3	2,509	740	77.2	22.8	11.89	.0006
OPV/IPV	108	10	91.5	8.5	2,737	512	84.2	15.8	4.61	.0318
VAR	43	75	36.4	63.6	619	2,330	19.1	80.9	21.79	< .0001
FVSE	35	83	29.7	70.3	619	2,630	19.1	80.9	18.5	< .0001

Note. Td/Tdap = tetanus-diphtheria/tetanus-diphtheria-acellular pertussis; Hep B = hepatitis B; MMR = measles-mumps-rubella; OPV/IPV = poliomyelitis; VAR = varicella; $p < .05$ statistically significant.

To determine whether vaccine coverage remained associated with HOR after controlling for race, ethnicity, and gender, I conducted multivariable logistic regression analyses. After controlling for sociodemographic risk factors, HOR no longer associated with UTD status for FVSE. As shown in Table 9, the race variable is the confounder because it influenced the outcome of UTD status for FVSE. Race influences the

relationship between FVSE and HOR, specifically through the OR, by increasing the likelihood of association between FVSE and HOR. In fact, compared to Caucasian adolescents, African American adolescents were statistically 77% more likely to be UTD for FVSE (OR = 1.77, 95% CI 1.49–2.09) whereas adolescents listed as Other were 46% less likely to be UTD (OR = 0.54, 95% CI 0.43–0.67).

Table 9

Logistic Regression Examining the Association Between Five Vaccines for School Entry and Home of Residence Controlling for Univariates

Variable and covariate	Odds ratio (*OR*)	95% confidence limits	*p*-value
Home-Residence			
Foster-care adolescent	1.02	0.67–1.56	.91
Natural-home adolescent	1		
Gender			
Male	1	0.86–1.17	.99
Female	1		
Race			
African American	1.77	1.49–2.09	< .0001
Other	0.54	0.43–0.67	< .0001
Caucasian	1		
Ethnicity			
Hispanic	1.21	0.78–1.87	.4005
Non-Hispanic	1		

Note. $p < .05$ statistically significant.

Therefore, I conducted multivariable logistic regression (see Table 9) to determine whether mediation existed between HOR, sociodemographic characteristics, and vaccine UTD coverage. In answering RQ2, I found that HOR was associated with FVSE. However, after controlling for sociodemographic risk factors, HOR was no longer

statistically significantly associated with UTD for FVSE. Therefore, this finding satisfied one of the criteria for mediation, that the association between the main outcome variable and the exposure variable may be mediated by a third variable.

For this research question, I further examined whether the overall association found in Research Question 2 could have been due to mediation. Results suggested that one variable, race, mediated the association between HOR and UTD for FVSE. Specifically, African American adolescents, regardless of their HOR, were statistically significantly more likely to be UTD for FVSE compared to Caucasian adolescents. In contrast, adolescents categorized as Other, regardless of HOR, were significantly less likely to be UTD for FVSE compared to Caucasian adolescents (see Table 9).

Research Question 3 and Hypothesis 3

RQ3: Is the association between HOR, defined as NHA and FCA, and UTD FVSE coverage mediated through sociodemographic characteristics, which include age, race, ethnicity, and gender in PCABC?

H_o3: The associations between HOR, defined as NHA or FCA, and UTD FVSE in PCABC is not mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

H_a3: The associations between HOR, defined as NHA or FCA, and UTD FVSE in PCABC is mediated through sociodemographic characteristics, including age, race, ethnicity and gender.

I conducted bivariate analyses to determine whether each covariate listed in Table 10 satisfied these criteria. If I failed to find an association between either the outcome variable and the mediator or the exposure variable and the mediator, then that variable

was not considered a mediator. The result for the bivariate mediation effect between HOR and race for African American was not statistically significant (OR = 1.23; 95% CI 0.85–1.88). African Americans were 23% more likely than Caucasians to be associated with HOR. The bivariate mediation effect between HOR and race for Other race groups was statistically significant (OR = 0.19; 95% CI 0.07–0.53). Other race groups were 81% less likely than Caucasians to with HOR. These results showed a weak positive association between HOR and race when including all race categories in the analysis, regardless of their home status as NHA or FCA.

When I tested HOR mediated by gender, the results for males were not statistically significant (OR = 1.29; 95% CI 0.90–1.85, p = .1716). Similarly, results for HOR mediated by ethnicity for Hispanic was not statistically significant (OR = 1.29; 95% CI 0.90–1.85, p = .1716). Then I conducted univariate analysis for the association between race and UTD for FVSE. Results were statistically significant for African Americans (OR = 1.79; 95% CI 1.51–2.12; p = < .0001) and Other race (OR = 0.48; 95% CI 0.39–0.59; p=< .0001). African Americans were 79% more likely than Caucasians to be associated with UTD for FVSE. Other race groups were 52% less likely than Caucasians to be associated with HOR.

Table 10

Bivariate Logistic Regression Results for Examining Possible Variables in the Association Between FVSE and HOR

Variable and covariate	Odds ratio	95% confidence limits	*p*-value
Home Residence (NHA and FCA) Mediated by Race			
Association between HOR and Race			
African American	1.23	0.85–1.88	.2422
Other	0.19	0.07–0.53	.0016
Caucasian	1.00		
Association between Race and UTD for All FVSE			
African American	1.79	1.51–2.12	< .0001
Other	0.48	0.39–0.59	< .0001
Caucasian	1.00		
Home Residence Mediated by Gender			
Association between Gender and HOR			
Male	1.29	0.90–1.85	.1716
Female	1.00		
Association between Gender and UTD for FVSE			
Male	0.98	0.85–1.14	.8072
Female	1.00		
Home Residence Mediated by Ethnicity			
Association between HOR and ethnicity			
Hispanic	1.07	0.61–1.88	.806
Not Hispanic	1.00		
Association between Ethnicity and UTD for FVSE			
Hispanic	1.12	0.64–1.96	.6984
Not Hispanic	1.00		

Note. $p < .05$ statistically significant.

I stratified HOR in Table 10 for the three covariates—race, ethnicity, and gender—to examine mediation. Race (OR = 1.79; 95% Cl, 1.51–2.12; $p < .0001$) significantly aligned with FVSE, but gender and ethnicity did not. The race OR and *p*-value did not decrease or change during multivariate and bivariate logistic regression

analyses. However, change did emerge in the ORs and *p*-values for gender and ethnicity. Race mediated the association between HOR and FVSE based on established statistical mediation criteria (Baron & Kenny, 1986; Fairchild & MacKinnon, 2009; MacKinnon et al., 2000; Preacher, Zyphur, & Zhang, 2010; Sobel, 1986).

The results shown in Table 11 of the logistic regression hypothesis test for HOR and FVSE revealed significant association when controlling for specific univariates: home-residence FCA versus NHA (OR = 1.61; 95% Cl 1.47–3.34–1.56; $p = 0.0001$), African American race versus Caucasian race (OR = 2.22; 95% Cl 1.29–2.004; p=<.0001) when controlling for Other race groups. An association emerged between HOR and FVSE, stratified for FCA versus NHA in logistic regression analysis (see Table 11). Controlling for covariates showed that FCAs have 122% greater odds of FVSE than NHAs after adjusting for race. This outcome also shows that race is significant in the model.

Table 11

Logistic Regression Examining the Association Between Five Vaccines for School Entry and Home of Residence FCA vs. NHA Controlling For Covariates

Variable and covariate	Odds ratio	95% confidence interval	*p*-value
Home-Residence FCA vs. NHA	2.22	1.47–3.34	.0001
Race African American vs. Caucasian	1.61	1.29–2.004	< .0001
Race Other vs. Caucasian	0.94	1.29	.405

Note. $p < .05$ statistically significant.

Results Research Question 4 and Hypothesis 4

RQ4: Will differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, affect group interest, measured by deaths as a result of nonvaccination for the FVSE among the PCA?

H_o4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will not affect group interest, measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

H_a4: Differences in individual vaccine payoff, measured by avoidance of disease development as a result of vaccine receipt, will affect group interest, measured by deaths as a result of nonvaccination, for the FVSE among the 1990 PCABC.

Table 12 reports the VGT results of the estimated payoff death for each of the nine vaccine-preventable diseases (diphtheria, hepatitis, measles, mumps, pertussis, poliomyelitis, rubella, tetanus, and varicella) and compares the results for individual equilibrium to the group optimum summarized payoff death for these same diseases. The estimated payoff deaths for the individual equilibrium for diphtheria was 2.61; pertussis 1.30; tetanus 3.39; Hep B 5.44; measles 0.001; mumps 0.000095; rubella 0.222; OPV/IPV 0.001; and VAR 12.03. The estimated payoff deaths for the group optimum were diphtheria 0.441; pertussis 0.22; tetanus 0.57; Hep B 1.78; measles 0.0002; mumps 0.000021; rubella 0.050; OPV/IPV 0.0002; and VAR 9.66.

The four highest estimated numbers of deaths were for varicella (12.0 deaths), Hep B (5.4), tetanus (3.4), and diphtheria (2.6). These four highest estimated deaths with

individual equilibrium, defined as a vaccine delayer or individual self-interest group. The four lowest estimated numbers of deaths reported in Table 12 are mumps (0.000021 death), measles (0.0002), poliomyelitis (0.0002), and rubella (0.05). These four lowest estimated numbers of deaths are associated with the group optimum, also defined as the preemptive vaccinator or altruistic group.

Table 12

Pulaski County Arkansas 1990 Birth Cohort Estimated Payoff Comparison Deaths Vaccination Game Theory

	Individual equilibrium deaths	Group optimum deaths
Diphtheria	2.610000	0.441000
Pertussis	1.300000	0.220000
Tetanus	3.390000	0.570000
Hepatitis B	5.440000	1.780000
Measles	0.001000	0.000200
Mumps	0.000095	0.000021
Rubella	0.222000	0.050000
Poliomyelitis	0.001000	0.000200
Varicella	12.030000	9.660000

Note. Pulaski County Arkansas Birth Cohort 1990 Data Analysis.

VGT payoff deaths represent vaccine-behavior scenarios and estimated numbers of deaths that would occur among this cohort of 3,371 adolescents if vaccines were unavailable due to refusal, shortage, or disruption in supply during an outbreak. Consequently, among the four highest estimated deaths, cohort adolescents in the individual-delayer–self-interest equilibrium who refused VAR vaccine would experience a high number of deaths compared to adolescents in the group-optimum preemptive-vaccinator or altruistic group.

Because fewer deaths are predicted for group-optimum behavior, this is the better vaccine behavior. These results suggests that preemptive vaccination was the most protective behavior strategy during an outbreak where group optimum had an estimated 9.6 varicella deaths compared to 12.0 among individual delayers or the self-interested. The group optimum Hepatitis B outcome was an estimated 1.78 death compared to 5.44 Hepatitis B deaths among individual equilibrium or the self-interested delayer equilibrium. Similarly, in the preemptive-vaccinator group optimum an estimated 0.57 tetanus deaths emerged, compared to 3.39 tetanus deaths among individual equilibrium or self-interest delayers. The group optimum estimated 0.441 death from diphtheria compared to 2.61 diphtheria deaths among individual equilibrium or self-interest delayers, suggesting the vaccine-delayer behavior offers a riskier outcome during an outbreak or disease resurgence.

The estimated deaths reported in Table 12 differed from and were higher than the actual number of deaths reported in Table B1 (ADH, 2015). The reported number of deaths in Table B1 is attributable to improvements in public health (CDC, 1999b) and improvements in disease surveillance, hospitalizations, and laboratory and medical services. Therefore, the choice of either the individual equilibrium vaccine behavior, self-interest or vaccine refusal, or the group optimum and preemptive vaccinator before an outbreak was important based on the estimated burden of the number of deaths associated with that specific vaccine.

Individual equilibrium was the self-interest and vaccine-delayer strategy whereas group optimum was the altruistic or group strategy. I calculated the vaccine estimated-payoff deaths based on a model generated from the analysis and the VGT mathematical

formula (Bauch et al., 2003). I reported the estimated payoff deaths for each of the nine VPDs: diphtheria, pertussis, tetanus, hepatitis B, measles, mumps rubella, poliomyelitis, and varicella. The best protection against these nine diseases were the five vaccines diphtheria, Hep B, MMR, OPV/IPV, and VAR that are required for school entry in PCA.

The vaccine-efficacy values of the five vaccines diphtheria, MMR, OPV/IPV, and VAR are important in the payoff-death calculation for each of the nine diseases protected by these vaccines. Tables B5 and B6 contain variables to calculate payoff deaths or risks associated with the individual equilibrium (P_{ind}) and group equilibrium (P_{gr}) constructs defined in the VGT. The VGT predicts the payoffs where the individual choice depended on the group choice. The game-theory constructs were behavior choices of self-interest or group interest that correlated with small or large vaccine-coverage rates. These parameters in each equation included probabilities of disease mortality, disease morbidity, disease attack rate, proportion of vaccinated or unvaccinated, efficacy of vaccines, probability of death from the vaccine, and protective values related to preemptive or delayed vaccination.

Table B5 focuses on the individual equilibrium whereas Table B6 focuses on group optimum. The main difference between Table B5 and Table B6 is the vaccine-delayer choice and the probability that the delayer became infected after a disease attack (d_s). Consequently, vaccine delay, risk of disease, and probability of successful vaccine during an outbreak influenced the individual-equilibrium payoff deaths. The vaccine behavior strategy was to delay or refuse vaccination. Each individual equilibrium equation parameter was used in the payoff-death calculation and these parameters are clearly defined in Table B7.

The main focus in Table B6 was the proportion of preemptive vaccinated population and minimized total number of deaths. I used the defined parameters to calculate group equilibrium in Table B6. Some disease parameters were constant for both groups such as probability of death from vaccine (d_v), probability of death from VPD (d_s), disease attack rate (r), and total number in the cohort. When the parameters in each equation were executed to obtain the payoff values for that vaccination choice or behavior, the comparison determined the preferred vaccination strategy before disease outbreaks occurred.

Table 12 illustrated the calculated payoff death scenario for the individual equilibrium and the group optimum for each disease. The payoff deaths were larger in the individual-equilibrium scenario. When the payoff-death scenario for each disease was compared to the group optimum, smaller numbers of payoff deaths aligned with the group-optimum scenario.

The conclusion was that more deaths occurred in individual equilibrium, where vaccine refusal was the dominant vaccination-behavior choice. The group optimum had fewer payoff deaths, as reported in Table 12. Therefore, the desired and preferred vaccination choice was the group optimum because of the minimal numbers of deaths associated with preemptive vaccination choice. The group optimum offered the greater preemptive public health protection during an outbreak for any of the nine VPDs.

Summary

The results and findings from analysis of the four research questions and hypotheses help explain the relationships between HOR and vaccine coverage. The first finding showed that U.S. adolescents have higher immunization coverage for Hep B,

MMR, and VAR than PCABC from 2006 to 2008. The exception was PCABC immunization rates for Td/Tdap, which was 16.4% greater than U.S. immunization rates. The U.S. comparative data for OPV/IPV was unavailable to evaluate against PCABC OPV/IPV data. The low finding for PCABC matches the research problem statement. Low vaccinations are associated with disease outbreaks (CDC, 2013). The low vaccine coverage and the consequences of low-vaccination rates are supported by several previous researchers on immunization strategies to increase coverage rates (Humiston et al., 2013; USDHHS, 2010b). Examples of strategies to increase vaccinations include the Behavior Risk Factor Surveillance System, the WIC program, the VFC program, school immunization laws, and Healthy People 2020 (CDC, 2013).

The second finding revealed that FCAs had a 10.6% higher UTD for FVSE than NHAs. The immunization rate for FCAs was greater than NHAs for each specific vaccine. In fact, FCA immunization rates for MMR (90.7%) and OPV/IPV (91.5%) attained the greater-than-90% threshold recommended by Health People 2010. Compared to FCA immunization rates, NHAs failed to achieve the recommended 90% threshold for any of the FVSE. This finding differs from other published studies and the expectation that FCAs are more predisposed to have fragmented medical homes than NHA. Other authors averred that, compared to NHAs with stable medical homes, FCAs have low immunization coverage due to social disruption and fragmented medical homes to access recommended age-specific vaccines. High vaccine UTDs are associated with stable medical homes (Humiston et al., 2013).

The third finding from the bivariate logistic regression revealed that race mediated the association between HOR and UTD for FVSE. Specifically, African

Americans have 80% greater odds of FVSE and Other races have 10% lower odds of FVSE compared to Caucasians, after adjusting for residence. The race ORs explained that race was significant regardless of residence status. This finding is significant because, historically, African Americans have had lower vaccination rates compared to Caucasians. Also, race was significant and accounted for in the model. The justification for not including gender and ethnicity (Hispanic and non-Hispanic) in the model was that these groupings did not significantly associate with FVSE.

The fourth finding from the VGT analysis showed that group optimum had lower estimated deaths compared to individual equilibrium for all nine vaccine-preventable diseases. This finding of lower estimated deaths associated with group optimum supports the VGT framework (Bauch et al., 2003). The VGT analysis also revealed that individual equilibrium had higher estimated deaths for each of the nine diseases compared to group optimum. High estimated deaths related to low immunization, which is not protective during a vaccine-preventable disease outbreak (Bauch et al., 2003).

In Chapter 5, I discuss the research findings, study limitations, implications, and positive social change.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

The purpose of this quantitative study was to examine adolescent immunization rates and uptake coverage for the 1990 PCABC. In Arkansas, some anecdotal evidence emerged that a disparity existed in vaccination coverage among adolescents in foster care compared to those in their natural home (Daniels, Jiles, Klevens, & Herrera, 2001; Lindley et al., 2011; Smith, Jain, et al., 2009; Smith, Santoli, et al., 2005). I implemented a retrospective cohort design to examine this immunization-coverage problem among PCABC. I analyzed immunization records for PCABC from the AIRD to answer four research questions. Although Arkansas law requires UTD immunization for FVSE, only 15.6% of PCABC attained the legal immunization requirement for FVSE.

This study produced four findings from the data analysis. First, U.S. adolescent adjusted vaccine-coverage uptake rates were 12.0% higher for Hep B, 11.6% for MMR, and 70.2% for VAR than for PCABC. For Td/Tdap, adjusted PCABC immunization rates were 16.4% higher than for U.S. adolescents. The second finding revealed FCAs had 10.6% higher UTD status for FVSE compared to NHAs. The immunization rate for FCAs was greater than NHAs for each specific vaccine. FCA immunization rates for MMR (90.7%) and OPV/IPV (91.5%) attained greater than the 90% threshold recommended by Healthy People 2010 compared to none among NHA. The third finding was an association between HOR and UTD status for FVSE. The results from a bivariate logistic regression revealed that race mediated the association between HOR and UTD status for FVSE. Specifically, African Americans have 80% greater odds of being UTD with FVSE and Other races have 10% lower odds of being UTD with FVSE compared to Caucasians,

after adjusting for home residence. Fourth, findings from the VGT analysis revealed individual equilibrium had higher estimated deaths for each of the nine diseases compared to the group optimum.

Chapter 5 is organized into seven parts: introduction, research results, interpretations of findings, limitations of the study, recommendations, implications, and conclusion.

Research Findings and Theoretical Context

The study results included significant underimmunization for individual vaccines among the PCABC. Only 15.6% of PCABC were UTD for FVSE. Significant differences emerged from 2006 to 2008 in UTD vaccine coverage between PCABC and U.S. adolescents. During 2006 to 2008 U.S. adolescents showed higher average adjusted UTD coverage rates for Hep B (85.9%); MMR (88.9%), OPV/IPV (no data available), and VAR (91.3%), compared to average adjusted PCABC Hep B (75.9%), MMR (77.7%), OPV/IPV (85.01%), and VAR (21.1%). In general, U.S. adolescents showed average lower Td/Tdap adjusted UTD coverage rates (67.5%) compared to PCABC (83.9%); the difference between the U.S. and PCABC *t* tests was 3.51, $p = .025$.

I found significant associations between HOR and UTD status for FVSE ($\chi^2 = 18.5$, $p \leq .0001$) from the chi-square analysis. The specific vaccines associated with HOR were Hep B ($\chi^2 = 10.89$, p 0.001), MMR ($\chi^2 = 11.89$, $p = .0006$), OPV/IPV ($\chi^2 = 4.61$, p=.318), and VAR ($\chi^2 = 21.79$, $p < .0001$). The vaccine not associated with HOR was Td/Tdap ($\chi^2 = 1.55$, $p = .21$). I further compared FCAs to NHAs; and the findings revealed that among FCAs only MMR (90.7%) and OPV/IPV (91.5%) achieved the 90%

UTD immunization threshold established in Healthy People 2010. In contrast, NHA had no vaccines that attained Healthy People 2010 immunization recommendations.

The mediation analysis revealed race mediated the association between HOR and UTD status for FVSE (OR = 1.79; 95% Cl 1.51–2.12; p = < .0001). This finding explains that African Americans have 80% greater odds of being UTD with FVSE compared to Caucasians, after adjusting for HOR. The race ORs explained that race was significant, regardless of HOR. The mediation analysis revealed race was a mediating variable. Race mediated the association between HOR and UTD status for FVSE.

The quantifiable payoffs or deaths associated with vaccine behavior and strategies supported the constructs in VGT. The theoretical construct for this study was the VGT (Bauch et al., 2003; von Neumann & Morgenstern, 1944). The quantified differences between the vaccine self-interest strategy and group-interest strategy in VGT are important findings. Disparity emerged for estimated deaths for each reported disease between individual equilibrium and group optimum immunization. These findings confirmed similar results reported by Bauch et al. (2003). Overall, study findings showed greater estimated deaths among individual equilibrium compared to group optimum. Specifically, the mortality differences ranged greater than one to three deaths for diphtheria, hepatitis B, pertussis, tetanus, and varicella diseases. In addition, a similar trend but with smaller differences emerged in estimated deaths between individual equilibrium and group optimum for measles, mumps, poliomyelitis, and rubella diseases.

