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Assessing the Impact of Cognitive Biases on Vaccine Hesitancy: A Cross-Sectional Study

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Master of Public Health

Epidemiology

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Bachelor of Science
University of Miami
2017

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Abstract

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Given the link between vaccine hesitancy and vaccine-preventable disease outbreaks, it is critical to examine the cognitive processes that contribute to the development of vaccine hesitancy, especially among parents of adolescents. We conducted a secondary analysis of baseline data from a two-phase randomized trial on human papillomavirus to investigate how vaccine hesitancy and intent to vaccinate are associated with six decision-making factors: base rate neglect, conjunction fallacy, sunk cost bias, present bias, risk aversion, and information avoidance. We recruited 1,413 adults residing in the United States with at least one daughter aged 9-17 years old through an online survey on Amazon Mechanical Turk. Vaccine hesitancy, intent to vaccinate, and susceptibility to cognitive biases was measured through a series of brief questionnaires. 1,400 participants were in the final analyzed sample. Most participants were white (74.1%), female (71.6%), married (75.3%), and had a college or graduate/professional education (88.8%). Conjunction fallacy and sunk cost bias, present bias, and information avoidance may be associated with vaccine hesitancy. Intent to vaccinate may be associated with information avoidance. These results suggest that cognitive biases play a role in developing parental vaccine hesitancy and vaccine-related behavior.

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Chapter I: Background

Since their introduction, vaccines have contributed to a substantial decrease in mortality and morbidity caused by vaccine-preventable diseases (VPDs), such as measles and polio (1). However, the perception of vaccines as unsafe has grown among some individuals, leading to vaccine hesitancy becoming a risk for the ongoing success of vaccination programs, especially among childhood vaccines (2-5). The choice to vaccinate children is one mostly done by parents, whose hesitancy can be attributed to lack of trust in the healthcare system or care providers, inadequate knowledge about vaccines, or the absence of a perceived need for vaccinating, among other factors (2). Increasingly, public health researchers are using concepts in behavioral economics to identify interventions that address health decision-making (6). Among these, cognitive biases have the potential to shape parents' vaccine-related decision-making processes; thus, greater understanding of how cognitive biases impact vaccine hesitancy could be beneficial in creating messages aimed at increasing vaccine uptake.

This review provides 1) a general overview of vaccine hesitancy and its impact on child and adolescent vaccine coverage, 2) how cognitive biases can potentially influence the development of hesitant attitudes, and 3) a discussion of the intersection between parental vaccine hesitancy and human papillomavirus (HPV) vaccine uptake among adolescents.

What is vaccine hesitancy? How does it affect vaccine coverage among youth?

Vaccine hesitancy reflects a set of attitudes and beliefs that lead to concerns about vaccinating oneself or one's children, leading to refusal or delays in accepting some or all vaccines (2-3, 5). While definitions of vaccine hesitancy may differ, this concept is often best understood as a spectrum. On one end, some individuals actively demand vaccinations for themselves and their children, and advocate for greater vaccine uptake. On the other, some individuals reject all vaccines. Vaccine-hesitant parents exist between these two extremes—some may feel distress watching their children receive shots, some may feel skepticism towards the safety of vaccines themselves, while others fear or distrust vaccine providers and policies. In terms of behavior, these parents may accept vaccines despite some concerns, they may delay vaccination, or they choose to abstain from some or all vaccination (3-5, 7).

Thus, vaccine-hesitant behavior impacts public health, since the success of an immunization program depends on comprehensive vaccination uptake within the population (3). While some countries have introduced policies that require children to be vaccinated, usually before school entry, policies such as these remain controversial, especially among vaccine-hesitant parents (6). There is some evidence that parents who oppose compulsory vaccination are more likely to have low confidence in the safety and protective value of vaccines (8). Such parents increasingly seek exemptions from school immunization requirements, which increases the risk of measles, varicella, pneumococcal diseases, influenza, and pertussis for both their children and for others who have not or cannot be vaccinated against these diseases (5). Evidence shows that these exemptions are geographically clustered within the United States, leading to outbreaks of VPDs in these vaccine-hesitant communities (3).

The issue of decreased vaccine coverage is clear. Although measles was declared eliminated in the United States since 2002, over 2,500 cases of measles have been confirmed in the United States since 2010, with over 500 cases identified during the most recent outbreak in early 2019 (9-10) . Over 32,000 cases of pertussis have been identified between 2017 and 2018 alone, with 44% of cases occurring in children younger than 10 years of age (11-12). For HPV, which can cause various cancers and genital warts, vaccine coverage has increased over the years. However, only about half of adolescents have received the number of recommended doses as of 2018 (13).