The estimated payoffs or deaths for individual-equilibrium specific-disease-rank order, highest to lowest, was varicella, 12.03 estimated deaths; hepatitis B, 5.44 estimated deaths; tetanus, 3.39 estimated deaths; diphtheria, 2.61 estimated deaths; pertussis, 1.30

estimated deaths; rubella, 0.222 estimated deaths; measles, 0.001 estimated deaths; poliomyelitis, 0.001 estimated deaths; and mumps, 0.0000895 estimated deaths.

The group optimum estimated death rate for specific-disease-rank orders was similar to that for individual equilibrium. However, group optimum estimated deaths were lower compared to those for individual equilibrium. The group-optimum disease-rank order from highest to lowest was varicella, 9.66 estimated deaths; Hepatitis B, 1.78 estimated deaths; tetanus, 0.57 estimated deaths; diphtheria, 0.441 estimated deaths; pertussis, 0.22 estimated deaths; rubella, 0.05 estimated deaths; measles, 0.002 estimated deaths; poliomyelitis, 0.0002 estimated deaths; and mumps, 0.000021 estimated deaths.

Four findings emerged. First, the 2003 to 2008 U.S. adjusted UTD vaccine rates for FVSE were greater than those for PCABC except for Td/Tdap. Second, significant differences existed between FCA and NHA individual vaccine UTD coverage-uptake rates. The FVSE was ($\chi^2 = 18.5$, $p < .0001$). In comparison, I found the FCA FVSE uptake rate (29.7%) was greater than that of the NHA FVSE (19.1%).

Third, an association emerged between HOR and UTD status for FVSE when stratified for FCA versus NHA (OR = 2.22; 95% CI 1.47–3.34, $p = .0001$). Results revealed FCA had 2.2 greater odds of UTD status for FVSE than NHA after adjusting for race However, race aligned with UTD status for FVSE, and African Americans were 1.8 times more likely to be UTD for FVSE compared to Caucasians. Race was a mediating variable in the association between being UTD with FVSE and HOR in the bivariate logistic regression model analysis. The mediator variables were gender and ethnicity in the multivariate analysis. Fourth, I reported individual equilibrium or self-interest

strategy in the VGT had greater estimated payoffs or deaths compared to the group-optimum or group-interest strategy.

Interpretation of the Findings

Low UTD coverage is an endemic public health problem (Dempsey & Zimet, 2015; Dorell et al., 2011) similar to the evident underimmunization problem prevalent in PCABC. This study provided two main contributions to the literature. It provided evidence that African Americans had higher UTD vaccine coverage for all five vaccines, compared to Caucasians. Evidence reported in Table 6 did not support findings from other studies that showed African Americans historically had low vaccine-coverage rates.

First, results from other registry data driven studies were lower for African American UTD coverage rates compared to findings from this PCABC study. The registry data are population-level-based data that are reproducible and stable (Bundy et al., 2013; Gowda, Dong, Potter, Dombkowski, & Dempsey, 2013; LoMurray & Sander, 2011a; Rees-Clayton, Montgomery, Enger, & Boulton, 2013) compared to sample-based, survey-dependent, dynamic, and fluid studies (Lindley et al., 2011a). Immunization registries have more reliable data (Curran, Bednarczyk, & Omer, 2013) and may be the gold standard for immunization population results compared to survey samples. These registries have comprehensive data and accurate descriptions of characteristics of young adolescents who have received recommended vaccines (Rees-Clayton et al., 2013).

Second, this study supported the value of registry data (Gowda et al., 2013; LoMurray & Sander, 2011a) required to establish verifiable true vaccine coverage based on historical documentation (Bundy et al., 2013) compared to surveyed vaccine-coverage studies (Curran et al., 2013). Furthermore, the registry system includes the AIRD, but

improved by eliminating duplicate and mismatched records to become useful, accurate, and efficient reporting tools for adolescent immunization (Rees-Clayton et al., 2013; Sittig, Teich, Osheroff, & Singh, 2009). I used registry data to examine trends in adolescent immunization similar to other published studies (LoMurray & Sander, 2011b; Rees-Clayton et al., 2013). Immunization-registry data are more reliable than surveys because of data cleaning, new technology, and standardized provider-reporting systems to the registry (Bundy et al., 2013).

A trend below the optimal 90% Healthy People threshold for UTD coverage rates persisted among PCABC and U.S. adolescents between 2006 and 2008. The low UTD rates for FVSE coverage associated with disease outbreaks among PCABC and U.S. adolescents are consistent with published literature on vaccines (CDC, 2009b). The low VAR coverage among PCABC may be attributed to varicella outbreaks in Arkansas in 2001, 2004, and 2006 (Gould et al., 2009; Lopez et al., 2006). Exposed siblings or those with a history of varicella did not require VAR immunization, and thus did not require reporting to the immunization registry, which is consistent with the low immunization trend between 2006 and 2008.

A congruent trend emerged in high UTD coverage rates among FCAs compared to NHAs. Similarly, FCAs had higher UTD rates for FVSE than NHAs. Furthermore, FCAs attained the Healthy People 2010 objectives for two vaccines—MMR and OPV/IPV—compared to none among NHAs. I found no significant or appreciable increases in vaccine uptake after the age of 16 among PCABC. This may be due to migration of individuals in the cohort. Vaccine coverage rates decreased over time from 2006 to 2008 among PCABC because the 1990 birth cohort was not fixed, but limited to

birth date and other inclusion criteria. Children moved in and out of the study area and vaccines administered outside Pulaski, Arkansas, may not have been reported to the registry. If the coverage rates of those who moved were better than those who stayed behind, one might expect to see a slight decrease in coverage between 2006 and 2008.

FCAs had greater UTD vaccine-coverage uptake rates for all FVSE compared to NHAs. The FVSE coverage uptake for FCAs was 29.7%, whereas for NHAs it was 19.1%, and χ^2 =18.5 (p = .0001). Children in foster care, contrary to prior hypotheses, are no less likely to complete immunization requirements than children in natural home settings. The significant differences in vaccine-coverage-uptake rates between FCAs and NHAs may be attributed to court-ordered immunization enforcement policies for all children entering the foster care system (ADHS, 2010). NHAs may exercise their medical, philosophical, and religious exemption rights allowed under Arkansas immunization laws (ADH, 2004b; ALB, 2003). This evidence of social services regulations and laws supports the contributions of other factors not included in the data and may account for the observed FCA–NHA differences in immunization rates.

The bivariate logistic model revealed an association between race and UTD for FVSE. Study findings revealed differences in odds of UTD for FVSE among PCABC race categories. Future race-specific interventions may improve overall PCABC immunization rates through education, recall/reminder messages, and social media information. For example, pediatricians, school nurses, health providers, and public health stakeholders may target each race category with culturally specific messages. The targeted messages may include evidence-based information with particular parental

vaccine concerns that address vaccine safety, delay, autism, trust, exemptions, hesitancy, and refusal.

African Americans contributed more than 50% of the PCABC population compared to Caucasians (30.7%). This sociodemographic distribution may not account for or completely explain the proportionally increased UTD coverage among PCABC. The dichotomous outcome variable of "Yes or No" for UTD for FVSE in the registry database may not include other measurable contributory factors that are not usually collected. However, in the general population, the inverse distribution occurs such that Caucasians account for the greater percentage of the population. Caucasians are twice as likely to receive vaccines compared to other races in the general population (Darden et al., 2011; Stokley et al., 2011). However, for race, a significant association emerged between African American and vaccine coverage UTD status when controlling for HOR, and Caucasian was the reference variable (OR = 1.77; 95% Cl 1.49–2.09). African Americans were 1.8 times more likely to have UTD vaccine-coverage-uptake rates. This association could not be explained from the data within the scope of this study. The association between race and immunization rates was established in the literature with inverse results to those of this study. Similarly, for race, a significant association emerged between Other and vaccine coverage UTD status when controlling for HOR, and Caucasian was the reference variable (OR = 0.54; 95% Cl 0.43–0.67). Other races had 10% lower odds of reaching UTD for FVSE.

This study supported VGT, which posits that the behavior of a group influences individual behavior (von Neumann & Morgenstern, 1944). In VGT, I partitioned participants into two groups: individual equilibrium/delayers/free-riders/refusers and

group optimum/preemptors/early acceptors/vaccinators. The study also confirmed the Bauch et al. (2003) construct of vaccine-uptake-behavior payoff differences between preemptors and delayers. Diseases with high estimated deaths require preemptive vaccinations, which are protective against potential disease risks, exposures, and outbreaks, and can help reduce unintended deaths. A correlation emerged between high-vaccine UTD and low number of estimated deaths associated with VGT. I concluded that high-vaccine UTD protects against disease outbreaks.

The interpretation of the higher estimated payoffs or deaths confirmed that the self-interest strategy was a high-risk behavior. Individual equilibrium indicated that this delayer vaccination strategy has greater estimated costs and higher estimated risks. The benefit of delaying vaccination was not protective. Vaccine delay increases VPD morbidity (Bauch & Bhattacharyya, 2012; Schlenker et al., 1992), which may result in death after a VPD outbreak (Bauch & Earn, 2004; Bauch et al., 2003; Baxter et al., 2013). The group optimum was a better and less costly strategy because lower estimated payoffs or deaths aligned with this preemptive vaccinator strategy. The benefits of the group optimum were protective and fewer estimated deaths would accrue during a VPD outbreak.

In summary, the findings yielded four important interpretations. First, U.S. adolescents had higher adjusted vaccine-UTD for Hep B, MMR, and VAR compared to PCABC. Overall, U.S. adolescents are more protected against Hepatitis B, measles, mumps, rubella, and varicella outbreaks compared to PCABC. Second, immunization rates among NHAs are low compared to FCAs. NHAs have less immunization protection and higher disease risk and exposure. The consequences of high disease predisposition

are disease risk and high estimated deaths during VPD outbreaks. VGT supports these consequences. In addition, low immunizations with increased disease outbreaks, school absenteeism, poor school performance, and adolescent hospitalization.

Third, the interpretation of improved immunization among African Americans in this cohort is that future possibilities exist to sustain this vaccination gain among this historically low-performing race. In future research, the process can be duplicated once these contributory factors are explored and understood. The challenge is to understand contributing factors associated with increased UTD for FVSE among African Americans in PCABC. Although contributing factors associated with increased immunizations are known in the published literature (Atwell et al., 2013; Darden et al., 2013; Diekema, 2012), they are outside the scope of this study. Immunization contributing-factor data were not collected and were unavailable for analysis in this PCABC study.

Fourth, the interpretation of VGT group-optimum preemptive vaccination behavior is protective compared to alternative behaviors. Preemptive vaccinations are encouraged because reducing the risks of outbreaks has greater individual and community-health benefits.VGT analysis showed numbers of payoff deaths associated with individual equilibrium are higher than group optimum. This finding supports VGT, showing that preemptive vaccination behavior among group optimum is protective and associated with fewer deaths. In contrast, however, individual-equilibrium vaccination behavior is riskier and aligns with higher numbers of deaths during a VPD outbreak or resurgence.

This study contributed evidence of increased vaccination among historically low-performing groups. Future researchers may examine benefits of immunization-registry

data and assess their reliability, compared to survey-sample data. Future researchers may enhance potential changes in cultural and social beliefs toward immunization among African Americans. Future research is needed to determine if mothers whose children are enrolled in vaccination social programs, such as VFC or WIC, are more receptive to vaccinations. Empirical data from a larger population study are desirable to indicate that vaccination is an essential requirement for enrollment in other welfare programs. Socioeconomic data analysis with African Americans immunization data may justify increase in immunization among such historically low-performing races as African Americans. Community and faith-based immunization research should include African Americans and address immunization safety, education, beliefs, biases, and cultural attitudes (Gamble, 1997); social media and vaccine hesitancy (Dredze et al., 2015); and health-provider ethical practices (Dempsey & Zimet, 2015). School nurses may use these findings to encourage parents to immunize their children. Community campaigns citing this improvement among this social group could cultivate community trust building. Awareness of immunization improves among members of a social class with historical mistrust for immunization.

Limitations of the Study: Generalizability

The study results and findings are generalizable to the 1990 birth cohort of all children who met the study criteria, born between January 1, 1990 and December 31, 1990 in PCA, and had immunization records in the AIR. There were 9,102 live births in 1990, from which I obtained the representative sample for this study cohort. The study was based on 3,371 children from the 1990 birth cohort and met the a priori established selection criteria such as foster care, geography, and documented immunization records

in the AIR. Records in the AIR database contained internal-validity issues similar to other states' immunization registries; documents contained incomplete records and many types of errors in reporting immunization information (Khare et al., 2000). The PCABC 1990 study did not measure or include known factors associated with low-immunization rates frequently analyzed in vaccine-coverage studies: socioeconomic factors(Wooten et al., 2007), lack of access to care, parental attitudes, and educational levels. Arkansas registry data were limited to vaccine type, vaccine-administration date, birth date in 1990, ethnicity, gender, and race demographic factors.

The racial and ethnic profile of the 1990 PCABC population was not comparable to the total United States, given the sample size (3,371), and the number of African Americans (1,851; 53.2%); Caucasians (1,036; 30.7%); and Others (543; 16.1%). Nevertheless, the findings should be generalizable to similar populations in the United States, given that all states receive federal funding, such as from the VFC fund, and follow the CDC ACIP guidelines (CDC, 2008b; Sneller et al., 2008). NHAs (96.3%) comprise a greater proportion of the population of interest compared to FCAs (3.7%). In contrast to FCAs (3.7%), NHAs' (96.3%) profiles in PCA were widely different from those of other counties across the United States. Furthermore, important variables associated with vaccination-coverage rates—including socioeconomic status, parental attitudes toward vaccination, and medical, philosophical, and religious exemptions—were not captured or available in the AIR. In addition, social values, educational levels, and parental attitudes toward children's immunization may be different and influential in parents' immunization decisions. These factors were not captured in the data. Inclusion of

such data in the analysis may help provide analytic evidence and explain differences in immunization rates in this study.

The limitations of this study included missing records, underreporting, and lack of reporting, such as in the case of the VAR, where more than 80% of the cohort had less than one dose of the VAR. Underimmunization among the other four vaccines was fairly consistent and in the range of 5–10% disparity from the desired 90% threshold recommended in Healthy People 2010 (USDHHS, 2000). I excluded incomplete or mismatched records from the analysis to minimize internal-validity limitations and unreliable results. I did not include duplicate doses of the same vaccine for the same unique identified immunization record when calculating UTD, which was limited to immunization rates based on the criteria in Appendix A, Table A1. Foster care residence was defined as any foster care residence regardless of duration in foster care and age when the child entered into foster care. This crude definition may have overestimated the benefit of foster care residence since the foster care system has strict immunization policies and is a potential limitation of the study. Another limitation was not all foster care children were included in this study because of place of birth. Excluding them may have limited the power to falsify the null hypothesis. The validity and reliability of interpretations of the results are applicable and specific to 1990 adolescents in PCABC.

Recommendations

The three main recommendations areas are research, public health stakeholders, and study improvement.

Recommendations for Research

Race- and culture-based immunization messaging through social media, physicians, and health provider recall/reminder messages may enhance vaccination acceptance for children and adolescents. African Americans have 1.8 greater odds of FVSE compared to Caucasians. These successful contributing factors may be included in educational interventions to increase adolescent immunization rates. I recommend future researchers examine race- and culture-focused messaging, physicians, and health provider influence, and social media contributing factors to this successful improvement in a historically low-performing race in PCABC.

Recommendations for Public Health Stakeholders and Health Practitioners

U.S. adolescents have higher immunization coverage for Hep B, MMR, and VAR compared to PCABC from 2006 to 2008. I recommend targeted vaccine intervention campaigns to encourage parents to accept vaccines to attain the 90% threshold established in Health People 2010. A targeted campaign in PCABC will address underimmunization. Social media immunization messages, school-based clinics, and physician recall/reminder are established best practices. Race- and culture-based immunization messaging through social media, physicians, and health provider recall/reminder messages may enhance vaccination acceptance for children and adolescents. Direct physician and health-provider vaccination communication with parents and adolescents may build trust and reduce vaccination misinformation that predisposes parents to delay, hesitate, refuse, or seek exemptions (Safi et al., 2012).

Underimmunization for Hep B (15.5%) was higher than for Td/Tdap and MMR, although the Hep B booster dose was strongly recommended for this age (Sneller et al.,

2008; Wei et al., 2010) due to high-risk behavior among this age group. The Hep B vaccine was also a seventh-grade school requirement (ADH, 2008). The low uptake of VAR is of concern and a history of varicella disease should be reported in the registry to reflect natural immunity compared to vaccine-induced immunity. The frequent importation of measles, recent outbreaks, and cases of measles in Arkansas (ADH, 2012b) require further investigation.

This study contributed evidence of increased vaccination among historically low-performing groups. The results could provide social-change benefits as public health officials, healthcare providers, policymakers, and community members plan intervention strategies that encourage parental vaccine decisions and improve UTD coverage among PCABC. Healthcare providers may include these results in vaccine communications during FCA and NHA wellness visits. Policymakers may include these findings to justify interventions and policies that sustain increased immunization coverage among FCA and NHA.

Recommendations for Study Improvement

I recommend clean and complete immunization information-systems data. The immunization-registry data used in this study required data cleaning. Missing, mismatched, or incomplete records were excluded from the analysis.

The Arkansas immunization data-quality and data-registration linkage with the Arkansas vital-statistics database requires improvement with advanced technology that can identify and control duplicate-records submission from immunization providers. The technology implemented in immunization records reduced mismatched-record and immunization-reporting errors from health providers (CDC, 2010h; Fath, Andujar,

Williams, & Kurilo, 2015; Greene et al., 2009). The implementation of the electronic standard HL7 form routinely used to report healthcare-provider immunization to the state-registry enhanced data linkage, improved the quality of archival data, and facilitates future research.

The AIR's real-time quality data provides an advantage for future research. Arkansas immunization state laws imposed legal penalties when immunization providers or vaccinators do not report to the AIR within 30 days (ADH, 2008). Timely evidence-based vaccine-coverage data on other birth cohorts provides justification to implement new policies that target vaccines and groups with low vaccine-coverage rates. National immunization surveys become very expensive and irrelevant. Therefore, I strongly recommend future studies on vaccine-coverage uptake base analysis on state-registry data.

Implications for Positive Social Change

Findings from this study may enhance social-change contributions toward immunization campaigns targeting natural-home parents and increase immunization rates among PCABC. I partitioned social-change implications in this study into four main areas: (a) protect vulnerable unvaccinated NHAs against recent VPD outbreaks; (b) reduce vaccine delay, distrust, and hesitancy; (c) build vaccine trust between providers and parents of unvaccinated or low UTD NHAs; and (d) health providers enhance vaccine communication with hesitant parents of PCABC.

This dissertation offers information that may lead to protection of vulnerable unvaccinated NHAs against recent VPD outbreaks, which would be an important social change (NVAC, 2015). Social change through awareness of low UTD for FVSE among

NHAs may prevent recent VPD outbreaks and resurgence among vulnerable unvaccinated NHAs. Immunization awareness would be an important positive social change for adolescents, minimizing school absenteeism and poor school performance associated with VPD illness. School immunization requirements contribute positive important roles to controlling VPDs (Omer et al., 2008). NHAs had lower UTD coverage rates compared to FCAs. Immunization-intervention campaigns targeting low UTD-performing NHAs with low-immunization rates will contribute to behavioral change to mitigate vaccine hesitancy, delay, or refusal. Hesitancy, delay, and refusal contribute to low UTD for FVSE among unvaccinated NHAs compared to FCAs with higher coverage rates.

The concerted focus to increase awareness and benefits of vaccines may contribute to cultural and behavior change among NHAs to improve their UTD for FVSE. Low-vaccination coverage is the most common risk factor associated with measles resurgence (Hamborsky et al., 2015; Kennedy & Gust, 2008). Such cultural and behavior changes toward vaccine acceptance are positive social changes at the individual NHA level. Avoidance of low vaccine coverage among NHAs has immeasurable downstream lifetime burden such as adolescent hospitalization. Acute encephalitis, otitis media, and coma are reported measles complications (Hamborsky et al., 2015). Mumps complications of orchitis in men and oophoritis in women contribute to infertility. Permanent unilateral deafness complications from mumps (Hamborsky et al., 2015) may impact an adolescent's school performance and future economic productivity.

Vaccine delay, distrust, and hesitancy reduction among African Americans would contribute to social change. Globally, African American parents who live in households

with their children delay vaccine administration for their children (Smith, Humiston, Parnell, Vannice, & Salmon, 2010). The African American increased UTD for FVSE coverage compared to Caucasians in this study is a positive outcome, influencing behavior or attitudes among other African American parents who delay, hesitate, and distrust vaccination (Gamble, 1997). Although African Americans had higher UTD compared to other races, the preferred target for PCABC was to attain greater than 90% UTD for FVSE. Overall, PCABC adolescents did not attain greater than 90% UTD for FVSE. Therefore, to attain immunization goals, direct physician–parent communication, continuous education, and positive social-media immunization messages are valuable to sustain and improve parental acceptance of vaccines for children and adolescents. Parents of NHAs may benefit from such information and reduce their vaccination delays, hesitations, and distrust (Phadke, Bednarczyk, Salmon, & Omer, 2016).

Social change as result of the outcomes from this study and others may increase immunization rates especially among inner-city African American children (Wood et al., 1998). Including findings of increased PCABC African American immunization in physician–parent communications is valuable. Parents understand and accept empirical, verifiable, and convincing evidence. These successful health-provider communications, when repeated during wellness visits at inner-city health clinics or community health centers, may convince other hesitant parents to accept vaccines. Such individual parental vaccine acceptance, when duplicated and incorporated into standard practices in the community, may increase the number of receptive parents and enhance overall immunization rates.

Building vaccine trust between providers and parents of unvaccinated or low UTD NHAs may contribute to positive social change. Health providers can cite increased coverage rates in UTD for FVSE as validation of vaccine confidence among African Americans through effective trustworthy vaccine communication. Vaccine trust built between providers and parents of unvaccinated or low UTD NHA may enhance positive social change. Health providers can cite increased coverage rates in UTD for FVSE from this study as validation and endorsement of vaccine confidence among African Americans. Health providers are highly supportive of vaccines and may refer to findings from this study to build trust so that parents engage their children in the recommended immunizations (NVAC, 2015).