Vaccines are critical to prevent the burden of these diseases. The psychosocial factors influencing the choice to not vaccinate must be understood in order to combat insufficient vaccine coverage (7). While some researchers have theorized that cognitive biases can shape parents' vaccine-related decision-making processes, few have investigated how specific biases individually impact vaccine hesitancy in this population (14-15). In this next section, we will discuss cognitive biases and how they might be used to understand and create messaging aimed at vaccine-hesitant individuals.

What are cognitive biases? How might they be involved in vaccine decision-making?

In decision-making research, the term "heuristics" describes a cognitive approach that is used to efficiently form judgements and create solutions. Cognitive biases are similar to heuristics; however, cognitive biases are characterized by their deviation from rational choice, which leads to decisions that are not based in logic or probability. While cognitive biases can be adaptive and lead to quicker action, a biased individual can create a flawed concept of reality based on their limited interpretation of information (16). In the case of vaccines, cognitive biases may contribute to a perception of risk from vaccination that is greater than the actual risk, or they may lead to an underestimation of the actual consequences of VPDs (6). Some of the cognitive biases that may impact vaccine decision-making (which are investigated in the following study) are detailed below.

Base Rate Neglect

Base rate neglect describes a tendency for individuals to focus on specific information about events, while ignoring general information about these same events. The representativeness heuristic (which uses a prior to make a judgement about a situation under uncertainty) leads to base rate neglect if one ignores the underlying incidence of a particular phenomenon (17). As immunization programs become more successful and the threat of VPDs decreases, awareness of vaccine risk may become more salient than the knowledge that vaccines generally do not cause harm (18). Vaccine-hesitant individuals may be concerned with alleged increases in incidence or the biological plausibility of negative outcomes, even if these outcomes are extremely rare (19).

Conjunction Fallacy

Conjunction fallacy occurs when an individual thinks a specific condition is more likely than a general condition. The probability of two or more events occurring simultaneously (i.e. a conjunction) is always less than the probability of any one of these events occurring individually. Such as with base rate neglect, conjunction fallacy results as a failure of the representativeness heuristic; an individual susceptible to this bias might favor a conjunction based off preconceived notions, even if the co-occurrence is less likely than the alternatives (15, 20).

In one example of how this impacts health-related decision-making, a 2009 study showed that conjunction fallacy may be a factor in incorrect medical diagnoses. Researchers asked medical students to assign probabilities to several symptoms experienced by a patient, which these students were primed to believe had a common cold (21). The medical students generally assumed that the patient would more likely experience both a runny nose and diarrhea instead of only diarrhea (since runny noses are generally more associated with colds), even though the latter option is mathematically more probable. This was an error, since the patient did not necessarily have a cold; the students only assumed that she did.

Similarly, some vaccine hesitancy stems from the pre-conceived notion that vaccination is associated with severe health outcomes, a belief which is influenced by temporality (22). This is exemplified by concerns that the MMR vaccine causes autism, since MMR is usually administered to children around the same time autism symptoms become apparent (22-23). Despite a great volume of evidence dispelling the MMR-autism connection, pre-existing ideas about vaccines may cause an individual susceptible to conjunction fallacy to assume that these events are co-occurring and not coincidental (23).

Sunk Cost Bias

Individuals susceptible to sunk cost bias are compelled to continue a behavior or efforts towards a goal because they have previously invested resources (time, money, etc.) that cannot be recovered. This may occur even if continued effort is unpleasant or requires additional invested resources (24). Conceptually, an individual having both vaccine confidence and susceptibility to sunk cost bias is not likely to ignore the sunk costs of previous vaccine receipt, and thus may make the decision to continue vaccinating.

Present Bias

Present bias describes a tendency for individuals to apply a greater value to immediate payoffs than long-term payoffs, even if the long-term impact would be greater (25). This bias has been identified as a factor in the development of health habits (26-28). For example, smokers are more likely to discount future outcomes, possibly because they assign greater value to current benefits, such as stress relief, over future health damage (26). In another study, those who are both present-biased and discount the value of future payoffs are partake in significantly less physical activity and tend to over-predict future gym attendance (27). This pattern was also apparent in a HPV vaccine uptake study investigating intent to vaccinate among the mothers of adolescent daughters. Here, some mothers indicated that they had safety concerns about the HPV vaccine, stemming from the "newness" of the vaccine, which explained their immediate lack of intent to vaccinate their daughters. However, many anticipated that they would vaccinate their daughters eventually (28). It is possible that vaccine-hesitant individuals emphasize the costs associated with receiving a vaccine in the present, while either being complacent about the risks of VPDs or overestimating future vaccination-seeking behavior.