Healthcare providers enhance vaccine communication with hesitant parents to improve UTD rates among PCABC during healthcare visits. Adolescent healthcare visits provide excellent opportunities to address concerns about vaccines. Concerns may include social norms, attitudes, beliefs, vaccine delays, hesitation, refusal, vaccine safety, vaccine effectiveness, vaccination benefits, building trust, confidence, VPD, and improving vaccine rates for adolescents. Social change may continue as school nurses include information on low-UTD coverage rates among PCABC compared to U.S. statistics when communicating and encouraging adolescents to accept vaccines. School nurses may use these findings to encourage parents to immunize their children. Healthcare-provider communication, endorsement of social norms, and vaccines are central components in establishing trust, nurturing, and fostering vaccine confidence among hesitant parents (NVAC, 2015).

The social change potential benefit could enhance public health officials' ability to plan intervention strategies that encourage parental vaccine decisions and improve UTD coverage among PCABC. Healthcare providers may include these results in vaccine communications during FCA and NHA wellness visits. Policymakers may include these findings to justify interventions and policies that sustain increased immunization coverage among FCAs and NHAs.

This study contributed evidence of increased vaccination among historically low-performing groups. Future researchers may examine benefits of immunization-registry data more reliable than using survey-sample data. Future researchers may enhance potential changes in cultural and social beliefs toward immunization among African Americans. Community campaigns citing this improvement among this social group cultivate community trust building. Awareness of immunization may improve among members of a social class with historical mistrust for immunization.

Parents have direct duties and responsibilities to vaccinate their children to provide health protection. Public health laws and policies require parents to comply with school-entry vaccine regulations established by Arkansas law (ADH, 2008). The PCABC adjusted UTD coverage for FVSE deficiency among Td/Tdap, Hep B, MMR, OPV/IPV, and VAR ranged from coverage rates of 5 to 14.1% during 2006–2008. PCABC failed to achieve the minimum recommended objectives established in Healthy People 2010. These vaccines disparities and deficiencies should be targeted by public health campaigns to prevent and reduce the burden of disease outbreaks among school children (Dempsey et al., 2015; Gaensbauer, Armon, & Todd, 2014).

Preemptive vaccination behavior was protective to the community and provides positive social change. High vaccine-coverage rates prevent resurgence of previously eradicated diseases, burden of disease imports, and outbreaks of VPDs (Cherry, 2010; Toner, 2014; Winter et al., 2012). The public health policies contributing to positive vaccine coverage among African Americans should continue to be encouraged. Such interventions will enhance improvements in future vaccine coverage and continue to break the historic cycle of low coverage among minority groups.

Low adolescent vaccine coverage was a public health threat and burden because adolescents are reservoirs of VPDs (Dempsey et al., 2015) and these diseases are highly communicable among school children. Therefore, public health initiatives targeted toward these vaccines with low-coverage rates have a preventive and protective impact against VPDs in the community. The quantifiable evidence reported in Table 7 for specific racial groups was primary justification to influence individual-behavior changes and improve the county-level immunization discussion.

Findings shown in Table 7 and trends shown in Figure 4 also indicated areas of significant differences in vaccine-coverage uptake rates among the cohort to initiate public health vaccine campaigns and achieve positive social change. Preemptive vaccination behavior created positive social change through payoffs, supporting justification. Thus, increased vigilance and compliance to reach required vaccination coverage would reduce morbidity, hospitalization, health costs, and other public health burdens. Preemptive vaccination behavior was preferred because low payoffs aligned with fewer deaths that would occur during a VPD outbreak. The correlation of vaccines with low-coverage rates and with vaccines that had high-payoff deaths was evident. The

vaccine-coverage-uptake results shown in Table 5 for low-coverage vaccines such as VAR and Hep B also correlated with high-payoff deaths shown in Table 12.

The low payoffs associated with preemptive behavior support justification for increased vigilance and compliance with vaccination-coverage requirements. The high estimated payoffs or deaths for individual self-interest aligned with low vaccine-coverage rates. Vaccine refusal (Dredze et al., 2015) or underimmunization increased the risks associated with disease outbreaks (Gould et al., 2009; Lopez et al., 2006). The reported results and findings also indicated significant correlations between underimmunization, race (Smith et al., 2004), and specific vaccines. These results may influence vaccine-intervention campaigns and public health policy in PCA. Adolescent immunization solutions to low immunization rates are implemented through policy at the individual level. Healthy People national health promotions from 2000 identified immunization as a national health priority (USDHHS, 1999).

Policy solutions include school-entry laws (ALB, 1967; Omer et al., 2009; Orenstein & Hinman, 1999) and access to immunization in Arkansas (ALB, 1967) through federal and state eligibility programs including VFC, Medicaid, and the supplemental children's insurance (ARKIDS) program in Arkansas (ADHS, 2011a). Legislative actions influence societal and environmental levels through immunization laws and school-entry requirements. School-based immunization clinics are associated with increased adolescent immunization coverage rates (Allison et al., 2007; Daley et al., 2009; Federico et al., 2010; McNall et al., 2010). Therefore, increased vaccination-coverage rates through these innovative modalities for vaccination are achievable and are improvements over current traditional vaccination-coverage methods.

The use of archival-data analysis with VGT should become the gold standard for determining coverage uptake compared to survey methods with potential systematic and recall biases. The availability of archival data is an advantage and true evidence of immunization providers' practices, compared to national immunization-survey methods. The second advantage is a comparison of different birth cohorts in the same community. The third advantage is predicting immunization coverage uptake from analysis of archival data with VGT. For example, VGT emphasizes and explains self-interest and group behavior, immunization policy decisions, and maximization of payoff concepts (Bauch & Earn, 2004; Bauch et al., 2003). I used VGT to establish different payoffs or deaths for individual self-interest behavior and group altruistic behavior. Desirable vaccination behavior decisions were supported with quantifiable payoff evidence. Future archival data analysis with VGT of different birth cohorts in the same community would provide comparative justifiable evidence for public health campaigns, vaccination intervention, and policy decisions. The empirical implications presented here will facilitate vaccination-strategy comparisons for future research.

Conclusion

The two novel findings in this study confirmed disparities in state-mandated immunizations and reported significant improvement in immunization rates among historically low-performing races. The first novel finding in this study confirmed disparities in state-mandated immunizations among PCABC. Adolescents in foster care were 2.2 times more likely to complete FVSE compared to adolescents in natural homes. This novel finding contradicted previous literature that associated NHAs with higher immunization rates. The second novel contribution of this PCABC study is that African

Americans were 80% more likely than Caucasians to be UTD for FVSE. In other population studies, immunization rates among Caucasian adolescents were usually higher than those of African Americans.

This study made two main contributions to the literature. First, the study provided evidence that African Americans had higher UTD vaccine coverage for all five vaccines compared to Caucasians at the county or community level. This higher vaccine coverage of African Americans compared to that of Caucasians is a novel finding, contrasting with state and national reports and previous research in which Caucasians were the majority race and usually had higher vaccine-coverage rates. Second, this study supported the value of registry data required to establish verifiable true vaccine coverage based on historical documentation compared to vaccine-coverage survey studies. Several previous studies used telephone surveys to establish vaccine-coverage rates (CDC, 2010a). These previous survey-designed studies often reported low vaccine-coverage rates for African Americans.

The PCABC study confirmed some information described in previous literature. The immunization rates in Arkansas, represented by the PCABC, are lower compared to those of the United States. This study supported previous research findings that Arkansas vaccine-coverage rates for Hep B, MMR, OPV/IPV, and VAR were lower than U.S. national vaccine-coverage rates among adolescents (CDC, 2009b). PCABC vaccine-coverage rates for Td/Tdap were higher than U.S. national vaccine-coverage rates. Estimates of immunization uptake from the national immunization survey should not be necessary with the advent of web-enabled immunization registries that facilitate actual computation of true vaccine coverage. Children in foster care, contrary to prior

hypotheses, are no less likely to complete immunization requirements than children in natural-home settings.

African Americans were twice as likely to complete their vaccine series compared to Caucasians. No intuitive explanation arose for African Americans' vaccine-coverage rates from this study. Contributory factors that may explain the African American coverage rate are outside the scope of this study. It is possible that, as a race, African Americans were more compliant with school vaccine requirements or were enrolled in federal vaccine programs compared to members of other races. Therefore, African Americans are more receptive to childhood vaccination, as evident in the vaccine-coverage uptake of school-entry requirements. Furthermore, shifts in vaccine attitudes among African Americans and persistent high infant mortality reported in other research were outside the scope of this study.

The analysis of immunization archival data provided empirical evidence in establishing vaccine-coverage uptake in this 1990 PCABC. No difference in immunization uptake emerged for HOR. Foster children had higher immunization rates before adjustment in a multivariate logistic-regression model. The difference, however, disappeared after controlling for gender, race, and ethnicity. This study also confirmed an immunization disparity between the 1990 PCABC and the NIS-Teen from 2006 to 2008.

The U.S. NIS-Teen adjusted vaccine-coverage-uptake rates for FVSE were higher than the 1990 PCABC adolescent adjusted vaccine-coverage-uptake rates from 2003 to 2008. This study confirmed the persistent problem of low adolescent immunization reported in previous research (Diekema et al., 2005; Imdad et al., 2013; USDHHS, 1999; Zhou, Santoli, et al., 2005). Very few studies used archival registry data to establish

immunization rates among adolescents (LoMurray & Sander, 2011b). This study addressed this gap in the literature and used archival data to establish vaccine-coverage rates for PCA.

Several peer-reviewed studies addressed components of immunization in Arkansas. These components included VPDs, exemptions, policy, state-mandated immunization laws, regulations, and infant and childhood coverage. However, these studies did not apply quantitative analysis of immunization-registry data, nor did they focus on NHA and FCA 1990 PCABC to establish immunization-coverage rates for the FVSE. The immunization rates reported for adolescents in Arkansas (CDC, 2008a; Darden et al., 2013; Jain et al., 2009; Stokley et al., 2011) were based on an RDDS of sample households. In contrast, this cross-sectional study focused on archival registry deidentified data to establish immunization coverage uptake rates for FVSE among the 1990 PCABC.

This study contributed evidence of increased vaccination among historically low-performing groups. Such improvements enhance potential future changes in cultural and social beliefs toward immunization among PCABC and specifically African Americans and FCAs. Direct social change encourages school nurses to motivate parents to immunize their children. Community immunization campaigns citing these improvements among these social groups of people cultivates community trust building and promotes overall health in the general society.

References

Allison, M. A., Crane, L. A., Beaty, B. L., Davidson, A. J., Melinkovich, & Kempe, A. (2007). School-based health centers: Improving access and quality of care for low-income adolescents. *Pediatrics, 120,* e887–e894. doi:10.1542/peds.2006-2314

American Academy of Child and Adolescent Psychiatry. (2005). *Foster care: Facts for families No. 64*. Retrieved from http://www.aacap.org/App_Themes/AACAP/docs/facts_for_families/64_foster_care.pdf

American Academy of Pediatrics. (2005). *Medical consents for children and adolescents in foster care.* Retrieved https://www.aap.org/en-us/advocacy-and-policy/aap-health-initiatives/healthy-foster-care-america/Documents/Ch6_Medical_%20Consents.pdf

American Immunization Registry Association. (2006). *Participating in immunization information systems: Turning barriers into opportunities. Survey and best practice report.* Retrieved from http://www.immregistries.org/resources/Provider_Participation_Final_2005.pdf

American Immunization Registry Association. (2008). Improving the quality of data entering the IIS. Retrieved from http://www.immregistries.org

Anderson, R. M., & May, R. M. (1985). *Vaccination and herd immunity to infectious diseases. Nature, 318,* 323–329. doi:10.1038/318323a0

Arinaminpathy, N., Ratmann, O., Koelle, K., Epstein, S. L., Price, G. E., Viboud, C., . . . Grenfell, B. T. (2012). Impact of cross-protective vaccines on epidemiological and evolutionary dynamics of influenza. *Proceedings of the National Academy of Sciences of the United States of America, 109,* 3173–3177. doi:10.1073/pnas.1113342109

Arkansas Department of Education. (2009). Statewide information system reports: Student status counts. Retrieved from https://adedata.arkansas.gov/statewide|/Students/StatusCounts.aspx?year

Arkansas Department of Education. (2011). Statewide information system reports: Student status counts. Retrieved from https://adedata.arkansas.gov/statewide/Students/StatusCounts.aspx?year=16&search=&pagesize=10

Arkansas Department of Education. (2012). Statewide information system reports: Student status counts. Retrieved from https://adedata.arkansas.gov/statewide/Students/StatusCounts.aspx?year

Arkansas Department of Health. (1993). *Rules and regulations pertaining to the kindergarten through 12th grade immunization requirements pursuant to Act 591 of 1993.* Retrieved from http://www.arkleg.state.ar.us/assembly/1993/R/Acts/591.pdf

Arkansas Department of Health. (1995). *Arkansas State Board of Health: Rules and regulations pertaining to immunization reporting.* Retrieved from http://www.arkleg.state.ar.us/assembly/1995/R/Acts/432.pdf

Arkansas Department of Health. (1997). *Rules and regulations pertaining to the kindergarten through 12th grade immunization requirements pursuant to ACT 244 of 1967, ACT 633 of 1973, and ACT 871 of 1997.* Retrieved from http://www .arkleg.state.ar.us/assembly/1997/R/Acts/871.pdf

Arkansas Department of Health. (2000). *Rules and regulations pertaining to the kindergarten through 12th grade immunization requirements pursuant to Act 244 of 1967, Act 633 of 1973, and Act 871 of 1997.* Retrieved from http://arked.state .ar.us/commemos/static/fy0001/attachments/k-12rrfinal.doc

Arkansas Department of Health. (2003). *Act 999: An act to revise the religious exemption to the school immunization requirements; and for other purposes. Arkansas Code Annotated, 2003.* Retrieved from http://www.arkleg.state.ar.us /assembly/2003/R/Acts/Act999.pdf

Arkansas Department of Health. (2004a). *Arkansas State Board of Health. Rules and regulations pertaining to immunization requirements. Promulgated under the authority of Ark. Code Ann. §§ 20-7-109, 6-18-702, 6-60-504, and 20-78-206.* Retrieved from http://www.sos.arkansas.gov/rulesRegs/Arkansas%20Register /2003/aug_2003/007.15.03-001.pdf

Arkansas Department of Health. (2004b). *Rules and regulations immunization requirements.* Retrieved from http://www.healthy.arkansas.gov/aboutADH /RulesRegs/ImmunizationReporting.pdf

Arkansas Department of Health. (2005). Unpublished vaccine codes. Internal Immunization Agency communication document.

Arkansas Department of Health. (2006). Press release: Division of Health (DOH) mumps update 2006. Retrieved from http://www.arktimes.com/arkansas/mumps-update /Content?oid=867021

Arkansas Department of Health. (2008). *Arkansas State Board of Health: Rules and regulations pertaining to immunization reporting.* Retrieved from http://www .Healthy.Arkansas.Gov/Aboutadh/Rulesregs/Immunizationreporting.pdf

Arkansas Department of Health. (2011a). Immunization registry. Retrieved from http:// www.healthy.arkansas.gov/programsServices/MeaningfulUse/Pages /ImmunizationRegistry.aspx

Arkansas Department of Health. (2011b). School report, 2011. Retrieved from http:// www.healthy.arkansas.gov/programsServices

Arkansas Department of Health. (2012a). ADH investigating whooping cough at Clinton Intermediate School. Retrieved from http://www.arkansas.gov/health/newsroom /index.php?do:newsDetail=1&news_id=784

Arkansas Department of Health. (2012b). Press release: Measles cases confirmed in northwest Arkansas. Retrieved from http://www.arkansas.gov/health/newsroom /index.php?do:newsDetail=1&news_id=716

Arkansas Department of Health. (2012c). Public health grand rounds. Arkansas immunization exemptions by counties since 2003. Unpublished internal Arkansas Department of Health report.

Arkansas Department of Health. (2014a). Financial impact statement: Immunization requirements. Retrieved from http://www.healthy.arkansas.gov/aboutADH /RulesRegs/FinancialImpactStatementIMMReq.pdf

Arkansas Department of Health. (2014b). NEDDS morbidity reports internal department communications. Unpublished internal report from the Epidemiology Branch of the Arkansas Department of Health.

Arkansas Department of Health. (2015). Vital statistics reports internal department communications. Unpublished internal report of the Health Statistics Branch, Arkansas Department of Health.

Arkansas Department of Human Services. (2007). *Annual Arkansas Department of Health and Human Services statistical report: SFY 2007 DHHS statistical report.* Retrieved from http://humanservices.arkansas.gov/AnnualStatisticalReports/SFY%202007%20DHHS%20Annual%20Statistical%20Report.pdf

Arkansas Department of Human Services. (2010). *Division of Children and Family Services. Executive summary.* Retrieved from http://humanservices.arkansas.gov/dcfs/dcfsDocs/ARCFSRREPORTEXECSUM.pdf

Arkansas Department of Human Services. (2011a). ARKids First health insurance. Retrieved from http://www.arkidsfirst.com/home.htm

Arkansas Department of Human Services. (2011b). *Children's reporting and information system.* Retrieved from http://www.arkansas.gov/dhs/chilnfam/Survey%20-%20CHRIS.PDF

Arkansas Department of Human Services. (2011c). Welcome to Arkansas Medicaid. Retrieved from https://www.medicaid.state.ar.us/InternetSolution/default.aspx

Arkansas Department of Human Services. (2013). *Standards of approval for foster and adoptive homes.* Retrieved from http://humanservices.arkansas.gov/dcfs/DCFSpublications/PUB-022.pdf

Arkansas Legislative Branch. (1967). *Act 244 of the 1967 regular session: "An act to require that no child shall be admitted to a public or private school in Arkansas who has not been immunized from poliomyelitis, diphtheria, tetanus, pertussis, red (rubeola) and measles."* Retrieved from http://www.arkleg.state.ar.us /assembly/1967/R/Acts/244.pdf

Arkansas Legislative Branch. (1973). *ACT 633 of the 1967 regular session: "An act to require rubella immunization added to list of school entry requirements. No child shall be admitted to a public or private school in Arkansas who has not been immunized from poliomyelitis, diphtheria, tetanus, pertussis, red (rubeola) measles, and rubella."* Retrieved from http://www.arkleg.state.ar.us/assembly /1967/R/Acts/633.pdf

Arkansas Legislative Branch. (1987). *Act 141 of the 1987 regular session: "An act to require that certain persons enrolled in public and private colleges and universities in the state of Arkansas furnish proof that they have immunity against measles, rubella, and such other diseases."* Retrieved from http://www.arkleg .state.ar.us/assembly/1987/R/Acts/141.pdf

Arkansas Legislative Branch. (1989). *Act 387 of the 1989 regular session: "An act to authorize the state board of health to implement a reimbursement system to recover part or all of the costs of certain medical supplies or services; to provide that the ability of patients to pay shall be considered when establishing fees; and for other purposes."* Retrieved from http://www.arkleg.state.ar.us/assembly/1989 /R/Acts/387.pdf

Arkansas Legislative Branch. (1993). *ACT 591 of the 1993 regular session: "An act to create the Arkansas health resources commission; and for other purposes."* Retrieved from http://www.arkleg.state.ar.us/assembly/1993/R/Acts/591.pdf

Arkansas Legislative Branch. (1995a). *ACT 432 of the 1995 regular session: "The preventive immunization reporting act; and for other purposes."* Retrieved from ftp://www.arkleg.state.ar.us/acts/1995/HTM/432.htm

Arkansas Legislative Branch. (1995b). *ACT 685 of the 1995 regular session. Mandate the coverage of children's preventive health care.* Retrieved from http://www .arkleg.state.ar.us/assembly/1995/R/Acts/685.pdf

Arkansas Legislative Branch. (1997a). *ACT 870 of the 1997 regular session: Require immunizations prior to admission to a childcare facility and for other purposes.* Retrieved from ftp://www.arkleg.state.ar.us/acts/1997/HTM/870.htm

Arkansas Legislative Branch. (1997b). *ACT 871 of the 1997 regular session: "An act to amend Arkansas code 6-18-702 to add other diseases as designated by the state board of health to required immunization for school children, and to add immunization as a requirement for enrollment in childcare facilities; and for other purposes."* Retrieved from ftp://www.arkleg.state.ar.us/acts/1997/HTM/871 .pdf

Arkansas Legislative Branch. (2003). *ACT 999 of the 2003 regular session: "An act to revise the religious exemption to the school immunization requirements; and for other purposes."* Retrieved from http://www.arkansascsh.org/tinymce /filemanager/files/act999.pdf

Arkansas Legislative Branch. (2012). Historic acts. Retrieved from http://www.arkleg .state.ar.us

Arkansas State Board of Health. (2003). *An act to revise the religious exemption to the school immunization requirements; And for other purposes: Arkansas Act 999 of 2003.* Regular session, 2003 Senate Bill 434. Retrieved from http://www.arkleg .state.ar.us/assembly/2003/R/Acts/Act999.pdf

Atwell, J. E., Van Otterloo, J., Zipprich, J., Winter, K., Harriman, K., Salmon, D. A., & Omer, S. B. (2013). Nonmedical vaccine exemptions and pertussis in California, 2010. *Pediatrics, 132,* 624–630. doi:10.1542/peds.2013-0878

Baggs, J., Gee, J., Lewis, E., Fowler, G., Benson, P., Lieu, T., . . . Weintraub, E. (2011). The vaccine safety datalink: A model for monitoring immunization safety. *Pediatrics, 127,* S45–53. doi:10.1542/peds.2010-1722H

Baguelin, M., Flasche, S., Camacho, A., Demiris, N., Miller, E., & Edmunds., W. J. (2013). Assessing optimal target populations for influenza vaccination programmes: An evidence synthesis and modelling study. *PLoS Medicine, 10,* e1001527. doi:10.1371/journal.pmed.1001527

Barclay, V. C., Smieszek, T., He, J., Cao, G., Rainey, J. J., Gao, H., . . . Salathé, M. (2014). Positive network assortativity of influenza vaccination at a high school: Implications for outbreak risk and herd immunity. *PLoS One, 9*(2), e87042. doi: 10.1371/journal.pone.0087042.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51,* 1173–1182. doi:10.1037/0022-3514.51.6.1173

Basu, S., Chapman, G. B., & Galvani, A. P. (2008). Integrating epidemiology, psychology, and economics to achieve HPV vaccination targets. *Proceedings of the National Academy of Sciences, 105,* 19018–19023. doi:10.1073.www.pnas.org_cgi_doi_10.1073_pnas.0808114105

Bauch, C. T. (2005). Imitation dynamics predict vaccinating behaviour. *Proceeding of the Royal Society of London: Biological Sciences, 272,* 1669–1675. doi:10.1098/rspb.2005.3153

Bauch, C. T., & Bhattacharyya, S. (2012). Evolutionary game theory and social learning can determine how vaccine scares unfold. *PLoS Computational Biology, 8*(4), e1002452. doi:10.1371/journal.pcbi.1002452

Bauch, C. T., & Earn, D. J. D. (2004). Vaccination and the theory of games. *Proceedings of the National Academy of Sciences, 101,* 13391–13394. doi:10.1073/pnas.0403823101

Bauch, C. T., Galvani, A. P., & Earn, D. J. D. (2003). Group interest versus self-interest in smallpox vaccination policy. *Proceedings of the National Academy of Sciences, 100,* 10564–10567. doi:10.1073/pnas.1731324100

Baxter, R., Ray, P., Tran, T. N., Black, S., Shinefield, H. R., Copland, P. M., & Sadier, P. (2013). Long-term effectiveness of varicella vaccine: A 14-year, prospective cohort study. *Pediatrics, 131,* e1389–e1396. doi:10.1542/peds.2012-3303

Blackwood, J. C., Cummings, D. A. T., Broutin, H., Iamsirithaworn, S., & Rohani, P. (2013). Deciphering the impacts of vaccination and immunity on pertussis epidemiology in Thailand. *Proceedings of the National Academy of Sciences, 110,* 9595–9600. doi:10.1073/pnas.1220908110

Bohensky, M. A., Jolley, D., Sundararajan, V., Evans, S., Pilcher, D. V., Scott, I., & Brand, C. A. (2010). Data linkage: A powerful research tool with potential problems. *BMC Health Services Research, 10,* 346. doi:10.1186/1472-6963-10-346

Broder, K. R., Cohn, A. C., Schwartz, B., & Working Group on Adolescent Prevention Priorities. (2008). Adolescent immunizations and other clinical preventive services: A needle and a hook? *Pediatrics, 121,* S25–S34. doi:10.1542/peds.2007-1115D

Broder, K. R., Cortese, M. M., Iskander, J. K., Kretsinger, K., Slade, B. A., Brown, K. H., & Murphy, T. V. (2006). Preventing tetanus, diphtheria, and pertussis among adolescents: Use of tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis vaccine. Recommendations of the Advisory Committee on Immunization Practices. Retrieved from http://www.cdc.gov/mmwr/pdf/rr/rr5503.pdf

Bugenske, E., Stokley, S., Kennedy, A., & Dorell, C. (2012). Middle school vaccination requirements and adolescent vaccination coverage. *Pediatrics, 129,* 1056–1063. doi:10.1542/peds.2011-2641

Bundy, D. G., Persing, N. M., Solomon, B. S., King, T. M., Murakami, P., Thompson, R. E., … Miller, M. R. (2013). The ImmProve Project: Leveraging electronic health record data to promote immunization delivery. *Academic Pediatrics, 13,* 458–465. doi:10.1016/j.acap.2013.03.004

Burns, I. T., & Zimmerman, R. K. (2005). Immunization barriers and solutions. *Journal of Family Practice, 54,* S58–S62.

Byrd, K. K., Santibanez, T. A., & Chaves, S. S. (2011). Predictors of hepatitis A vaccination among young children in the United States. *Vaccine, 29,* 3254–3259. doi:10.1016/j.vaccine.2011.02.028

California Department of Public Health Immunization Branch. (2010). *California pertussis summary report.* Retrieved from http://www.cdph.ca.gov/programs /immunize/Documents/PertussisSummary Report20100630.pdf

California Department of Public Health Immunization Branch. (2012). *California pertussis summary report.* Retrieved from http://www.cdph.ca.gov /programs/immunize/Documents/PertussisReport1-6-2012.pdf

Caskey, R., Lindau, S. T., & Alexander, G. C. (2009). Knowledge and early adoption of the HPV vaccine among girls and young women: Results of a national survey. *Journal of Adolescent Health, 45,* 453–462. doi:10.1016/j.jadohealth.2009.04.021

Centers for Disease Control and Prevention. (1982). Current trends childhood immunization initiative, United States—5-year follow-up. *Morbidity and Mortality Weekly Report, 31,* 231–232. Retrieved from http://www.cdc.gov /mmwr/preview/mmwrhtml/00001091.htm

Centers for Disease Control and Prevention. (1991a). Diphtheria, tetanus, and pertussis: Recommendations for vaccine use and other preventive measures. Recommendations of the Immunization Practices Advisory Committee. *Morbidity and Mortality Weekly Report, 40*(RR-10), 1–28. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00041645.htm

Centers for Disease Control and Prevention. (1991b). Hepatitis B virus: A comprehensive strategy for eliminating transmission in the United States through universal childhood vaccination: Recommendations of the Immunization Practices Advisory Committee. *Morbidity and Mortality Weekly Report, 40*(RR-13), 1–19. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00033405.htm

Centers for Disease Control and Prevention. (1998a). Measles, mumps, and rubella—Vaccine use and strategies for elimination of measles, rubella, and congenital rubella syndrome and control of mumps: Recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 47*(RR-8), 1–57. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00053391.htm

Centers for Disease Control and Prevention. (1998b). Measles—United States, 1997. *Morbidity and Mortality Weekly Report, 47,* 273–276. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00051986.htm

Centers for Disease Control and Prevention. (1998c). Progress toward global measles control and regional elimination, 1990–1997. *Morbidity and Mortality Weekly Report, 47,* 1049–1054. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00055965.htm

Centers for Disease Control and Prevention. (1998d). The vaccines for children operations guide: Appendix CMS policy letter to state Medicaid officials. Retrieved from http://www.cdc.gov/vaccines/programs/vfc/downloads/vfc-op-guide/24-appx-8-st-med-dir-schip-ltr.pdf

Centers for Disease Control and Prevention. (1999a). Achievements in public health, 1900–1999: Changes in the public health system. *Morbidity and Mortality Weekly Report, 48,* 1141–1147. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm4850a1.htm

Centers for Disease Control and Prevention. (1999b). Achievements in public health, 1900–1999: Control of infectious diseases. *Morbidity and Mortality Weekly Report, 48,* 621–629. Retrieved from https://www.cdc.gov/mmwr/preview/mmwrhtml/mm4829a1.htm

Centers for Disease Control and Prevention. (1999c). Achievements in public health, 1900–1999: Impact of vaccines universally recommended for children—United States, 1990–1998. *Morbidity and Mortality Weekly Report, 48,* 243–248. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/00056803.htm

Centers for Disease Control and Prevention. (1999d). Combination vaccines for childhood immunization: Recommendations of the Advisory Committee on Immunization Practices, the American Academy of Pediatrics and the American Academy of Family Physicians. *Morbidity and Mortality Weekly Report, 48*(RR-5), 1–15. Retrieved from http://www.cdc.gov/mmwr/PDF/rr/rr4805.pdf

Centers for Disease Control and Prevention. (1999e). Epidemiology of measles—United States, 1998. *Morbidity and Mortality Weekly Report, 48,* 749–753. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml /mm4834a1.htm

Centers for Disease Control and Prevention. (1999f). Global disease elimination and eradication as public health strategies. *Morbidity and Mortality Weekly Report, 48*(Suppl), S1–208. Retrieved from http://www.cdc.gov/mmwr/pdf/other /mm48su01.pdf

Centers for Disease Control and Prevention. (1999g). Ten great public health achievements—United States 1900–1999. *Morbidity and Mortality Weekly Report, 48,* 241–243. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/00056796.htm

Centers for Disease Control and Prevention. (2000a). Measles—United States, 1999. *Morbidity and Mortality Weekly Report, 49,* 557–560. Retrieved from http://www .cdc.gov/mmwr/preview/mmwrhtml/mm4925a1.htm

Centers for Disease Control and Prevention. (2000b). Poliomyelitis prevention in the United States. Updated recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 49*(RR-5), 1–19. Retrieved from http://www.cdc.gov/mmwr/PDF/rr/rr4905.pdf

Centers for Disease Control and Prevention. (2000c). Use of diphtheria toxoid-tetanus toxoid-acellular pertussis vaccine as a five-dose series: Supplemental recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 49*(RR-13), 1–8. Retrieved from http:// www.cdc.gov/mmwr/preview/mmwrhtml/rr4913a1.htm

Centers for Disease Control and Prevention. (2001). Progress in development of immunization registries—United States, 1999. *Morbidity and Mortality Weekly Report, 50,* 3–7. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5001a2.htm

Centers for Disease Control and Prevention. (2005a). A comprehensive immunization strategy to eliminate transmission of hepatitis B virus infection in the United States: Recommendations of the Advisory Committee on Immunization Practices. Part 1: Immunization of infants, children, and adolescents. *Morbidity and Mortality Weekly Report, 54*(RR-16), 1–32. Retrieved from http://www.cdc.gov/mmwr/PDF/rr/rr5416.pdf

Centers for Disease Control and Prevention. (2005b). Import-associated measles outbreak—Indiana, May–June 2005. Retrieved from *Morbidity and Mortality Weekly Report, 54,* 1073–1075. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5442a1.htm

Centers for Disease Control and Prevention. (2006a). General recommendations on immunization: Recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 55*(RR-15), 1–46. Retrieved from http://www.cdc.gov/mmwr/pdf/rr/rr5515.pdf

Centers for Disease Control and Prevention. (2006b). Measles—United States, 2005. *Morbidity and Mortality Weekly Report, 55,* 1348–1351. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5550a2.htm#tab

Centers for Disease Control and Prevention. (2006c). Preventing tetanus, diphtheria, and pertussis among adolescents: Use of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis vaccines. Recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 55*(RR-3), 1–35. Retrieved from http://www.cdc.gov/mmwr/pdf/rr/rr5503.pdf

Centers for Disease Control and Prevention. (2006d). Summary of notifiable diseases—United States, 2004. *Morbidity and Mortality Weekly Report, 53,* 1–79. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5353a1.htm

Centers for Disease Control and Prevention. (2006e). Update: Multistate outbreak of mumps—United States, January 1–May 2, 2006. *Morbidity and Mortality Weekly Report, 55,* 559–563. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/mm5520a4.htm

Centers for Disease Control and Prevention. (2007a). Laboratory surveillance for wild and vaccine-derived polioviruses—Worldwide, January 2006–June 2007. *Morbidity and Mortality Weekly Report, 56,* 965–969. Retrieved from http:// www.cdc.gov/mmwr/preview/mmwrhtml/mm5637a4.htm

Centers for Disease Control and Prevention. (2007b). National vaccination coverage among adolescents aged 13–17 years—United States, 2006. *Morbidity and Mortality Weekly Report, 56,* 885–888. Retrieved from http://www.cdc.gov /mmwr/preview/mmwrhtml/mm5634a3.htm

Centers for Disease Control and Prevention. (2007c). Prevention of varicella. Recommendations of the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 56*(RR-4), 1–40. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5604a1.htm

Centers for Disease Control and Prevention. (2007d). Recommended immunization schedules for persons aged 0–18 years—United States, 2007. *Morbidity and Mortality Weekly Report, 55,* 1–4. Retrieved from http://www.cdc.gov/mmwr/pdf/wk/mm5551-immunization.pdf

Centers for Disease Control and Prevention. (2008a). National, state, and local area vaccination coverage among children aged 19–35 months—United States, 2007. *Morbidity and Mortality Weekly Report, 57,* 961–966. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5735a1.htm

Centers for Disease Control and Prevention. (2008b). Recommended immunization schedules for persons aged 0 through 18 years—United States, 2009. *Morbidity and Mortality Weekly Report, 57,* 1–4. Retrieved from https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5751a5.htm

Centers for Disease Control and Prevention. (2009a). Mumps outbreak—New York, New Jersey, Quebec, 2009. *Morbidity and Mortality Weekly Report, 58*(Dispatch), 1–4. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm58d1112a1.htm

Centers for Disease Control and Prevention. (2009b). National, state, and local area vaccination coverage among adolescents aged 13–17 Years—United States, 2008. *Morbidity and Mortality Weekly Report, 58,* 997–1001. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5836a2.htm

Centers for Disease Control and Prevention. (2009c). Progress toward interruption of wild poliovirus transmission—worldwide, 2008. *Morbidity and Mortality Weekly Report, 58,* 308–312. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/mm5812a3.htm

Centers for Disease Control and Prevention. (2009d). Recommended immunization schedules for persons aged 0 through 18 years—United States, 2009. *Morbidity and Mortality Weekly Report, 57,* 1–4. Retrieved from http://www.cdc.gov/mmwr /preview/mmwrhtml/mm5751a5.htm

Centers for Disease Control and Prevention. (2009e). Surveillance summaries: Surveillance for acute viral hepatitis—United States, 2007. *Morbidity and Mortality Weekly Report, 58*(SS-3), 1–9. Retrieved from http://www.cdc.gov /mmwr/PDF/ss/ss5803.pdf

Centers for Disease Control and Prevention. (2009f). Updated recommendations of the Advisory Committee on Immunization Practices regarding routine poliovirus vaccination. *Morbidity and Mortality Weekly Report, 58,* 829–844. Retrieved from http://www.cdc.gov/mmwr/PDF/wk/mm5830.pdf

Centers for Disease Control and Prevention. (2009g). Wild poliovirus Type 1 and Type 3 importations—15 countries, Africa, 2008–2009. *Morbidity and Mortality Weekly Report, 58,* 357–362. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/mm5814a1.htm

Centers for Disease Control and Prevention. (2010a). National, state, and local area vaccination coverage among adolescents aged 13–17 years—United States, 2009. *Morbidity and Mortality Weekly Report, 59,* 1018–1023. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5932a3.htm

Centers for Disease Control and Prevention. (2010b). NIS-IIS Match Project: Arkansas NIS-IIS Match Project 2010. *Morbidity and Mortality Weekly Report, 61,* 464–467. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6125a3.htm?s_cid=mm6125a3_w

Centers for Disease Control and Prevention. (2010c). Outbreaks following wild poliovirus importations—Europe, Africa, and Asia, January 2009–September 2010. *Morbidity and Mortality Weekly Report, 59,* 1393–1399. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5943a1.htm

Centers for Disease Control and Prevention. (2010d). Recommended immunization schedules for persons aged 0 through 18 years—United States, 2010. *Morbidity and Mortality Weekly Report, 58,* 1–4. Retrieved from http://www.cdc.gov/mmwr/pdf/wk/mm5953.pdf

Centers for Disease Control and Prevention. (2010e). Summary of notifiable diseases—United States, 2008. *Morbidity and Mortality Weekly Report, 57,* 1–94. Retrieved from http://www.cdc.gov/mmwr/PDF/wk/mm5754.pdf

Centers for Disease Control and Prevention. (2010f). Update: Mumps outbreak—New York and New Jersey, June 2009–January 2010. *Morbidity and Mortality Weekly Report, 59,* 125–129. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5905a1.htm

Centers for Disease Control and Prevention. (2010g). Updated recommendations for use of tetanus toxoid, reduced diphtheria toxoid and acellular pertussis (Tdap) vaccine from the Advisory Committee on Immunization Practices. *Morbidity and Mortality Weekly Report, 60,* 13–15. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6001a4.htm

Centers for Disease Control and Prevention. (2010h). Vaccine Adverse Event Reporting System. Retrieved from http://www.cdc.gov/vaccinesafety/Activities/vaers.html

Centers for Disease Control and Prevention. (2011a). Final 2010 reports of nationally notifiable infectious diseases. *Morbidity and Mortality Weekly Report, 60,* 1088–1101.

Centers for Disease Control and Prevention. (2011b). Local health department costs associated with response to a school-based pertussis outbreak—Omaha, Nebraska, September–November 2008. *Morbidity and Mortality Weekly Report, 60,* 5–9. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6001a2.htm

Centers for Disease Control and Prevention. (2011c). Measles imported by returning U.S. travelers aged 6–23 months, 2001–2011. *Morbidity and Mortality Weekly Report, 60,* 397–400. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6013a1.htm?s_cid=mm6013a1_w#fig

Centers for Disease Control and Prevention. (2011d). National and state vaccination coverage among adolescents aged 13 through 17 years—United States, 2010 *Morbidity and Mortality Weekly Report, 60,* 1117–1123. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6033a1.htm

Centers for Disease Control and Prevention. (2011e). National Notifiable Diseases Surveillance System: Annual summary of notifiable diseases. Retrieved from http://www.cdc.gov/osels/ph_surveillance/nndss/nndsshis.htm

Centers for Disease Control and Prevention. (2011f). National vaccine program office immunization laws. Retrieved from http://www.hhs.gov/nvpo/law.htm

Centers for Disease Control and Prevention. (2011g). Notes from the field: Measles outbreak—Hennepin County, Minnesota, February–March 2011. *Morbidity and Mortality Weekly Report, 60,* 421. Retrieved from http://www.cdc.gov/mmwr /preview/mmwrhtml/mm6013a6.htm

Centers for Disease Control and Prevention. (2011h). Notes from the field: Measles outbreak—Indiana, June–July 2011. *Morbidity and Mortality Weekly Report, 60,* 1169–1169. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml /mm6034a5.htm

Centers for Disease Control and Prevention. (2011i). Recommended immunization schedules for persons aged 0 through 18 years—United States, 2011. *Morbidity and Mortality Weekly Report, 60,* 1–4. Retrieved from http://www.cdc.gov/mmwr /preview/mmwrhtml/mm6005a6.htm?s_cid=mm6005a6_w

Centers for Disease Control and Prevention. (2011j). Summary of notifiable diseases—United States, 2009. *Morbidity and Mortality Weekly Report, 58,* 1–93. Retrieved from http://www.cdc.gov/mmwr/pdf/wk/mm5853.pdf

Centers for Disease Control and Prevention. (2011k). Ten great public health achievements—United States, 2001–2010. *Morbidity and Mortality Weekly Report, 60,* 619–623. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/mm6019a5.htm

Centers for Disease Control and Prevention. (2011l). Tracking progress toward global polio eradication—worldwide, 2009–2010. *Morbidity and Mortality Weekly Report, 60,* 441–445. Retrieved from http://www.cdc.gov/mmwr/preview /mmwrhtml/mm6014a2.htm

Centers for Disease Control and Prevention. (2011m). Vaccination coverage among children in kindergarten—United States, 2009–10 school year. *Morbidity and Mortality Weekly Report, 60,* 700–704. Retrieved from http://www.cdc.gov /mmwr/preview/mmwrhtml/mm6021a4.htm?s_cid=mm6021a4_w

Centers for Disease Control and Prevention. (2011n). Vaccines and preventable diseases: Polio: Unprotected story. Retrieved from http://www.cdc.gov/vaccines/vpd-vac/polio/unprotected-story.htm

Centers for Disease Control and Prevention. (2011o). Vaccines for Children Fund. Retrieved from http://www.cdc.gov/vaccines/programs/vfc/index.html

Centers for Disease Control and Prevention. (2012a). Advisory Committee on Immunization Practices vaccination recommendations by published dates. Retrieved from http://www.cdc.gov/vaccines/pubs/ACIP-list-by-date.htm

Centers for Disease Control and Prevention. (2012b). *Diseases and the vaccines that prevent them.* Retrieved from http://www.cdc.gov/vaccines/vpd-vac/polio /downloads/dis-polio-bw-office.pdf

Centers for Disease Control and Prevention. (2012c). History of the Vaccines for Children program. Retrieved from http://www.cdc.gov/vaccines/programs/vfc/about/index.html

Centers for Disease Control and Prevention. (2012d). Measles—United States, 2011. *Morbidity and Mortality Weekly Report, 61,* 253–257. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6115a1.htm?s_cid=mm6115a1_w

Centers for Disease Control and Prevention. (2012e). National and state vaccination coverage among adolescents aged 13–17 years—United States, 2011. *Morbidity and Mortality Weekly Report, 61,* 671–677. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6134a3.htm

Centers for Disease Control and Prevention. (2012f). *National Health Interview Survey.* Retrieved from http://www.cdc.gov/nchs/data/factsheets/factsheet_nhis.pdf

Centers for Disease Control and Prevention. (2012g). Pertussis epidemic—Washington, 2012. *Morbidity and Mortality Weekly Report, 61,* 517–522. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6128a1.htm

Centers for Disease Control and Prevention. (2012h). Pertussis outbreaks: Recent outbreak activity. Retrieved from http://www.cdc.gov/pertussis/outbreaks.html

Centers for Disease Control and Prevention. (2012i). Pertussis (whooping cough): Surveillance and reporting. Retrieved from http://www.cdc.gov/pertussis/surv-reporting.html

Centers for Disease Control and Prevention. (2012j). Progress in immunization information systems—United States, 2012. *Morbidity and Mortality Weekly Report, 62,* 1005–1008. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6125a3.htm

Centers for Disease Control and Prevention. (2012k). Recommended immunization schedules for persons aged 0 through 18 years—United States, 2012. *Morbidity and Mortality Weekly Report, 61,* 1–4 Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6105a5.htm

Centers for Disease Control and Prevention. (2012l). Vaccination coverage among children in kindergarten—United States, 2011–12 school year. *Morbidity and Mortality Weekly Report, 61,* 647–652. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6133a2.htm

Centers for Disease Control and Prevention. (2012m). Vaccine for Children Program eligibility criteria. Retrieved from http://www.cdc.gov/vaccines/programs/vfc/providers/eligibility.html

Centers for Disease Control and Prevention. (2013). *2013 recommended immunizations for children from 7 through 18 years old.* Retrieved from http://www.cdc.gov/vaccines/who/teens/downloads/parent-version-schedule-7-18yrs.pdf

Centers for Disease Control and Prevention. (2014a). Advisory Committee on Immunization Practices recommended immunization schedules for persons aged 0 through 18 years—United States, 2014. *Morbidity and Mortality Weekly Report, 63,* 108–109. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6305a6.htm

Centers for Disease Control and Prevention. (2014b). Birth–18 years and "catch-up" immunization schedules United States, 2014. Retrieved from http://www.cdc .gov/vaccines/schedules/hcp/imz/child-adolescent.html

Centers for Disease Control and Prevention. (2014c). Reduction of racial/ethnic disparities in vaccination coverage, 1995–2011. *Morbidity and Mortality Weekly Report, 63,* 7–12. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml /su6301a3.htm

Centers for Disease Control and Prevention. (2015). Measles—United States, January 4–April 2, 2015. *Morbidity and Mortality Weekly Report, 64,* 373–376. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6414a1.htm

Chaves, S. S., Haber, P., Walton, K., Wise, R. P., Izurieta, H. S., Schmid, D. S., & Seward, J. F. (2008). Safety of varicella vaccine after licensure in the United States: Experience from reports to the Vaccine Adverse Event Reporting System, 1995–2005. *Journal of Infectious Diseases, 197*(S2), S170–S177. Retrieved from http://jid.oxfordjournals.org/content/197/Supplement_2/S170.full.pdf

Cherry, J. D. (2010). The present and future control of pertussis. *Clinical Infectious Diseases, 15,* 663–667. doi:10.1086/655826

Cherry, J. D. (2013). Pertussis: Challenges today and for the future. *PLoS Pathogens*, *9*(7), e1003418. doi:10.1371/journal.ppat.1003418.