Risk Aversion

Risk aversion is indicated by a preference to invest in an opportunity with lower returns and known risks rather than an opportunity with higher returns, but greater or unknown risk (29). Perceptions of risk impact both vaccine confidence and vaccine hesitancy. Persons who perceive VPDs as risky are more likely to accept vaccines, while those who perceive vaccines as risky are more likely to refuse them (7, 30). Since vaccines are generally administered to healthy patients and the outcome is the absence of disease, risk averse people may choose to avoid the immediate risks of vaccines (either perceived or actual) over the eventual, but invisible, benefits of avoiding disease.

Previous research has investigated omission bias, which is a related cognitive bias that describes the tendency to prefer harms caused by omissions or inaction over harms caused by actions. Those susceptible to omission bias are more averse to the immediate risks of vaccination than the potential risks of choosing not to vaccinate (31). This suggests that assigning greater value to choosing a current risk versus avoiding a future, unknown risk can influence an individual to choose to not vaccinate. Thus, risk aversion may be a contributor to vaccine-hesitant behaviors.

Information Avoidance

Information avoidant individuals prefer not to obtain knowledge that is freely available, often to avoid unwanted or unpleasant knowledge (32). Information avoidance's impact on hesitancy may be explained using several components of the 5C Model, which details the psychological antecedents of vaccine acceptance (Confidence, Constraints, Complacency, Calculation, and Collective Responsibility). Calculation, described as an individual's engagement in vaccine-related information-seeking, has the potential to improve one's knowledge about the benefits and risks of vaccines. But, given the high availability of anti-vaccination discourse, information-seeking behavior may also influence hesitant individuals to perceive vaccination as riskier. Similarly, vaccine confidence presupposes knowledge of the effectiveness and safety of vaccines, but misinformation can contribute to the development of distrust in vaccines or the healthcare systems that provide them (7). Thus, information avoidance may either cause individuals to be unaware of the benefits of vaccination, worsening confidence, or it may prevent individuals who trust vaccines from encountering sources of vaccine-critical sentiment and consequently becoming more hesitant.

What about the HPV vaccine? How can we address parental vaccine hesitancy to improve HPV vaccine uptake among adolescents?

HPV is the most common sexually transmitted disease in the United States. Adolescents and young adults account for most incident cases, although HPV is so prevalent that nearly all sexually active individuals are infected at some point during their lives (33). Worldwide, an estimated 630,000 individuals develop an HPV-related cancer each year (33). While most HPV infections are asymptomatic and resolve without intervention, some high-risk strains cause the majority of cervical, oropharyngeal, and genital cancers (34). Therefore, high HPV vaccine uptake is critical to reduce the burden of HPV-related cancer morbidity and mortality.

In the United States, current recommendations indicate that children should initiate 2-dose HPV vaccine by age 11 or 12 (35). Although HPV vaccine coverage in the United States is improving, coverage rates are still below the goal of 80% set by Healthy People 2020 (36). A variety of parental factors are associated with low HPV vaccine uptake, including lack of knowledge about the vaccine, low perception of HPV risk, and other vaccine attitudes (37).

While inadequate knowledge about HPV and its vaccine are cited as a reason for low uptake, providing parents with information about HPV does not appear to improve vaccine acceptance (38). Some evidence suggests that attempts to correct vaccine misinformation can actually backfire, reinforcing beliefs that vaccines are harmful and reducing intent to vaccinate (39). Thus, parents' attitudes and perceptions of risk may be better targets to combat hesitancy.

The following study investigates the how cognitive biases in parents of adolescent girls relate to both vaccine hesitancy and intent to vaccinate one's daughters with the HPV vaccine. The aim of this investigation is to identify some of the cognitive processes through which individuals develop vaccine attitudes, in order to develop improved tactics to combat false beliefs about vaccines and to modify perceptions of risk about vaccination.

Chapter II: Manuscript

Assessing the Impact of Cognitive Biases on Vaccine Hesitancy: A Cross-Sectional Study

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Introduction

Vaccines are one of the most successful public health interventions, preventing an estimated 20 million cases of preventable disease and over 40,000 deaths for each United States birth cohort (1). The economic savings from vaccinations include $14 billion in direct healthcare costs and $69 billion in societal costs. However, an upward trend in vaccine exemptions and recent outbreaks of vaccine-preventable diseases, like measles, indicates an increase in vaccine hesitancy in some individuals (3-4). For example, a survey from the Centers for Disease Control and Prevention estimated that 10% of parents in the United States are opposed to compulsory vaccination (8). Parents who oppose compulsory vaccination are more likely to have low confidence in the safety and protective value of vaccines, indicating that investigation regarding vaccine hesitancy in this group is a critical matter of public health concern (8).