Chiappini, E., Stival, A., Galli, L., & Martino, D. E. (2013). Pertussis re-emergence in the post-vaccination era. *BMC Infectious Diseases, 13,* 151. doi:10.1186/1471-2334 -13-151

Children's Reporting and Information System. (2013). Foster care immunization. Retrieved from https://ardhs.sharepointsite.net/CW/_layouts/searchresults.aspx?k=foster%20care%20immunization&u=http%3A%2F%2Fardhs%2Esharepointsite%2Enet%2FC

Chu, S. Y., Barker, L. E., & Smith, P. J. (2004). Racial/ethnic disparities in preschool immunizations: United States, 1996–2001. *American Journal of Public Health, 94,* 973–977. doi:10.2105/AJPH.94.6.973

Civen, R., Lopez, A. S., Zhang, J., Garcia-Herrera, J., Schmid, D., Chaves, S. S., & Mascola, L. (2008). Varicella outbreak epidemiology in an active surveillance site, 1995–2005. *Journal of Infectious Diseases, 197,* S114–119. doi:10.1086/522144

Clark, S. J., Butchart, A., Kennedy, A., & Dombkowski, K. J. (2011). Parents' experiences with and preferences for immunization reminder/recall technologies. *Pediatrics, 128,* e1100–1105. doi:10.1542/peds.2011-0270

Cooper, L. Z., Larson, H. J., & Katz, S. L. (2008). Protecting public trust in immunization. *Pediatrics, 122,* 149–153. doi:10.1542/peds.2008-0987

Curran, E. A., Bednarczyk, R. A., & Omer, S. B. (2013). Evaluation of the frequency of immunization information system use for public health research. *Human Vaccines and Immunotherapeutics, 9,* 1346–1350. doi:10.4161/hv.24033

Daniels, D., Jiles, R. B., Klevens, R. M., & Herrera, G. A. (2001). Undervaccinated African-American preschoolers: A case of missed opportunities. *American Journal of Preventive Medicine, 20,* S61–68. doi:10.1016/S0749-3797(01)00278-1

Daley, M. F., Crane, L. A., Markowitz, L. E., Black, S. R., Beaty, B. L., Barrow, J., & Kempe, A. (2010). Human papillomavirus vaccination practices: A survey of U.S. physicians 18 months after licensure. *Pediatrics, 126,* 425–433. doi:10.1542/peds .2009-3500

Daley, M. F., Curtis, C. R., Pyrzanowski, J., Barrow, J., Benton, K., Abrams, L., & Kempe, A. (2009). Adolescent immunization delivery in school-based health centers: A national survey. *Journal of Adolescent Health, 45,* 445–452. doi:10 .1016/j.jadohealth.2009.04.002

Darden, P. M., Gustafson, K. K., Nietert, P. J., & Jacobson, R. M. (2011). Extra-immunization as a clinical indicator for fragmentation of care. *Public Health Reports, 126,* S48–S59. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles /PMC3113430/

Darden, P. M., Thompson, D. M., Roberts, J. R., Hale, J. J., Pope, C., Naifeh, M., & Jacobson, R. M. (2013). Reasons for not vaccinating adolescents: National Immunization Survey of Teens, 2008–2010. *Pediatrics, 131,* 645–651. doi:10 .1542/peds.2012-2384

Davis, M. M., Broder, K. R., Cowan, A. E., Mijalski, C., Katrina, K., Stokley, S., & Clark, S. J. (2006). Physician attitudes and preferences about combined Tdap vaccines for adolescents. *American Journal of Preventive Medicine, 31,* 176–180. doi:10.1016/j.amepre.2006.03.023

Davis, M. M., King, J. C., Jr., Moag, L., Cummings, G., & Magder, L. S. (2008). Countywide school-based influenza immunization: Direct and indirect impact on student absenteeism. *Pediatrics, 122,* e260–e265 doi:10.1542/peds.2007-2963

Davis, T. C., Fredrickson, D. D., Arnold, C. L., Cross, J. T., Humiston, S. G., Green, K. W., & Bocchini, J. A., Jr. (2001). Childhood vaccine risk/benefit communication in private practice office settings: A national survey. *Pediatrics, 107,* e17. doi:10 .1542/peds.107.2.e17

Dempsey, A. F., & Zimet, G. D. (2015). Interventions to improve adolescent vaccination: What may work and what still needs to be tested. *American Journal of Preventive Medicine, 49,* S445–S454. doi:10.1016/j.amepre.2015.04.013

Diekema, D. S. (2005). Responding to parental refusals of immunization of children. *Pediatrics, 115,* 1428–1431. doi:10.1542/peds.2005-0316

Diekema, D. S. (2012). Improving childhood vaccination rates. *New England Journal of Medicine, 366,* 391–393. doi:10.1056/NEJMp1113008.

Dombkowski, K. J., Harrington, L., Hanauer, D., Kennedy, A., & Clark, S. (2012). Current and potential use of new technologies for reminder notifications. *Clinical Pediatrics, 51*(4), 394–397. doi:10.1177/0009922811420715

Dombkowski, K. J., Lantz, P. M., & Freed, G. L. (2004a). The need for surveillance of volume delay in age-appropriate immunization. *American Journal of Preventive Medicine, 23,* 36–42. doi:10.1016/S0749-3797(02)00442-7

Dombkowski, K. J., Lantz, P. M., & Freed, G. L. (2004b). Risk factors for delay in age-appropriate vaccination. *Public Health Reports, 119,* 144–155. Retrieved from http://www.publichealthreports.org

Domenech de Cellès, M., Riolo, M. A., Magpantay, F. M., Rohani, P., & King, A. A. (2014). Epidemiological evidence for herd immunity induced by acellular pertussis vaccines. *Proceedings of the National Academy of Sciences, 111,* e716–717. doi:10.1073/pnas.1323795111

Dorell, C. G., Jain, N., & Yankey, D. (2011). Validity of parent-reported vaccination status for adolescents aged 13–17 years: National Immunization Survey—Teen, 2008. *Public Health Reports, 126,* S60–S69. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3113431/

Dorell, C. G., Yankey, D., Byrd, K. K., & Murphy, T. V. (2012). Hepatitis A vaccination coverage among adolescents in the United States. *Pediatrics, 129,* 213–221. doi: 10.1542/peds.2011-2197

Dorell, C., Yankey, D., Kennedy, A., & Stokley, S. (2013). Factors that influence parental vaccination decisions for adolescents, 13 to 17 years old: National Immunization Survey-Teen, 2010. *Clinical Pediatrics, 52,* 162–70. doi:10.1177/0009922812468208

Dorell, C., Yankey, D., & Strasser, S. (2011). Parent-reported reasons for no receipt of recommended adolescent vaccinations, National Immunization Survey: Teen, 2009. *Clinical Pediatrics, 50,* 1116–1124. doi:10.1177/0009922811415104

Dredze, M., Broniatowski, D. A., Smith, M. C., & Hilyard, K. M. (2015). Understanding vaccine refusal: Why we need social media now. *American Journal of Preventive Medicine, 50,* 550–552. doi:10.1016/j.amepre.2015.10.002

Fairchild, A. J., & MacKinnon, D. P. (2009). A general model for testing mediation and moderation effects. *Prevention Science, 10,* 87–99. doi:10.1007/s11121-008-0109-6

Fath, J., Andujar, U., Williams, W., & Kurilo, M. B. (2015). *Interfacing immunization information systems with CDC's vaccine ordering system: Strategies for improving accountability, efficiency and provider satisfaction. Immunization Information Systems.* Retrieved from http://www.cdc.gov/vaccines/programs/iis/downloads/interfacing-vos.pdf

Federico, S. G., Abrams L., Everhart, R. M., Melinkovich, P., & Hambidge, S. J. (2010). Addressing adolescent immunization disparities: A retrospective analysis of school-based health center immunization delivery. *American Journal of Public Health, 100,* 1630–1634. doi:10.2105/AJPH.2009.176628

Fiks, A. G., Grundmeier, R. W., Margolis, B., Bell, L. M., Steffes, J., Massey, J., & Wasserman, R. C. (2012). Comparative effectiveness research using the electronic medical record: An emerging area of investigation in pediatric primary care. *Journal of Pediatrics, 160,* 719–724. doi:10.1016/j.jpeds.2012.01.039

Fiks, A. G., Grundmeier, R. W., Mayne, S., Song, L., Feemster, K., Karavite, D., & Localio, A. R. (2013). Effectiveness of decision support for families, clinicians, or both on HPV vaccine receipt. *Pediatrics, 131,* 1114–1124. doi:10.1542/peds.2012-3122

Freed, G. L., Clark, S. J., Butchart, A. T., Singer, D. C., & Davis, M. M. (2011). Sources and perceived credibility of vaccine-safety information for parents. *Pediatrics, 127,* S107–S112. doi:10.1542/peds.2010-1722P

Freundlich, M. (2003). *Time running out: Teens in foster care.* Retrieved from http://www.childrensrights.org/wp-content/uploads/2014/09/time_running_out_teens_in_foster_care_nov_2003.pdf

Gaensbauer, J., Armon, C., & Todd, J. (2014). *Vaccine-preventable diseases in Colorado's children.* Retrieved from https://www.childrensimmunization.org/uploads/Vaccine-preventable-disease-2014.pdf

Galvani, A. P., Reluga, T. C., & Chapman, G. B. (2007). Long-standing influenza vaccination policy is in accord with individual self-interest but not with the utilitarian optimum. *Proceedings of the National Academy of Sciences, 104,* 5692–5697. doi:10.1073/pnas.0606774104

Gamble, V. N. (1997). Under the shadow of Tuskegee: African Americans and health care. *American Journal of Public Health, 87,* 1773–1778. doi:10.1542/peds.2011-3073

Glanz, J. M., McClure, D. L., Magid, D. J., Daley, M. F., Eric, K., France, E. K., … Hambidge, S. J. (2009). Parental refusal of pertussis vaccination is associated with an increased risk of pertussis infection in children. *Pediatrics, 123,* 1446–1451. doi:10.1542/peds.2008-2150

Glanz, J. M., McClure, D. L., Magid, D. J., Daley, M. F., France, E. K., & Hambidge, S. J. (2010). Parental refusal of varicella vaccination and the associated risk of varicella infection in children. *Archives of Pediatrics and Adolescent Medicine, 164,* 66–70. doi:10.1001/archpediatrics.2009.244

Glass, K., & Barnes, B. (2007). How much would closing schools reduce transmission during an influenza pandemic? *Epidemiology, 18,* 623–628. doi:10.1097/EDE .0b013e31812713b4

Gould, P. L., Leung, J., Scott, C., Schmid, D. S., Deng, H., Lopez, A., & Snow, S. (2009). An outbreak of varicella in elementary school children with two-dose varicella vaccine recipients—Arkansas, 2006. Retrieved from *Pediatric Infectious Disease Journal, 28,* 678–681. doi:10.1097/IF.0b013e31819c1041

Gowda, C., Dong, S., Potter, R. C., Dombkowski, K. J., & Dempsey, A. F. (2013). A population-level assessment of factors associated with uptake of adolescent-targeted vaccines in Michigan. *Journal of Adolescent Health, 53,* 498–505. doi:10 .1016/j.jadohealth.2013.07.022

Grannis, S. J., Overhage, J. M., & McDonald, C. J. (2002). Analysis of identifier performance using a deterministic linkage algorithm. *Proceedings of the AMIA Symposium, 2002,* 305–309. Retrieved from http://www.ncbi.nlm.nih.gov/pmc /articles/PMC2244404/

Greene, S. K., Shi, P., Dutta-Linn, M. M., Shoup, J. A., Hinrichsen, V. L., Ray, P., & Yih, W. K. (2009). Accuracy of data on influenza vaccination status at four vaccine safety datalink sites. *American Journal of Preventive Medicine, 37,* 552–555. doi:10.1016/j.amepre.2009.08.022z

Gust, D. A., Darling, N., Kennedy, A., & Schwartz, B. (2008). Parents with doubts about vaccines: Which vaccines and reasons why. *Pediatrics, 122,* 718–725. doi:10 .1542/peds.2007-0538

Hall, R., & Jolley, D. (2011). International measles incidence and immunization coverage. *Journal of Infectious Diseases, 204,* S158–S163. doi:10.1093/infdis/jir124

Hambidge, S. J., Phibbs, S. L., Chandramouli, V., Fairclough, D., & Steiner, J. F. (2009). A stepped intervention increases well-child care and immunization rates in a disadvantaged population. *Pediatrics, 124,* 455–464. doi:10.1542/peds.2008-0446

Hamborsky, J., Kroger, A., & Wolfe, S. (Eds.). (2015). *Epidemiology and prevention of vaccine-preventable diseases* (13th ed.). Washington, DC: National Center for Immunization and Respiratory Diseases, Centers for Disease Control and Prevention.

Haselow, D. T. (2014). Arkansas Department of Health Public Health grand rounds: The control of pertussis: Successful collaboration between clinicians and public health practitioners. Retrieved from https://vimeopro.com/healthyarkansas/20140605

Haviland, A. M., Elliott, M. N., & Hambarsoomian, L. N. (2011). Immunization disparities by Hispanic ethnicity and language preference. *Archives of Internal Medicine, 171,* 158–165. doi:10.1001/archinternmed.2010.499

Healthy People 2010. (2011). *Immunization and infectious diseases.* Retrieved from http://www.cdc.gov/nchs/data/hpdata2010/hp2010_final_review_focus_area_14.pdf

Healthy People 2020. (2012). Who's leading the leading health indicators? Retrieved from http://www.healthypeople.gov/2020/LHI/whosleading.aspx

Hilbe, C., Nowak, M. A., & Sigmund, K. (2013). Evolution of extortion in iterated prisoner's dilemma games. *Proceedings of the National Academy of Sciences, 110,* 6913–6918. doi:10.1073/pnas.1214834110.

Hinman, A. R., Orenstein, W. A., & Schuchat, A. (2011). Vaccine-preventable diseases, immunizations, and MMWR—1961–2011. Retrieved from http://www.cdc.gov /mmwr/preview/mmwrhtml/su6004a9.htm

Hinman, A. R., Orenstein, W. A., Williamson, D. E., & Darrington, D. (2002). Childhood immunization: Laws that work. *Journal of Law, Medicine and Ethics, 30,* 122–127. Retrieved from http://img2.tapuz.co.il/forums/1_148523156.pdf

Hogue, M. D., Grabenstein, J. D., Foster, S. L., & Rothholz, M. C. (2006). Pharmacist involvement with immunizations: A decade of professional advancement. *Journal of the American Pharmacists Association, 46*(2), 168–182. doi:10.1331 /154434506776180621

Hughes, C. C., Jones, A. L., Feemster, K. A., & Fiks, A. G. (2011). HPV vaccine decision making in pediatric primary care: A semi structured interview study. *BMC Pediatrics, 11,* 74. doi:10.1186/1471-2431-11-74

Humiston, S. G., Albertin, C., Schaffer, S., Rand, C., Shone, L. P., Stokley, S., & Szilagyi, P. G. (2009). Health care provider attitudes and practices regarding adolescent immunizations: A qualitative study. *Patient Education and Counseling, 75,* 121–127. doi:10.1016/j.pec.2008.09.012

Humiston, S. G., Serwint, J. R., Szilagyi, P. G., Vincelli, P. A., Dhepyasuwan, N., Rand, C. M., & Curtis, C. R. (2013). Increasing adolescent immunization rates in primary care: Strategies physicians use and would consider implementing. *Clinical Pediatrics, 52,* 710–720. doi:10.1177/00009922813483359

Ibuka, Y., Chapman, G. B., Meyers, L. A., Li, M., & Galvani, A. P. (2010). The dynamics of risk perceptions and precautionary behavior in response to 2009 (H1N1) pandemic influenza. *BMC Infectious Disease, 10,* 296. doi:10.1186 /1471-2334-10-296

Ibuka, Y., Li, M., Vietri, J., Chapman, G. B., & Galvani, A. P. (2014). Free-riding behavior in vaccination decisions: An experimental study. *PLoS One, 9,* e87164. doi:10.1371/journal.pone.0087164

Imdad, A., Tserenpuntsag, B., Blog, B. S., Halsey, N. A., Easton, D. E., & Shaw, J. (2013). Religious exemptions for immunization and risk of pertussis in New York State, 2000–2011. *Pediatrics, 132,* 37–43. doi:10.1542/peds.2012-3449

Immunization Action Coalition. (2010). State information: State mandates on immunization and vaccine-preventable diseases. 2010. Retrieved from http://www.immunize. org/laws/.

Immunization Action Coalition. (2011). State mandates on immunization and vaccine-preventable diseases. Retrieved from http://www.immunize.org/laws

Immunization Action Coalition. (2012). State mandates on immunization and vaccine-preventable diseases. Retrieved from http://www.immunize.org/laws/

Institute of Medicine. (2011a). Adverse effects of vaccines: Evidence and causality. Retrieved from http://www.iom.edu/Reports/2011/Adverse-Effects-of-Vaccines-Evidence-and-Causality.aspx

Institute of Medicine. (2011b). Serious adverse events rare with vaccines: Extensive review finds few causal relationships. Retrieved from http://www.aafp.org/online/en/home/publications/news/news-now/health-of-the-public/20110912iomreview.html

Institute of Medicine. (2012). Adverse effects of vaccines: Evidence and causality. Retrieved from http://www.nap.edu/catalog.php?record_id=13164

Institute of Medicine. (2013). The childhood immunization schedule and safety: Stakeholder concerns, scientific evidence, and future studies. Retrieved from http://www.nap.edu/catalog.php?record_id=13563

Jackson, C. L. (1969). State laws on compulsory immunization in the United States. *Public Health Reports, 84,* 787–795. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2031602/

Jackson, M. C., Leyton-Brown, K., & Shoham, Y. (2015). Game theory II: Advanced Applications. Retrieved from http://www.game-theory-class.org/game-theory-II.html

Jackson, C., Vynnycky, E., Hawker, J., Olowokure, B., & Mangtani, P. (2013). School closures and influenza: Systematic review of epidemiological studies. *BMJ Open, 3,* e002149. doi:10.1136/bmjopen-2012-002149

Jacobs, R. J., & Meyerhoff, A. S. (2004). Effect of middle school entry requirements on hepatitis B vaccination coverage. *Journal of Adolescent Health, 34,* 420–423. doi: 10.1016/j.jadohealth.2003.08.014

Jain, N., Singleton, J. A., Montgomery, M., & Skalland, B. (2009). Determining accurate vaccination coverage rates for adolescents: The National Immunization Survey—Teen 2006. *Public Health Reports, 124,* 642–651. Retrieved from http://www .ncbi.nlm.nih.gov/pmc/articles/PMC2728656/

Kalies, H., Redel, R., Varga, R., Tauscher, M., & von Kries, R. (2008). Vaccination coverage in children can be estimated from health insurance data. *BMC Public Health, 8,* 82. doi:10.1186/1471-2458-8-82

Kaplan, D. W. (2010). Barriers and potential solutions to increasing immunization rates in adolescents. *Journal of Adolescent Health, 46,* S24–S33. doi:10.1016/j .jadohealth.2009.12.004

Kennedy, A. M., Basket, M., & Sheedy, K. (2011a). Vaccine attitudes, concerns, and information sources reported by parents of young children: Results from the 2009 HealthStyles Survey. *Pediatrics, 127,* S92–S99. doi:10.1542/peds.2010-1722N

Kennedy, A. M., & Gust, D. A. (2008). Measles outbreak associated with a church congregation: A study of immunization attitudes of congregation members. *Public Health Reports, 123,* 126–134. Retrieved from http://www.ncbi.nlm.nih.gov /pubmed/18457065

Kennedy, A. M., Stokley, S., Curtis, C. R., & Gust, D. A. (2011b). Limited awareness of vaccines recommended for adolescents and other results from two national consumer health surveys in the United States. *Journal of Adolescent Health, 50,* 198–200. doi:10.1016/j.jadohealth.2011.04.017

Kesselsa, S. J. M., Marshall, H. S., Watson, M., Braunack-Mayera, A. J., Reuzel, R., & Tooher, R. L. (2012). Factors associated with HPV vaccine uptake in teenage girls: A systematic review. *Vaccine, 30,* 3546–3556.

Khare, M., Battaglia, M. P., Huggins, V. J., Stokley, S., Hoaglin, D. C., Wright, R. A., & Rodén, A. (2000). *Accuracy of vaccination dates reported by immunization providers in the National Immunization Survey.* Retrieved from http://www.cdc .gov/nchs/data/nis/data_collection/khare2000.pdf

Kim, E. Y., & Lee, M. S. (2011). Related factors of age-appropriate immunization among urban-rural children aged 24–35 months in a 2005 population-based survey in Nonsan, Korea. *Yensei Medical Journal, 52,* 104–112. doi:10.3349/ymj.2011.52.1 .104

King, J. C., Jr., Stoddard, J. J., Gaglani, M. J., Moore, K. A., Magder, L., McClure, E., & Neuzil, K. (2006). Effectiveness of school-based influenza vaccination. *New England Journal of Medicine, 355,* 2523–2532. doi:10.1056/NEJMoa055414

Klein, N. P., Lewis, E., Baxter, R., Weintraub, E., Glanz, J., Naleway, A., & Fireman, B. (2012). Measles-containing vaccines and febrile seizures in children age 4 to 6 years. *Pediatrics, 129,* 809–814. doi:10.1542/peds.2011-3198

Kroger, A. T., Sumaya, C. V., Pickering, L. K., & Atkinson, W. L. (2011). General recommendations on immunization. Recommendations of the Advisory Committee on Immunization Practices ACIP. Retrieved from http://www.cdc.gov /mmwr/preview/mmwrhtml/rr6002a1.htm

Ladak, F., Gjelsvik, A., Feller, E., Rosenthal, S., & Montague, B. T. (2012). Hepatitis B in the United States: Ongoing missed opportunities for hepatitis B vaccination, evidence from the Behavioral Risk Factor Surveillance Survey, 2007. *Infection, 40,* 405–413.

Leathers, S. J. (2005). Separation from siblings: Associations with placement adaptation and outcomes among adolescents in long-term foster care. *Children and Youth Services Review, 27,* 793–819. doi:10.1016/j.childyouth.2004.12.015

Lee, B. R., Feaver, S. L., Miller, C. A., Hedberg, C. W., & Ehresmann, K. R. (2004). An elementary school outbreak of varicella attributed to vaccine failure: Policy implications. *Journal of Infectious Diseases, 190,* 477–483. doi:10.1086/422041

Lee, G. M., Lorick, S. A., Pfoh, E., Kleinman, K., & Fishbein, D. (2008). Adolescent immunizations: Missed opportunities for prevention. *Pediatrics, 122,* 711–717. doi:10.1542/peds.2007-2857

Lee, G. M., Santoli, J. M., Hannan, C., Messonnier, M. L., Sabin, J. E., Rusinak, D., Lieu, T. A. (2007). Gaps in vaccine financing for underinsured children in the United States. *Journal of the American Medical Association, 298,* 638–643. doi:10.1001/jama.298.6.638

Lee, L. E., Ho, H., Lorber, E., Fratto, J., Perkins, S., & Cieslak, P. R. (2008). Vaccine-era varicella epidemiology and vaccine effectiveness in a public elementary school population, 2002–2007. *Pediatrics, 121,* e1548. doi:10.1542/peds.2007-2031

Lin, T. M. (2003). Designing the optimal file linkage algorithm. Retrieved from http:// webcast.hrsa.gov/conferences/mchb/cdc/mchepi2003/index.htm

Lin, T. M. (2004). Designing the optimal file linkage algorithm OFLA. Retrieved from http://www.lexjansen.com/scsug/2004/Lin%20-%20Designing%20the %20Optimal%20File%20Linkage%20Algorithm.pdf

Lin, T. M. (2011). Arkansas state systems development initiative project. Presented at the third annual Sustainability Conference, March 29–31, 2011. Retrieved through ADH internal Health Statistics communication.

Lindley, M. C., Smith, P. J., & Rodewald, L. E. (2011). Vaccination coverage among U.S. adolescents aged 13–17 years eligible for the Vaccines for Children program, 2009. *Public Health Reports, 126,* S124–S134. Retrieved from http://www .publichealthreports.org/issueopen.cfm?articleID=2681

LoMurray, K., & Sander, M. (2011a). Information system to determine adolescent vaccination rates and uptake. *Public Health Reports, 126.* Retrieved from http:// www.ncbi.nlm.nih.gov/pmc/articles/PMC3113433/

LoMurray, K., & Sander, M. (2011b). Using the North Dakota Immunization Information System to determine adolescent vaccination rates and uptake. *Public Health Reports, 126,* 78–86. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles /PMC3113433/

Lopez, A. S., Guris, D., Zimmerman, L., Gladden, L., Moore, T., Haselow, D. T., & Snow, S. L. (2006). One dose of varicella vaccine does not prevent school outbreaks: Is it time for a second dose? *Pediatrics, 117,* e1070. doi:10.1542/peds .2005-2085

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of the mediation, confounding and suppression effect. *Prevention Science, 1,* 173–181. doi:10.1023/A:1026595011371

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods, 7,* 83–104. doi:10.1037/1082-989X.7.1.83

Mahon, B. E., Shea, K. M., Dougherty, N. N., & Loughlin, A. M. (2008). Implications for registry-based vaccine effectiveness studies from an evaluation of an immunization registry: A cross-sectional study. *BMC Public Health, 8,* 160. doi: 10.1186/1471-2458-8-160

Marin, M., Guris, D., Chaves, S. S., Schmid, S., & Seward, J. F. (2007). Prevention of varicella: Recommendations of the Advisory Committee on Immunization Practices. Retrieved from http://www.cdc.gov/mmwr/PDF/rr/rr5604.pdf

McCauley, M. M., Stokley, S., Stevenson, J., & Fishbein, D. B. (2008). Adolescent vaccination: Coverage achieved by ages 13–15 years, and vaccinations received as recommended during ages 11–12 years, National Health Interview Survey 1997–2003. *Journal of Adolescent Health, 43,* 540–547. doi:10.1016/j.jadohealth .2008.08.02

McElligott, J. T., Roberts, J. R., O'Brien, E. S., Freeland, K. D., Kolasa, M. S., Stevenson, J., & Darden, P. M. (2012). Improving immunization rates at 18 months of age: Implications for individual practices. *Public Health Reports, 126,* 33–38. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3113428/

McNall, M. A., Lichty, L. F., & Mavis, B. (2010). The impact of school-based health centers on the health outcomes of middle school and high school students. *American Journal of Public Health, 100,* 1604–1610. doi:10.2105/AJPH.2009.183590

Meszaros, J. R., Asch, D. A., Baron, J., Hershey, J. C., Kunreuther, H., & Schwartz-Buzaglo, J. (1996). Cognitive processes and the decisions of some parents to forego pertussis vaccination for their children. *Journal of Clinical Epidemiology, 49,* 697–703. doi:10.1016/0895-4356(96)00007-8

Meyer, P.A., Seward, J. F., Jumaan, A. O., & Wharton, M. (2000). Varicella mortality: Trends before vaccine licensure in the United States, 1970–1994. *Journal of Infectious Diseases, 182,* 383–90. doi:10.1086/315714

Miller, J. C., Danon, L., O'Hagan, J. J., Goldstein, E., Lajous, M., & Lipsitch, M. (2010). Student behavior during a school closure caused by pandemic influenza A/H1N1. *PLoS ONE, 5,* e10425. doi:10.1371/journal.pone.0010425

Morita, J. Y., Ramirez, E., & Trick, W. E. (2008). Effect of a school-entry vaccination requirement on racial and ethnic disparities in hepatitis B immunization coverage levels among public school students. *Pediatrics, 121,* e547. doi:10.1542/peds.2007-0799

National Network for Immunization Information. (2006). Community immunity. Retrieved from http://www.immunizationinfo.org/issues/general/community-immunity

National Vaccine Advisory Committee. (2005). Adolescent vaccination: Recommendations from the National Vaccine Advisory Committee—Adolescent Working Group. Retrieved from http://www.hhs.gov/nvpo/nvac/reports/index.html#2005

National Vaccine Advisory Committee. (2008). Mandates for adolescent immunizations. Recommendations from the National Vaccine Advisory Committee. *American Journal of Preventive Medicine, 35,* 145–151. doi:10.1016/j.amepre.2008.03.033

National Vaccine Advisory Committee. (2009). Financing vaccination of children and adolescents: National Vaccine Advisory Committee recommendations. *Pediatrics, 124,* S558–S562. doi:10.1542/peds.2009-1542P

National Vaccine Advisory Committee. (2014). The State of the National Vaccine Plan – 2014.Retrieved from http://www.hhs.gov/nvpo/national-vaccine-plan/state-of-national-vaccine-plan-annual-report-2014/

National Vaccine Advisory Committee. (2015). *Reports and recommendations: Assessing the state of vaccine confidence in the United States: Recommendations from the National Vaccine Advisory Committee.* Retrieved from http://www.hhs.gov/sites/default/files/nvpo/about/vaccines/nvac-vaccine-confidence-public health-report-2015.pdf

Ndiaye, S. M., Madhavan, S., Washington, M. L., Shui, I., Tucker, J., Rosenbluth, S., & Richards, T. (2003). The use of pharmacy immunization services in rural communities. *Public Health, 117,* 88–97. doi:10.1016/S0033-3506(02)00022-7

Neuhauser, M. M., Wiley, D., Simpson, L., & Garey, K. W. (2004). Involvement of immunization-certified pharmacists with immunization activities. *Annals of Pharmacotherapy, 38,* 226–231. doi:10.1345/aph.1D257

Niccolai, L. M., & Hansen, C. E. (2015). Practice- and community-based interventions to increase human papillomavirus vaccine coverage: A systematic review. *JAMA Pediatrics, 169,* 686–692. doi:10.1001/jamapediatrics.2015.0310.

Offit, P. A., Quarles, J., Gerber, M. A., Hackett, C. J., Marcuse, E. K., Kollman, T. R., & Landry, S. S. (2002). Addressing parents' concerns: Do multiple vaccines overwhelm or weaken the infant's immune system? *Pediatrics, 109,* 124–129. doi:10.1542/peds.109.1.124

Omer, S. B., Enger, K. S., Moulton, L. H., Halsey, N. A., Stokley, S., & Salmon, D. A. (2008). Geographic clustering of nonmedical exemptions to school immunization requirements and associations with geographic clustering of pertussis. *American Journal of Epidemiology, 168,* 1389–1396. doi:10.1093/aje/kwn263

Omer, S. B., Richards, J. L., Ward, M., & Bednarczyk, R. A. (2012). Vaccination policies and rates of exemption from immunization, 2005–2011. *New England Journal of Medicine, 367,* 1170–1171. doi:10.1056/NEJMc1209037

Omer, S. B., Salmon, D. A., Orenstein, W. A., deHart, M. P., & Halsey, N. (2009). Vaccine refusal, mandatory immunization, and the risks of vaccine-preventable diseases. *New England Journal of Medicine, 360,* 1981–1988. doi:10.1056/NEJMsa0806477

Opel, D. J., Mangione-Smith, R., Taylor, J. A., Korfiatis, C., Wiese, C., Catz, S., & Martin, D. P. (2011). Development of a survey to identify vaccine-hesitant parents: The Parent Attitudes About Childhood Vaccines survey. *Human Vaccines, 7,* 419–425. doi:10.4161/hv.7.4.14120

Opel, D. J., Taylor, J. A., Zhou, C., Catz, S., Myaing, M., & Mangione-Smith, R. (2013). The relationship between Parent Attitudes About Childhood Vaccines survey scores and future child immunization status: A validation study. *JAMA Pediatrics, 167,* 1065–1071. doi:10.1001/jamapediatrics.2013.2483

Orenstein, W. A., & Hinman, A. R. (1999). The immunization system in the United States—The role of school immunization laws. *Vaccine, 3,* S19–S24. doi:10.1016/S0264-410X(99)00290-X

Parker, A. A., Staggs, W., Dayan, G. H., Ortega-Sanchez, I. R., Rota, P. A., Lowe, L., & LeBaron, C. W. (2006). Implications of a 2005 measles outbreak in Indiana for sustained elimination of measles in the United States. *New England Journal of Medicine, 355,* 447–455. doi:10.1056/NEJMoa060755

Phadke, V. K., Bednarczyk, R. A., Salmon, D. A., & Omer, S. B. (2016). Association between vaccine refusal and vaccine-preventable diseases in the United States: A review of measles and pertussis. *Journal of the American Medical Association, 315,* 1149–1158. doi:10.1001/jama.2016.1353

Preacher, K. J., &. Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers 2004, 36*(4), 717–731. Retrieved from http://quantpsy.org/pubs /preacher_hayes_2004.pdf

Preacher, K. J., &. Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879–891. doi:10.3758/BRM.40.3.879.

Preacher, K. J., Zyphur, M. J., & Zhang, Z. (2010). A general multilevel SEM framework for assessing multilevel mediation. *Psychological Methods, 15,* 209–233. doi:10 .1037/a0020141

Rand, C. M., Humiston, S. G., Schaffer, S. J., Albertin, C. S., Shone, L. P., Blumkin, A. K., … Szilagyi, P. G. (2011). Parent and adolescent perspectives about adolescent vaccine delivery: Practical considerations for vaccine communication. *Vaccine, 29,* 7651–7658.

Rees-Clayton, E. J., Montgomery, J. P., Enger, K. S., & Boulton, M. L. (2013). Trends in Michigan early adolescent immunization: 2006–2008. *American Journal of Public Health, 102,* 1735–1741. doi:10.2105/AJPH.2011.300577

Reluga, T. C. (2010). Game theory of social distancing in response to an epidemic. *PLoS Computational Biology, 6,* e1000793. doi:10.1371/journal.pcbi.1000793

Reluga, T. C., Bauch, C., & Galvani, A. P. (2006). Evolving public perceptions and stability in vaccine uptake. *Mathematical Bioscience, 204,* 185–198. doi:10.1016 /j.mbs.2006

Reluga, T. C., & Galvani, A. P. (2011). A general approach for population games with application to vaccination. *Mathematical Bioscience 230*(2), 67–78. doi:10.1016/j.mbs.2011.01.003.

Reynolds, M. A., Watson, B. M., Plott-Adams, K. K., Jumaan, A. O., Galil, K., Maupin, T. J., … Seward, J. F. (2008). Epidemiology of varicella hospitalizations in the United States, 1995–2005. *Journal of Infectious Diseases, 197,* S120–S126.

Rodewald, L., Maes, E., Stevenson, J., Lyons, B., Stokley, S., & Szilagyi, P. (1999). Immunization performance measurement in a changing immunization environment. *Pediatrics, 103,* 889–897. doi:10.1542/peds.103.4.S1.889

Rosenthal, S. L., Rupp, R., Zimet, G. D., Meza, H. M., Loza, M. L., Short, M. B., & Succop, P. A. (2008). Uptake of HPV vaccine: Demographics, sexual history and values, parenting style, and vaccine attitudes. *Journal of Adolescent Health, 43,* 239–245. doi:10.1016/j.jadohealth.2008.06.009

Ross, A. H. (1962). Modification of chickenpox in family contacts by administration of gamma globulin. *New England Journal of Medicine, 267,* 369–376. doi:10.1056/NEJM196208232670801

Safi, H., Wheeler, J. G., Reeve, G. R., Ochoa, E., Romero, J. R., Hopkins, R., . . Jacobs, J. F. (2012). Vaccine policy and Arkansas childhood immunization exemptions: A multi-year review. *American Journal of Preventive Medicine, 42,* 602–605. doi:10.1016/j.amepre.2012.02.022

Salk, J. E. (1955a). A concept of the mechanism of immunity for preventing paralysis in poliomyelitis. *Annals of the New York Academy of Science, 61,* 1023–1038. doi:10.1111/j.1749-6632.1955.tb42563.x

Salk, J. E. (1955b). Poliomyelitis vaccine in the fall of 1955. *American Journal of Public Health and the Nations Health, 46,* 1–14. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1623400/

Salmon, D. A., Dudley, M. Z., Glanz, J. M., & Omer, S. B. (2015). Vaccine hesitancy: Causes, consequences, and a call to action. *American Journal of Preventive Medicine, 49,* S391–S398. doi:10.1016/j.amepre.2015.06.009

Salmon, D. A., Smith, P. J., Pan, W. K. Y., Navar, A. M., Omer, S. B., & Halsey, N. A. (2009). Disparities in preschool immunization coverage associated with maternal age. *Human Vaccines, 5,* 557–561. doi:10.4161/hv.5.8.9009

Santoli, J. M., Huet, N. J., Smith, P. J., Barker, L. E., Rodewald, L. E., Inkelas, M., … Halfon, N. (2004). Insurance status and vaccination coverage among U.S. preschool children. *Pediatrics, 113,* S1959–S1964. Retrieved from http://pediatrics.aappublications.org/content/pediatrics/113/Supplement_5/1959.full.pdf

SAS Institute. (2012). SAS Software version 9.1.3. Cary, NC: SAS Institute. Retrieved from http://support.sas.com/documentation/cdl/en/whatsnew/64209/PDF/default/whatsnew.pdf

Sawyer, M. G., Carbone, J. A., Searle, A. K., & Robinson, P. (2007). The mental health and wellbeing of children and adolescents in home-based foster care. *Medical Journal of Australia, 186,* 181–184. Retrieved from https://www.mja.com.au

Schaffer, S. J., Fontanesi, J., Rickert, D., Grabenstein, J. D., Rothholz, M. C., Wang, S. A., & Fishbein, D. (2008). How effectively can health care settings beyond the traditional medical home provide vaccines to adolescents? *Pediatrics, 121,* S35–45. doi:10.1542/peds.2007-1115E

Schaffer, S. J., Gillette, H., Hedberg, K., & Cieslak, P. (2006). A community-wide pertussis outbreak: An argument for universal booster vaccination. *Archives of Internal Medicine, 166,* 1317–1321. doi:10.1001/archinte.166.12.1317

Schempf, A. H., Minkovitz, C. S., Strobino, D. M., & Guyer, B. (2007). Parental satisfaction with early pediatric care and immunization of young children: The mediating role of age-appropriate well-child care utilization. *Archives of Pediatrics and Adolescent Medicine, 161,* 50–56. doi:10.1001/archpedi.161.1.50

Schlenker, T. L., Bain, C., Baughman, A. L., & Hadler, S. C. (1992). Measles herd immunity: The association of attack rates with immunization rates in preschool children. *Journal of the American Medical Association, 267,* 823–826. doi:10 .1001/jama.267.6.823

Schmid, D. S., & Jumaan, A. O. (2010). Impact of varicella vaccine on varicella-zoster virus dynamics. *Clinical Microbiology Reviews, 23,* 202–217. doi:10.1128/CMR .00031-09

Seward, J. F., Marin, M., & Vázquez, M. (2008). Varicella vaccine effectiveness in the U.S. vaccination program: A review. *Journal of Infectious Diseases, 197,* S82–S89. doi:10.1086/522145

Shapiro, E. D., Vazquez, M., Esposito, D., Holabird, N., Steinberg, S. P., Dziura, J., & Gershon, A. A. (2011). Effectiveness of 2 doses of varicella vaccine in children. *Journal of Infectious Diseases, 203,* 312–315. doi:10.1093/infdis/jiq052

Shefer, A., Briss, P., Rodewald, L., Bernier, R., Strikas, R., Yusuf, H., . . . Hinman, A. R. (1999). Improving immunization coverage rates: An evidence-based review of the literature. *Epidemiologic Reviews, 21,* 96–142. doi:10.1093/oxfordjournals.epirev .a017992

Shefer, A., Webb, E., & Wilmoth, T. (2000). Determination of up-to-date vaccination status for preschool-aged children: How accurate is manual assessment conducted by paraprofessional staff? *Pediatrics, 106,* 493–496. doi:10.1542/peds.106.3.493

Shim, E., Chapman, G. B., & Galvani, A. P. (2010). Decision making with regard to antiviral intervention during influenza pandemic. *Medical Decision Making, 30,* e64–81. doi:10.1177/0272989X10374112

Shim, E., Kochin, B., & Galvani, A. (2010). Insights from epidemiological game theory into gender-specific vaccination against rubella. *Mathematical Biosciences and Engineering, 6,* 839–854. doi:10.3934/mbe.2009.6.839

Shim, E., Meyers, L. A., & Galvani, A. P. (2011). Optimal H1N1 vaccination strategies based on self-interest versus group interest. *BMC Public Health, 25,* S4. doi:10 .1186/1471-2458-11-S1-S4

Shojania, K. G., Jennings, A., Mayhew, A., Ramsay, C. R., Eccles, M. P., & Grimshaw, J. (2009). The effects of onscreen, point of care computer reminders on processes and outcomes of care. *Cochrane Database of Systematic Reviews, 3,* CD001096. doi:10.1002/14651858.CD001096.pub2

Sittig, D. F., Teich, J. M., Osheroff, J. A., & Singh, H. (2009). Improving clinical quality indicators through electronic health records: It takes more than just a reminder. *Pediatrics, 124,* 375–377. doi:10.1542/peds.2009-0339

Skoff, T. H., Cohn, A. C., Clark, T. A., Messonnier, N. E., & Martin, S. W. (2012). Early impact of the U.S. Tdap vaccination program on pertussis trends. *Archives of Pediatrics and Adolescent Medicine, 166,* 344–349. doi:10.1001/archpediatrics.2011.1093

Skoff, T. H., & Martin, W. M. (2016). Impact of tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis vaccinations on reported pertussis cases among those 11 to 18 years of age in an era of waning pertussis immunity: A follow-up analysis. *JAMA Pediatrics*. Advance online publication. doi:10.1001/jamapediatrics.2015.4875

Slade, B. A., Leidel, L., Vellozzi, C., Woo, E. J., Hua, W., Sutherland, A., & Iskander, J. (2009). Postlicensure safety surveillance for quadrivalent human papillomavirus recombinant vaccine. *Journal of the American Medical Association, 302,* 750–757. doi:10.1001/jama.2009.1201

Smith, P. J., Chu, S. Y., & Barker, L. E. (2004). Children who have received no vaccines: Who are they and where do they live? *Pediatrics, 114,* 187–195. doi:10.1542/peds.114.1.187

Smith, P. J., Hoaglin, D. C., Battaglia, M. P., Khare, M., & Barker, L. E. (2005). Statistical methodology of the National Immunization Survey, 1994–2002 (Series 2, Number 138). *Vital and Health Statistics, 2,* 1–55. Retrieved from http://www.cdc.gov/nchs/data/series/sr_02/sr02_138.pdf

Smith, P. J., Humiston, S. G., Parnell, T., Vannice, K. S., & Salmon, D. A. (2010). The association between intentional delay of vaccine administration and timely childhood vaccination coverage. *Public Health Reports, 125,* 534–541. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2882604/

Smith, P. J., Jain, N., Stevenson, J., Männikkö, N., & Molina, N. (2009). Progress in timely vaccination coverage among children living in low-income households. *Archives of Pediatrics and Adolescent Medicine, 163,* 462–468. doi:10.1001 /archpediatrics.2009.25

Smith, P. J., Kennedy, A. M., Wooten, K., Gust, D. A., & Pickering, L. K. (2006). Association between health care providers' influence on parents who have concerns about vaccine safety and vaccination coverage. *Pediatrics, 118,* e1287. doi:10.1542/peds.2006-0923

Smith, P. J., Lindley, M. C., Shefer, A., & Rodewald, L. E. (2009). Underinsurance and adolescent immunization delivery in the United States. *Pediatrics, 124,* S515–S521. doi:10.1542/peds.2009-1542K

Smith, P. J., Santoli, J. M., Chu, S. Y., Ochoa, D. Q., & Rodewald, L. E. (2005). The association between having a medical home and vaccination coverage among children eligible for the Vaccines for Children Program. *Pediatrics, 116,* 130–139. doi:10.1542/peds.2004-1058

Smith, P. J., Singleton, J. A., & National Center for Immunization and Respiratory Diseases. (2011). County-level trends in vaccination coverage among children aged 19–35 months—United States, 1995–2008. Retrieved from http://www.cdc .gov/mmwr/preview/mmwrhtml/ss6004a1.htm

Smith, P. J., Stevenson, J., & Chu, S. Y. (2006). Associations between childhood vaccination coverage, insurance type, and breaks in health insurance coverage. *Pediatrics, 117,* 1972–1978. doi:10.1542/peds.2005-2414

Sneller, V. P., Fishbein, D. B., Weinbaum, C. M., Lombard, A., Murray, P., McLaurin, J. A., & Friedman, L. (2008). Vaccinating adolescents in high-risk settings: Lessons learned from experiences with hepatitis B vaccine. *Pediatrics, 121,* S55–S62. doi: 10.1542/peds.2007-1115G

Sobel, M. E. (1986). Some new results on indirect effects and their standard errors in covariance structure models. *Sociological Methodology, 16,* 159–186. doi:10 .2307/270922.