Vaccine-hesitant individuals hold attitudes and beliefs that lead to concerns about vaccinating themselves or their children, which may in turn lead to refusing or delaying some or all recommended vaccines (2). Multiple factors contribute to vaccine hesitancy, including lack of trust in the healthcare system or care providers, lack of knowledge about vaccines and vaccine-preventable diseases, and a lack of perceived need for vaccines (5, 40). While parental vaccine hesitancy has been explored along several sociodemographic and psychosocial dimensions (e.g. education, race/ethnicity, peer group norms), basic underlying cognitive and decision-making characteristics such as temporal orientation and risk aversion are also likely associated with vaccine attitudes and intentions, and may be critical but understudied moderators of intervention effects.

In this study, we explore six common heuristics and cognitive biases that we hypothesize may be associated with parental vaccine hesitancy and intentions to vaccinate for the HPV vaccine. Heuristics, a concept in decision-making research, describe a simplified cognitive approach to solving problems and forming judgments (16). Decision-making associated with heuristics simplify and expedite complex problem-solving; however, these rules can sometimes deviate from logic, probability, or rational choice theory (16). These logical errors in decision-making are referred to as cognitive biases. While some researchers have theorized that cognitive biases can shape parents' vaccine-related decision-making processes, few have investigated how specific biases individually impact vaccine hesitancy (14-15). To broaden the current understanding of this topic, this study aims to investigate how both hesitancy towards vaccines and parental intent have their child receive the HPV vaccine are associated with these decision-making factors (Table 1).

Methods

We conducted a secondary analysis of baseline data from a two-phase randomized trial to investigate how vaccine hesitancy and intent to vaccinate among participants are associated with six decision-making factors: base rate neglect, conjunction fallacy, sunk cost bias, present bias, risk aversion, and information avoidance (see Table 1). These six factors were selected for prior studies of smoking behavior and vaccine hesitancy based on conceptual relevance, existing valid instruments, and relative ease of measurement in a brief online survey.

We recruited adult men and women residing in the United States with at least one daughter 9-17 years old who had not completed the full HPV vaccine series. This survey was conducted through Amazon Mechanical Turk (mTurk). Eligibility and compensation are as detailed in Porter et al., 2018 (41). The Emory University Institutional Review Board approved all study activities (Study #00087211). The study was registered on ClinicalTrials.gov, under reference number NCT03002324.

The primary outcome measure of this analysis, overall vaccine hesitancy, was measured by the Vaccine Confidence Scale (VCS) (42). The VCS is an 8-item questionnaire measuring the perceived benefits and perceived harms of vaccinating one's teenager, as well as the parent's trust in their relationship with their healthcare providers. Likert-type scales are used to measure a parent's agreement with statements about vaccines, (e.g. "Vaccines are safe") with higher scores relating to positive attitudes towards vaccines for all but two items. These two harm-related items were reverse-coded. VCS scores were calculated by averaging the numeric scores for all 8 questions. Lower scores on this measure indicate greater vaccine hesitancy.

The secondary outcome measure was intent to vaccinate with the human papillomavirus (HPV) vaccine, which asked participants if they intended to vaccinate their child (if not previously vaccinated) or if they intended to complete the full HPV vaccine series (if the child had already received at least one dose). Key sociodemographic data was also collected (see Table 2).The selected sociodemographic variables were considered as potential confounders in the analysis. Cognitive biases were measured using previously-validated questionnaires, adapted in some cases for our survey (Appendix A).

The association between each cognitive bias and VCS score was assessed using a series of multivariate linear regression models. The following steps were used in the model selection process for each cognitive bias. The initial, fully adjusted model contained the cognitive bias under analysis, as well as gender, age, marital status, education, daughter's age, number of children in the household, ethnicity, and income. We first examined each fully-adjusted model for collinearity, using a threshold of <30 for the condition indices. Then, we used backwards stepwise elimination to identify demographic covariates for removal, based on a p-value > 0.05, until all remaining covariates in the model were significant. We then conducted a confounding assessment on this model using the all-possible-subsets approach, re-introducing the removed covariates to determine the most likely confounders across the biases. Based on the 10% change in estimate guideline and conceptual plausibility, the final model for each cognitive bias was chosen. Model results were reported as beta coefficients with confidence estimates (Figure 1).