Steckler, A., & McLeroy, K. R. (2007). The importance of external validity. *American Journal of Public Health, 98,* 9–10. doi:10.2105/AJPH.2007.126847

Stevenson, J., Luman, B., Wright, R. A., Khare, M., Canavan, B., Hoaglin, D. C., & Strella, R. (2000). The National Immunization Survey Registry validation study: Methodology for matching and analyses. *Proceedings of the American Statistical Association.* Retrieved from http://www.amstat.org/sections/srms/Proceedings/

Stokley, S., Cohn, A., Dorell, C., Hariri, S., Yankey, D., Messonnier N., & Wortley, P. M. (2011). Adolescent vaccination-coverage levels in the United States: 2006–2009. *Pediatrics, 128,* 1078–1086. doi:10.1542/peds.2011-1048

Stokley, S., Freed, G., Curtis, R., Gordon, L., Humiston, S., Parnell, T., & McCauley, M. (2009). Adolescent vaccination: Recommendations from the National Vaccine Advisory Committee. *American Journal of Preventive Medicine, 36,* 278–279. doi:10.1016/j.amepre.2008.10.015.

Sugerman, D. E., Barskey, A. E., Delea, M. G., Ortega-Sanchez, I. R., Bi, D., Ralston, K. J., & LeBaron, C. W. (2010). Measles outbreak in a highly vaccinated population, San Diego, 2008: Role of the intentionally undervaccinated. *Pediatrics, 125,* 747–755. doi:10.1542/peds.2009-1653

Suh, C. A., Saville, A., Daley, M. F., Glazner, J. E., Barrow, J., Stokley, S., & Kempe, A. (2012). Effectiveness and net cost of reminder/recall for adolescent immunizations. *Pediatrics, 129,* e1437–e1445. doi:10.1542/peds.2011-1714

Szilagyi, P. G., Rand, C. M., McLaurin, J., Tan, L., Britto, M., Francis, A., & Rickert, D. (2008). Delivering adolescent vaccinations in the medical home: A new era? *Pediatrics, 121,* S15–S24. doi:10.1542/ peds.2007-1115C

Szilagyi, P. G., Schaffer, S., Barth, R., Shone, L. P., Humiston, S. G., Ambrose, S., & Averhoff, F. (2006). Effect of telephone reminder/recall on adolescent immunization and preventive visits: Results from a randomized clinical trial. *Archives of Pediatrics and Adolescent Medicine, 160,* 157–163. doi:10.1001 /archpedi.160.2.157

Szilagyi, P. G., Schaffer, S., Shone, L., Barth, R., Humiston, S. G., Sandler, M., & Rodewald, L. E. (2002). Reducing geographic, racial, and ethnic disparities in childhood immunization rates by using reminder/recall interventions in urban primary care practices. *Pediatrics, 110,* e58. doi:10.1542/peds.110.5.e58

Thompson, J. W., Tyson, S., Card-Higginson, P., Jacobs, R. F., Wheeler, J. G., Simpson, P., & Salmon, D. A. (2007). Impact of addition of philosophical exemptions on childhood immunization rates. *American Journal of Preventive Medicine, 32,* 194–201. doi:10.1016/j.amepre.2006.10.014

Toner, E. (2014). Resurgence of vaccine-preventable childhood diseases. Retrieved from http://www.upmc-cbn.org/report_archive/2014/cbnreport_07022014.html

Trochim, W. M. K. (2006). External validity. Retrieved from http://www .socialresearchmethods.net/kb/external.php

U.S. Department of Health and Human Services. (1987). *Title 42—The Public Health and Welfare: Vaccine information.* Retrieved from http://www.hhs.gov/nvpo/about /legislation.pdf

U.S. Department of Health and Human Services. (1996). *Healthy People 2000: Review, 1995–96.* Retrieved from http://www.cdc.gov/nchs/data/hp2000/hp2k95.pdf

U.S. Department of Health and Human Services. (1999). Progress review: Immunizations and infectious diseases. Retrieved from http://www.cdc.gov/nchs/healthy_people /hp2000/reviews/immunization.htm

U.S. Department of Health and Human Services. (2000) Healthy People 2010. Retrieved from http://www.healthypeople.gov/document/html/objectives/14-27.htm

U.S. Department of Health and Human Services. (2009). Objective 14-24: Increase the proportion of young children and adolescents who receive all vaccines that have been recommended for universal administration for at least 5 years. Retrieved from http://www.healthypeople.gov/document/html/objectives/14-24.htm

U.S. Department of Health and Human Services. (2010a). Healthy people 2020: Immunization and infectious diseases. Retrieved from http://www.healthypeople .gov/2020/topicsobjectives2020/overview.aspx?topicId=23.

U.S. Department of Health and Human Services. (2010b). Healthy People 2010 objective 14-24: Increase the proportion of young children and adolescents who receive all vaccines that have been recommended for universal administration for at least 5 years. Retrieved from www.healthypeople.gov/document/html/objectives/14-24.htm

U.S. Department of Health and Human Services. (2010c). Objective 14-27: Increase routine vaccination coverage levels for adolescents. Retrieved from http://www.healthypeople.gov/document/html/objectives/14-27.htm

U.S. Department of Health and Human Services. (2010d). Objective IID-7: Achieve and maintain effective vaccination coverage levels for universally recommended vaccines among young children. Retrieved from http://www.hhs.gov/nvpo/vacc_plan/2010-Plan/appendix1.pdf

U.S. Department of Health and Human Services. (2010e). Summary of objectives: Immunization and infectious diseases. Retrieved from http://www.healthypeople.gov/2020

U.S. Department of Health and Human Services. (2012). Healthy people 2020. Retrieved from http://www.healthypeople.gov/2020/topicsobjectives2020/objectiveslist.aspx?topicId=23

Vadaparampil, S. T., Kahn, J. A., Salmon, D., Lee, J. H., Quinn, G. P., Roetzheim, R., & Giuliano, A. R. (2011). Missed clinical opportunities: Provider recommendations for HPV vaccination for 11–12 year old girls are limited. *Vaccine, 29,* 8634–8641. doi:10.1016/j.vaccine.2011.09.006

Vázquez, M., LaRussa, P. S., Gershon, A. A., Niccolai, L. M., Muehlenbein, C. E., Steinberg, S. P., & Shapiro, E. D. (2004). Effectiveness over time of varicella vaccine. *Journal of the American Medical Association, 291,* 851–855. doi:10 .1001/jama.291.7.851

Vitek, C. R., Aduddell, M., Brinton, M. J., Hoffman, R. E., & Redd, S. C. (1999). Increased protections during a measles outbreak of children previously vaccinated with a second dose of measles-mumps-rubella vaccine. *Pediatric Infectious Diseases Journal, 18,* 620–623. doi:10.1097/00006454-199907000-00010

Von Neumann, J. V., & Morgenstern, O. (1944). *Theory of games and economic behavior.* Princeton, NJ: Princeton University Press.

Washington State Department of Health. (2012). Pertussis epidemic 2012. Retrieved from http://www.doh.wa.gov/YouandYourFamily/IllnessandDisease /WhoopingCough.aspx

Wei, S. C., Tatti, K., Cushing, K., Rosen, J., Brown, K., Cassiday, P., & Martin, S. W. (2010). Effectiveness of adolescent and adult tetanus, reduced-dose diphtheria, and acellular pertussis vaccine against pertussis. *Clinical Infectious Diseases, 51,* 315–321. doi:10.1086/653938.

Wheeler, J. G. (2012). *Possible measles cases in northwest Arkansas* (unpublished manuscript). Internal communications Arkansas Department of Health.

Wheeler, J. G., Tran, T. C., North, P., Beavers-May, T., Schutze, G. E., & Snow, S. L. (2004). Barriers to public health management of a pertussis outbreak in Arkansas. *Archives of Pediatric and Adolescent Medicine, 158*(2), 146–152. doi:10.1001 /archpedi.158.2.146

Whitney, C. G., Zhou, F., Singleton, J., & Schuchat, A. (2014). Benefits from immunization during the Vaccines for Children Program era—United States, 1994–2013. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml /mm6316a4.htm

Wilson, T. R., Fishbein, D. B., Ellis, P. A., & Edlavitch, S. A. (2005). The impact of a school entry law on adolescent immunization rates. *Journal of Adolescent Health, 37,* 511–516. doi:10.1016/j.jadohealth.2005.07.009

Winter, K., Harriman, K., Zipprich, J., Schechter R., Talarico, J., Watt, J., & Chavez, G. (2012). California pertussis epidemic, 2010. *Journal of Pediatrics, 161,* 1091–1096. doi:10.1016/j.jpeds.2012.05.041

Wood, D., Halfon, N., Donald-Sherbourne, C., Mazel, R. M., Schuster, M., Shea Hamlin, J., … Duan, N. (1998). Increasing immunization rates among inner-city, African American children: A randomized trial of case management. *Journal of the American Medical Association, 279,* 29–34. doi:10.1001/jama.279.1.29

Wooten, K. G., Luman, E. T., & Barker, L. E. (2007). Socioeconomic factors and persistent racial disparities in childhood vaccination. *American Journal of Health Behavior, 31,* 434–445. doi:10.5555/ajhb.2007.3.4.434

World Health Organization. (2011a). Polio eradication targets. Retrieved from http://www.polioeradication.org/Dataandmonitoring/Polioeradicationtargets.aspx

World Health Organization. (2011b). Polio this week—As of Wednesday 14 December 2011. Retrieved from http://www.polioeradication.org/Dataandmonitoring /Poliothisweek.aspx

World Health Organization. (2013). WHO: Measles deaths decline, but elimination progress stalls in some regions. Retrieved from http://www.who.int/mediacentre /news/notes/2013/measles_20130117/en/

Zhao, Z., & Luman, E. T. (2010). Progress toward eliminating disparities in vaccination coverage among U.S. children, 2000–2008. *American Journal of Preventive Medicine, 38,* 127–137. doi:10.1016/j.amepre.2009.10.035

Zhou, F., Harpaz, R., Jumaan, A. O., Winston, C. A., & Shefer, A. (2005). Impact of varicella vaccination on health care utilization. *Journal of the American Medical Association, 294,* 797–802. doi:10.1001/jama.294.7.797

Zhou, F., Reef, S., Massoudi, M., Papania, M. J., Yusuf, H. R., Bardenheier, B., & McCauley, M. M. (2004). An economic analysis of the current universal 2-dose measles-mumps-rubella vaccination program in the United States. Retrieved from *Journal of Infectious Diseases, 189,* S131–S145. doi:10.1086/378987

Zhou, F., Santoli, J., Messonnier, M. L., Yusuf, H. R., Shefer, A., Chu, S. Y., & Harpaz, R. (2005). Economic evaluation of the 7-vaccine routine childhood immunization schedule in the United States, 2001. *Archives of Pediatrics and Adolescent Medicine, 159,* 1136–1144. doi:10.1001/archpedi.159.12.1136

Appendix A: Tables

Table A1

School Entry Requirements: Arkansas Adolescent Immunization Rules and Regulations

AIRR Table II, 2008

Vaccine	Number of doses	Age/school grade	Exemptions
Diphtheria/Tetanus/ Acellular Pertussis (DTaP), Diphtheria/Tetanus/Pertussis	4	All Grades Kindergarten to 12th Grade	Notarized Annual Application for Medical, Religious, and Philosophical Exemptions.
(DTP), Diphtheria/Tetanus (DT pediatric), or Tetanus/Diphtheria (Td Adult), vaccine		Adolescent 13–18 years	
Hepatitis B vaccine	3	Kindergarten, seventh grade, and Transfer students	Notarized Annual Application for Medical, Religious, and Philosophical Exemptions.
		Adolescent 13–18 years	
Measles vaccine, Mumps vaccine, Rubella vaccine (German measles)	2	All Grades	Notarized Annual Application for Medical, Religious, and Philosophical Exemptions.
		Adolescent 13–18 years	
Polio vaccine	3	All Grades Kindergarten to 12th Grade	Notarized Annual Application for Medical, Religious, and
		Last dose on/ after 4th birthday	Philosophical Exemptions.
Varicella (chickenpox)	2	Kindergarten, seventh grade, and Transfer students	Notarized Annual Application for Medical, Religious, and
		Adolescent 13–18 years	Philosophical Exemptions.

Note. Adapted from Table II of "Arkansas State Board of Health: Rules and regulations pertaining to immunization reporting," by Arkansas Department of Health, 2008, Retrieved from http://www.Healthy .Arkansas.Gov/Aboutadh/Rulesregs/Immunizationreporting.pdf.

Table A2

Changes Arkansas Adolescent Immunization Requirements, 1991–2009

Vaccine	Required number of doses				
	1991	2003	2004	2008	2009
Diphtheria/Tetanus/ Acellular Pertussis (DTaP), Diphtheria/Tetanus/Pertussis	4 Doses	3 Doses	3–4 doses	3–4 doses	3 Doses
(DTP), Diphtheria/Tetanus (DT pediatric), or Tetanus/Diphtheria (Td Adult)	4 Doses	3 Doses	3–4 doses	3–4 doses	3 doses
Tdap—Adult with Pertussis (2008)	4 Doses	3 Doses	3–4 doses	3–4 doses	3 doses 7th grade
					1 dose on or after 4th birthday). 1 dose of Tdap
Polio					
OPV—Oral	3 doses	3 doses	3 doses	3 doses	3 doses
IPV—Inactivated					
Rubeola (measles) +MMR	1 dose	2 doses	2 doses	2 doses	2 doses
(M, M/R, M/M/R) 2002/2004 Measles 2008 (M, M/R, M/M/R, MMRV)				Dose 2 at least 28 days after dose 1	Dose 2 at least 28 days after dose 1
MMR (Measles, Mumps, and Rubella) 2009					Dose 2 at least 28 days after dose 1
Rubella (German measles) (R, M/R, M/M/R) (R, M/R, M/M/R, MMRV) 2008	1 dose	1 dose	1 dose	1 dose	N/A
Mumps vaccine. (M, M/M/R)	1 dose	1 dose	1 dose	1 dose	N/A
Hepatitis B	N/A	3 doses	3 dose	3 doses	3 doses
				2 dose alternative schedule for 11–15-yr. olds	2 dose alternative schedule for 11–15-yr. olds
Varicella (chickenpox) (Varicella, MMRV) 2008	1 dose	1 dose	1 or 2 doses	1 or 2 doses	1 or 2 doses
				28 days apart	28 days apart
				2 doses for 7th grade; 13 yrs. and older or Disease History	2 doses for 7th grade; 13 yrs. and older or Disease History

Note. Adapted from "Arkansas State Board of Health: Rules and regulations pertaining to immunization reporting," by Arkansas Department of Health, 2008, Retrieved from http://www.Healthy .Arkansas.Gov/Aboutadh/Rulesregs/Immunizationreporting.pdf.

Table A3

Significant Arkansas Immunization Laws 1987–2008

Year	Arkansas legislative acts	Purpose
1987	Act 141	Mandated proof of measles, rubella, and other diseases immunization prior to enrolling in Arkansas colleges and universities
1989	Act 387	To achieve and maintain adequate immunization levels for all children in Arkansas. Children in childcare facilities 90% and Children in public and private schools 95%.
1993	ACT 591	Availability, adequacy, promotion and utilization of immunization programs for infants and preschool children in Arkansas.
1995	ACT 432	Established a statewide childhood immunization registry in Arkansas.
		Immunization registry provides information on childhood immunization status from birth to age 22 years to parents, guardians and providers.
		All providers shall register and report all vaccine administered to children and adolescents from birth to age 22 years.
		Imposed a penalty of $25 dollars enforced to all providers who do not report administered vaccines to the registry.
1995	ACT 685	Mandated coverage of children's preventive health care from birth through age 18 years.
		Funded immunization services under the Medicaid program.
		Eased financial burden and exempts low income, uninsured children from any copayment, coinsurance, deductible or dollar limit provisions.
1997	ACT 870	Mandated immunization prior to school enrolment and specific required vaccines for all children.
1997	ACT 871	Required immunization for students in kindergarten through 12th grade attending Arkansas schools.
		Authorized immunization compliance enforcement responsibilities on school boards, superintendents, and principals, and any school.
2003	ACT 999	Authorized immunization exemptions for: Personal beliefs, religious, and philosophical, and medical exemptions

Note. Adapted from "Historic acts," by Arkansas Legislative Branch, 2012, Retrieved from http://www .arkleg.state.ar.us.

Table A4

Pulaski County Public School Enrollment and Adolescent 1990 Birth Cohort Census 2001–2008

Year	Education grade level	Adolescent cohort age (years)	Adolescent cohort enrollment	Pulaski County wide public school enrollment	Percent adolescent cohort
2001	5th	11	4,168	52,177	8.0
2002	6th	12	4,134	51,448	8.0
2003	7th	13	4,216	51,967	8.1
2004	8th	14	4,140	52,181	7.9
2005	9th	15	4,797	53,112	9.0
2006	10th	16	4,360	53,487	8.2
2007	11th	17	3,703	53,864	6.9
2008	12th	18	3,123	54,184	5.8

Note. Adapted from "Statewide Information System Reports: Student Status Counts," by Arkansas Department of Education, 2011, Retrieved from https://adedata.arkansas.gov/statewide/Students/StatusCounts.aspx?year=16&search=&pagesize=10.

Table A5

Total Number of Foster Care Adolescents School Attendance 2000–2009

Year	Age in years	Adolescents school attendance data 2000–2009
2000	10	27
2001	11	42
2002	12	43
2003	13	63
2004	14	90
2005	15	116
2006	16	146
2007	17	135
2008	18	86
2009	19	20

Note. Adapted from *Children's Reporting and Information System,* Arkansas Department of Human Services, 2011b, Retrieved from http://www.arkansas.gov/dhs/chilnfam/Survey%20-%20CHRIS.PDF.

Table A6

Trends in Pertussis Cases, United States, and Arkansas, 2000–2010

Year	U.S. pertussis cases	Arkansas pertussis cases
2010	27,550	245
2009	16,858	396
2008	13,278	197
2007	10,454	173
2006	15,632	112
2005	25,616	208
2004	25,827	95
2003	11,647	92
2002	9,771	486
2001	7,580	1324
2000	7,867	44

Note. Adapted from "Summary of Notifiable Diseases—United States, 2004," by Centers for Disease Control and Prevention, 2006d, Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5353a1.htm.

Table A7

Pulaski County, Arkansas Public School Enrollment and Adolescent 1990 Birth Cohort Census 2000–2008

Year	Education grade level	Adolescent cohort age years	Adolescent cohort enrollment	Pulaski County wide public school enrollment	Percent (%) adolescent cohort
2001	5th	11	4,168	52,177	8.0
2002	6th	12	4,134	51,448	8.0
2003	7th	13	4,216	51,967	8.1
2004	8th	14	4,140	52,181	7.9
2005	9th	15	4,797	53,112	9.0
2006	10th	16	4,360	53,487	8.2
2007	11th	17	3,703	53,864	6.9
2008	12th	18	3,123	54,184	5.8

Note. Adapted from "Statewide Information System Reports: Student Status Counts," Arkansas Department of Education, 2012, Retrieved from https://adedata.arkansas.gov/statewide/Students/StatusCounts.aspx?year.

Table A8

Vaccine-Preventable-Disease Reported Cases, All Ages, Pulaski County, Arkansas, 1995–2012

	1995–1999		2000–2004		2005–2009		2010–2012	
Vaccine	Pulaski County, Arkansas	Arkansas	Pulaski County, Arkansas	Arkansas	Pulaski County, Arkansas	Arkansas	Pulaski County, Arkansas	Arkansas
Hepatitis B	81	499	78	550	53	365	25	179
Measles	0	2	1	24	0	0	0	0
Mumps	1	24	0	1	6	23	0	0
Pertussis	57	253	413	1613	270	1,179	117	543
Rubella	0	12	1	4	0	0	0	1
Tetanus	0	1	1	3	0	1	1	2
Varicella	0	0	0	0	202	3,466	47	803

Note. Adapted from Arkansas Department of Health, 2014b.

Table A9

Vaccine-Preventable Diseases, By Year of Vaccine Development or Licensure United States, 1798–1998

Disease	Year licensed
Smallpox	1798
Diphtheria	1923
Pertussis	1926
Tetanus	1927
Poliomyelitis	1955
Measles	1963
Mumps	1967
Rubella	1969
Hepatitis B	1981
Haemophilus influenzae type b	1985
Varicella	1995

Note. Adapted from "Final 2010 Reports of Nationally Notifiable Infectious Diseases," Centers for Disease Control and Prevention, 2011a, *Morbidity and Mortality Weekly Report, 60,* 1088–1101.

Table A10

Vaccine Codes Arkansas Department of Health, 2005

Vaccine ID code	Type vaccine family	Vaccine name
1; 2; 3; 4; 21; 22; 24; 31;35; 42;43;44	A	DTP; PED DT; DTAP; Td; DTP-ACTHIB; DTP-HBOC; DTP-HIB; DTAP/HIB; DTAP/P/HPB; DECAVAC; Tdap; Tetanus
5;6; and 7	B	OPV; EIPV; IPV
8;9;10;11; and 12	C	MMR; M/R; Measles; Rubella; Mumps
13;14;15;16; 23; 32	D	HBOC; PEDVAX-HIB; PROHIBIT; HIB; ACT/OMNI; HEP B/HIB
17;18;19 and 34	E	HEP B-3dose; PHEPB-3dos; HBIG; HEP B 2 dose
27; 89	I	Varicella; Chicken PO

Note. Adapted from " Unpublished vaccine codes. Internal Immunization Agency communication document," Arkansas Department of Health, 2005.

Table A11

Definitions of Variables

Variable type	Variable name	Type of variable / measurement scale
Independent	Adolescent in 1990 cohort	Categorical
	FCA	Categorical
	NHA	Categorical
Dependent	Five Vaccines School Entry (FVSE)	Categorical
	Immunization rates	Ratio variables
	Up-to-date status UTD	Categorical
	Diphtheria Tetanus toxoid acellular Pertussis (DTaP DTP, Tap)	Nominal; Categorical
	Hepatitis B (Hep B)	Nominal; Categorical
	Measles, Mumps and Rubella (MMR)	Nominal; Categorical
	Poliomyelitis	Nominal; Categorical
	Varicella	Nominal; Categorical
Covariates	Gender	Nominal; Categorical
	Race	Nominal; Categorical
	Ethnicity	Nominal; Categorical
	Age	Continuous

Note. Adapted from Pulaski County, Arkansas Birth Cohort, Analysis 2015.

Appendix B: Calculation Tables

Table B1

Pulaski County, Arkansas Mortality Data, 1990–2008

	Diphtheria	Pertussis	Tetanus	Hepatitis B	Measles	Mumps	Rubella	Poliomyelitis	Varicella
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0

Note. Adapted from Arkansas Department of Health NEDDS Statistics Data, 2015 for PCABC.

Table B2

Calculations Direct Standardization Vaccination Rates, Age Standardized to 2010 U.S. Population

	Arkansas 2006 PCABC	Standard population 2010 census			United States 2006 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.846	0.244	0.207	13	0.483	0.244	0.118
14	0.842	0.247	0.208	14	0.571	0.247	0.141
15	0.838	0.252	0.211	15	0.642	0.252	0.162
16	0.836	0.256	0.214	16	0.627	0.256	0.161
		sum(*m***w*)	84.00%			sum(*m***w*)	58.20%
Hep B	Arkansas 2007 PCABC	Standard population 2010 census		Hep B	United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.595	0.244	0.145	13	0.886	0.244	0.217
14	0.842	0.247	0.208	14	0.846	0.247	0.209
15	0.838	0.252	0.211	15	0.8	0.252	0.202
16	0.836	0.256	0.214	16	0.756	0.256	0.194
		sum(*m***w*)	77.90%			sum(*m***w*)	82.10%
MMR	Arkansas 2006 PCABC	Standard population 2010 census		MMR	United States 2006 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.774	0.244	0.189	14	0.87	0.244	0.213
14	0.778	0.247	0.192	15	0.901	0.247	0.223
15	0.778	0.252	0.196	16	0.883	0.252	0.222
16	0.778	0.256	0.199		0.83	0.256	0.213
		sum(*m***w*)	77.70%			sum(*m***w*)	87.10%

Table B2 continues

Polio	Arkansas 2006 PCABC	Standard population 2010 census		Polio	United States 2006 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.872	0.244	0.213	13		0.244	0.000
14	0.865	0.247	0.214	14		0.247	0.000
15	0.86	0.252	0.217	15		0.252	0.000
16	0.853	0.256	0.219	16		0.256	0.000
		sum(*m***w*)	86.20%			sum(*m***w*)	0.00%
Varicella	Arkansas 2006 PCABC	Standard population 2010 census		Varicella	United States 2006 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.157	0.244	0.038	13	0.895	0.244	0.219
14	0.162	0.247	0.04	14	0.893	0.247	0.221
15	0.172	0.252	0.043	15	0.905	0.252	0.228
16	0.188	0.256	0.048	16	0.883	0.256	0.226
		sum(*m***w*)	17.00%			sum(*m***w*)	89.40%

Note. Adapted from PCABC 1990 Data Analysis, 2015; MMR = measles-mumps-rubella; PCABC = Pulaski County, Arkansas, birth cohort; NIS = national immunization.

Table B3

Calculations Direct Standardization Vaccination Rates, Age Standardized to 2010 U.S. Population

	Arkansas 2007 PCABC	Standard population 2010 census			United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.846	0.194	0.164	13	0.64	0.194	0.124
14	0.842	0.196	0.165	14	0.704	0.196	0.138
15	0.838	0.2	0.167	15	0.73	0.2	0.146
16	0.836	0.203	0.17	16	0.765	0.203	0.155
17	0.836	0.207	0.173	17	0.773	0.207	0.16
		sum(*m***w*)	84.00%			sum(*m***w*)	72.30%
Hep B	Arkansas 2007 PCABC	Standard population 2010 census		Hep B	United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.595	0.194	0.115	13	0.906	0.194	0.176
14	0.842	0.196	0.165	14	0.919	0.196	0.18
15	0.838	0.2	0.167	15	0.863	0.2	0.172
16	0.836	0.203	0.17	16	0.854	0.203	0.174
17	0.67	0.207	0.139	17	0.841	0.207	0.174
		sum(*m***w*)	75.60%			sum(*m***w*)	87.60%

Table B3 continues

MMR	Arkansas 2007 PCABC	Standard population 2010 census		MMR	United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m*w*	Age	*m*	*w*	*m*w*
13	0.774	0.194	0.15	13	0.888	0.194	0.172
14	0.778	0.196	0.153	14	0.91	0.196	0.179
15	0.778	0.2	0.155	15	0.872	0.2	0.174
16	0.778	0.203	0.158	16	0.904	0.203	0.184
17	0.778	0.207	0.161	17	0.872	0.207	0.18
		sum(*m*w*)	77.70%			sum(*m*w*)	88.90%
Polio	Arkansas 2007 PCABC	Standard population 2010 census		Polio	United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m*w*	Age	*m*	*w*	*m*w*
13	0.872	0.194	0.169	13		0.194	0
14	0.865	0.196	0.17	14		0.196	0
15	0.86	0.2	0.172	15		0.2	0
16	0.853	0.203	0.173	16		0.203	0
17	0.853	0.207	0.177	17		0.207	0
		sum(*m*w*)	86.00%			sum(*m*w*)	0.00%
Varicella	Arkansas 2007 PCABC	Standard population 2010 census		Varicella	United States 2007 NIS	Standard population 2010 census	
Age	*m*	*w*	*m*w*	Age	*m*	*w*	*m*w*
13	0.157	0.194	0.03	13	0.926	0.194	0.18
14	0.162	0.196	0.032	14	0.929	0.196	0.182
15	0.172	0.2	0.034	15	0.91	0.2	0.182
16	0.188	0.203	0.038	16	0.885	0.203	0.18
17	0.188	0.207	0.039	17	0.94	0.207	0.195
		sum(*m*w*)	17.40%			sum(*m*w*)	91.80%

Note. Adapted from PCABC 1990 Data Analysis, 2015; MMR = measles-mumps-rubella; PCABC = Pulaski County, Arkansas, birth cohort; NIS = national immunization.

Table B4

Calculations Direct Standardization Vaccination Rates, Age Standardized to 2010 U.S. Population

	Arkansas 2008 PCABC	Standard Population 2010 Census			United States 2008 NIS	Standard Population 2010 Census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.846	0.16	0.135	13	0.641	0.16	0.103
14	0.842	0.162	0.136	14	0.697	0.162	0.113
15	0.838	0.165	0.138	15	0.777	0.165	0.128
16	0.836	0.168	0.14	16	0.748	0.168	0.125
17	0.836	0.171	0.143	17	0.737	0.171	0.126
18	0.831	0.175	0.145	18	0.722	0.175	0.126
		sum(*m***w*)	83.80%			sum(*m***w*)	72.10%

Hep B	Arkansas 2008 PCABC	Standard Population 2010 Census		Hep B	United States 2008 NIS	Standard Population 2010 Census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.595	0.16	0.095	13	0.928	0.16	0.148471
14	0.842	0.162	0.136	14	0.931	0.162	0.150686
15	0.838	0.165	0.138	15	0.896	0.165	0.147696
16	0.836	0.168	0.14	16	0.815	0.168	0.136666
17	0.67	0.171	0.114	17	0.829	0.171	0.141563
18	0.674	0.175	0.118	18	0.879	0.175	0.153706
		sum(*m***w*)	74.20%			sum(*m***w*)	87.90%

Table B4 continues

MMR	Arkansas 2008 PCABC	Standard population 2010 Census		MMR	United States 2008 NIS	Standard population 2010 Census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.774	0.16	0.124	13	0.903	0.16	0.144
14	0.778	0.162	0.126	14	0.918	0.162	0.149
15	0.778	0.165	0.128	15	0.901	0.165	0.149
16	0.778	0.168	0.13	16	0.862	0.168	0.145
17	0.778	0.171	0.133	17	0.881	0.171	0.15
18	0.777	0.175	0.136	18	0.893	0.175	0.156
		sum(*m***w*)	77.70%			sum(*m***w*)	89.30%
Polio	Arkansas 2008 PCABC	Standard Population 2010 Census		Polio	United States 2008 NIS	Standard Population 2010 Census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.872	0.16	0.14	13		0.16	0
14	0.865	0.162	0.14	14		0.162	0
15	0.86	0.165	0.142	15		0.165	0
16	0.853	0.168	0.143	16		0.168	0
17	0.853	0.171	0.146	17		0.171	0
18	0.674	0.175	0.118	18		0.175	0
		sum(*m***w*)	82.80%			sum(*m***w*)	0.00%
Varicella	Arkansas 2008 PCABC	Standard Population 2010 Census		Varicella	United States 2008 NIS	Standard Population 2010 Census	
Age	*m*	*w*	*m***w*	Age	*m*	*w*	*m***w*
13	0.157	0.16	0.025	13	0.94	0.16	0.15
14	0.162	0.162	0.026	14	0.926	0.162	0.15
15	0.172	0.165	0.028	15	0.926	0.165	0.153
16	0.188	0.168	0.032	16	0.925	0.168	0.155
17	0.188	0.171	0.032	17	0.92	0.171	0.157
18	0.83	0.175	0.145	18	0.927	0.175	0.162
		sum(*m***w*)	28.80%			sum(*m***w*)	92.70%

Note. Adapted from PCABC 1990 Data Analysis, 2015; MMR = measles-mumps-rubella; PCABC = Pulaski County, Arkansas, birth cohort; NIS = national immunization.

Table B5

Individual Payoff Equation Estimated Payoff values Game Theory Comparison

Individual Equilibrium Equation $E_{del}(p) = -r[\phi_s(p)d_s + \phi_v(p)d_v]$*							
Vaccine	$\phi_v(p)$	d_s	d_v	p	p_{eff}	$\phi_s(p)$	r
Td/Tdap	0.09	0.01692902	0.000001	0.831	0.83071	0.169290169	0.270034843
Pertussis	0.09	0.00846451	0.000001	0.831	0.83071	0.169290169	0.270034843
Tetanus	0.09	0.02200772	0.000001	0.831	0.83071	0.169290169	0.270034843
Hep B	0.09	0.30355509	0.000001	0.674	0.673597	0.326403326	0.01631913
Measles	0.09	0.00044609	0.000001	0.777	0.776953	0.223047223	0.002649007
Mumps	0.09	4.46E−05	0.000001	0.777	0.776953	0.223047223	0.002649007
Rubella	0.09	0.11152361	0.000001	0.777	0.776953	0.223047223	0.002649007
OPV/IPV	0.09	0.00775171	0.000001	0.845	0.844966	0.155034155	0.000297
Varicella	0.09	0.24101574	0.000001	0.197	0.196614	0.803385803	0.018456995

Individual Equilibrium Equation Estimated Payoff Calculations. *						
Vaccine	$\phi_s(p)d_s$	$\phi_v(p)d_v$	$[\phi_s(p)d_s + \phi_v(p)d_v]$	$E_{del}(p)$	Cohort	Payoff Deaths
Td/Tdap	0.002866	0.00000009	0.002866006	0.0007739	3371	2.605793755
Pertussis	0.001433	0.00000009	0.001433048	0.000387	3371	1.302937792
Tetanus	0.003726	0.00000009	0.003725781	0.0010061	3371	3.387507333
Hep B	0.099081	0.00000009	0.099081482	0.0016169	3371	5.444181609
Measles	9.95E−05	0.00000009	9.96E−05	2.64E−07	3371	0.000888265
Mumps	9.95E−06	0.00000009	1.00E−05	2.66E−08	3371	8.95E−05
Rubella	0.024875	0.00000009	0.024875122	6.59E−05	3371	0.221866319
OPV/IPV	0.001202	0.00000009	0.001201869	3.57E−07	3371	0.001201868
VAR	0.193629	0.00000009	0.193628715	0.0035738	3371	12.03299894

Note. Td/Tdap = tetanus-diphtheria/tetanus-diphtheria-acellular pertussis; Hep B = hepatitis B; MMR = measles-mumps-rubella; OPV/IPV = poliomyelitis; VAR = varicella; Pulaski County Arkansas 1990 Birth Cohort Data Analysis. * All equation parameters are defined in Table B7.

Table B6

Group Optimum Equation Estimated Payoff Values Game Theory Comparison

Group Optimum Equation $C(p) = pd_v + r(1-p)[(d_s - d_v)\phi_s(p) + d_v]$*									
Vaccine	$\phi_v(p)$	d_s	d_v	P	p_{eff}	$\phi_s(p)$	r	pd_v	$1-p$
Td/Tdap	0.09	0.016929	0.000001	0.831	0.83071	0.16929	0.27	8.31E−07	0.169
Pertussis	0.09	0.008465	0.000001	0.831	0.83071	0.16929	0.27	8.31E−07	0.169
Tetanus	0.09	0.022008	0.000001	0.831	0.83071	0.16929	0.27	8.31E−07	0.169
Hep B	0.09	0.303555	0.000001	0.674	0.6736	0.3264	0.0163	6.74E−07	0.326
Measles	0.09	0.000446	0.000001	0.777	0.77695	0.22305	0.0027	7.77E−07	0.223
Mumps	0.09	4.46E−05	0.000001	0.777	0.77695	0.22305	0.0027	7.77E−07	0.223
Rubella	0.09	0.111524	0.000001	0.777	0.77695	0.22305	0.0027	7.77E−07	0.223
OPV/IPV	0.09	0.007752	0.000001	0.845	0.84497	0.15503	0.0003	8.45E−07	0.155
VAR	0.09	0.241016	0.000001	0.197	0.19661	0.80339	0.0185	1.97E−07	0.803

Group Optimum Equation Estimated Payoff Calculations*								
Vaccine	$r(1-p)$	(d_s-d_v)	$(d_s-d_v)\phi_s(p)$	$[(d_s-d_v)\phi_s(p)+d_v]$	$pd_v+r(1-p)$	$C(p)$	Cohort	$C(p)$ Cohort
Td/Tdap	0.045636	0.016928	0.002866	0.0029	0.04564	0.00013	3371	0.440503
Pertussis	0.045636	0.008464	0.001433	0.0014	0.04564	6.54E−05	3371	0.220315
Tetanus	0.045636	0.022007	0.003726	0.0037	0.04564	0.00017	3371	0.572615
Hep B	0.00532	0.303554	0.099081	0.0991	0.00532	0.00053	3371	1.775147
Measles	0.000591	0.000445	9.93E−05	0.0001	0.00059	5.93E−08	3371	0.0002
Mumps	0.000591	4.36E−05	9.73E−06	1E−05	0.00059	6.35E−09	3371	2.14E−05
Rubella	0.000591	0.111523	0.024875	0.0249	0.00059	1.47E−05	3371	0.049561
OPV/IPV	4.60E−05	0.007751	0.001202	0.0012	4.7E−05	5.66E−08	3371	0.00019
VAR	0.014821	0.241015	0.193628	0.1936	0.01482	0.00287	3371	9.663155

Note. Td/Tdap = tetanus-diphtheria/tetanus-diphtheria-acellular pertussis; Hep B = hepatitis B; MMR = measles-mumps-rubella; OPV/IPV = poliomyelitis; VAR = varicella.

Table B7

Vaccination Theory of Game Parameters Definition and Calculation

Parameter	Definition
$E_{del}(p)$	Individual Payoff
Individual equilibrium	$E_{del}(p) = -r[\phi_s(p)d_s + \phi_v(p)d_v]$
Group optimum	$C(p) = pd_v + r(1 - p)[(d_s - d_v)\phi_s(p) + d_v]$
$C(p)$	Group optimum Payoff
p	Proportion of individuals preemptively vaccinated
	[Number vaccinated before a disease attack]
r	Attack rate of the disease
	[Number infected from no vaccine divided by population at risk]
$\phi_s(p)$	Probability an individual delayer becomes infected after an outbreak
	[Number unvaccinated divided by number vaccinated]
d_s	Probability of death from vaccine preventable disease
	[Death among unvaccinated divided by total population at risk]
$\phi_v(p)$	Probability an individual delayer is successfully vaccinated after an outbreak
	[Number of vaccinated delayers divided by delayers who received the vaccine]
pd_v	Probability of death from vaccine
d_v	Probability of death from vaccine defined as vaccine efficacy
	[Number of vaccine deaths divided by number vaccinated]

Note. Pulaski County Arkansas Birth Cohort 1990 Data Analysis.

.

Appendix C: Immunization Acronyms

Table C1

Immunization Acronyms

Acronym	Description
1990 Birth Cohort	Children Born In Pulaski County, Arkansas
ACIP 4:3:1:3:3:1	4+DTP, 3+Polio, 1+MMR, 3+Hib, 3+Hep B, 1+Varicella
AIRR 4:3:2:3:3:2	4+DTP, 3+Polio, 2+MMR, 3+Hep B, 2+Varicella Vaccine Dose Series
ACIP	Advisory Committee on Immunization Practices
ADH	Arkansas Department of Health
ADHS	Arkansas Department of Human Services
AIL	Arkansas Immunization Laws
AIR	Arkansas Immunization Registry
AIRD	Arkansas Immunization Registry Database
AIRR	Arkansas Immunization Rules and Regulations
AIRR	4:3:2:3:3:2 Vaccine Dose Series
ALB	Arkansas Legislative Branch
ARKIDS	Medicaid and Supplemental Children's Insurance
CDC	Centers for Disease Control and Prevention
CHRIS	Children's Reporting and Information System
DTP	Diphtheria, Tetanus and Pertussis
DTaP	Diphtheria toxoid Tetanus toxoid acellular Pertussis
EHR	Electronic Health Records
FCA	Foster Care Adolescents
FVSE	Five Vaccines For School Entry
Healthstyles	National Healthstyles Survey [CDC focuses on health orientations and practices]
Hep B	Hepatitis B Vaccine
Hib	Haemophilus influenza type b
HOR	home of residence
IAC	Immunization Action Committee
IOM	Institute of Medicine
IPV	Inactivated Poliomyelitis Vaccine
IRB	Institutional Review Board
MCV	Meningococcal Conjugate Vaccine
MMR	Measles-Mumps-Rubella Vaccine
NHA	Natural Home Adolescents
NIS-Teen	National Immunization Survey Teen
NVAC	National Vaccine Advisory Committee
NVDD	Number of Vaccine Doses Administered and Documented
OPV	Oral Poliomyelitis Vaccine
PCA	Pulaski County, Arkansas

Table C1 continues

PCABC	Pulaski County, AR birth cohort
SAC	Scientific Advisory Committee
Td/Tdap	Diphtheria/Tetanus-Diphtheria-Acellular Pertussis diphtheria/tetanus-diphtheria-acellular pertussis
Tdap	Diphtheria/tetanus-diphtheria-acellular pertussis
TOG	Theory of games
UTD	Up To Date Status
USDHHS	U.S. Department of Health and Human Services
Vaccine Dose Series A1	4:3:1:3:3:1 = 4+DTP, 3+Polio, 1+MMR, 3+Hib, 3+Hep B, 1+Varicella
Vaccine Dose Series A2	4:3:2:3:3:2 = 4+DTP, 3+Polio, 2+MMR, 3+Hep B, 2+Varicella
VAR	Varicella Vaccine
VCU	vaccination uptake
VFC	Vaccine For Children
VGT	vaccination game theory
VIS	Vaccine Information Statements
VPD	Vaccine Preventable Diseases
WHO	World Health Organization
WIC	Special Supplemental Nutrition Program for Women, Infants, and Children