A sensitivity analysis was conducted using multinomial logistic regression for each final cognitive bias model by dividing VCS score into three categories [Low (VCS ≤ 6), Medium (6 < VCS ≤ 8), and High (VCS > 8], based off the cut-points established in Gilkey et al., 2016 (43). High VCS score was used as the reference group. We used multinomial logistic regression because the VCS score outcomes violate the proportional odds assumption. The analysis for the relationship between intent to vaccinate and the individual cognitive biases was performed using univariate logistic regression. The analyses in this study were completed using SAS (version 9.4, SAS Institute Inc., Cary, North Carolina). We used multinomial logistic regression because the VCS score outcomes violate the proportional odds assumption for an ordered logit.

Results

16,474 participants from Amazon Mechanical Turk were assessed for eligibility, with 1,481 participants eligible for entry into the study. Of those, 1,413 participants participated in the first phase survey. The majority of participants were white (74.1%), female (71.6%), and married (75.3%). Most (88.8%) of the sample had a college or graduate/professional education (Table 1). Participants who responded with “Prefer not to answer” for their gender were excluded in the final analysis due to low sample size (n = 13).

After controlling for sociodemographic factors, we found positive associations between VCS score and 2 of the cognitive biases: conjunction fallacy and sunk cost bias; information avoidance and present bias were found to have a negative association with VCS score (Figure 1a-b). Base rate neglect and risk aversion were not significantly associated with VCS score.

Interpretation of these outcomes depend on whether the bias used a binary or interval measure. For example, more present-biased participants scored, on average, 0.70 points lower on the VCS than less present-biased participants; for each one standard deviation reduction in the information avoidance score, the VCS score decreased by 0.46 points. The sensitivity analyses showed evidence that the associations for most of the cognitive biases are robust to different treatments of the VCS outcome (Table 3).

Among participants whose daughters had not completed the HPV vaccine series, the odds of intending to vaccinate is lower among participants who experience information avoidance (Table 4). There was a 13% lower odds of intending to vaccinate for each standard deviation increase in information avoidance. The odds of having an intent to vaccinate do not differ by susceptibility for the remaining biases.

Discussion

This study found that parental susceptibility to established cognitive biases is associated with vaccine hesitancy. We found that the presence of certain cognitive biases - conjunction fallacy and sunk cost bias - was associated with more positive attitudes towards vaccines. Information avoidance and present bias were positively associated with parental vaccine hesitancy. For our secondary outcome, lower intent to vaccinate was associated with information avoidance.

Attitudes and beliefs about vaccination are crucial to achieving adequate vaccine coverage, but the specific cognitive processes underlying the development of vaccine hesitancy require continued research. Previous research has looked at omission bias, a cognitive heuristic not studied here. It measures a tendency to prefer harms caused by omissions or inaction over harms caused by actions. In this research, vaccine-hesitant participants were more likely to exhibit omission bias, which was associated with a belief that vaccinating posed a greater danger than not vaccinating (31). Otherwise, previous evidence on the existence of a relationship between cognitive biases and vaccine hesitancy is limited. The purpose of this study was to further investigate how several cognitive biases are associated with vaccine confidence and intent to vaccinate.

Although this analysis is meant to serve as a broad examination of cognitive biases in a vaccine context, previous vaccine hesitancy research can be evaluated to form potential hypotheses for the results observed here. In an earlier study of parental vaccine hesitancy, there was no evidence of an association between parental vaccine hesitancy and adolescent vaccine uptake (44). This may explain the seemingly contradictory results for conjunction fallacy and sunk cost bias – the cognitive biases that are associated with lower vaccine hesitancy, but do not appear to influence intent to vaccinate.

This study was limited primarily by the original randomized trial outcomes' focus on only the HPV vaccine. Our sample was restricted to a population of parents of daughters who are eligible for the HPV vaccine, and limits generalizability to parents of male children and hesitancy towards vaccines targeting other diseases. The stigma towards the HPV vaccine, fostered by the cultural stigma towards sexually transmitted diseases and fear that HPV vaccination will cause sexual disinhibition, may impact the nature and degree of hesitancy in this group, especially among parents of daughters (38). However, a more homogenous parent population may be desirable for an exploratory study such as this one. Another limitation of this study was the difficulty in interpreting the results between the binary-outcome (susceptible vs. not susceptible to bias) and interval-outcome cognitive bias measures (here, only information avoidance). For this reason, the results from the two categories of cognitive biases are presented separately. Because each cognitive bias in this study was individually regressed with VCS score, the interrelation between the cognitive biases cannot be assessed. Furthermore, it is unclear if susceptibility to cognitive biases influences vaccine attitudes or if some third factor influences both susceptibility and attitudes.

Future research should investigate the relationships between vaccine hesitancy and each of the cognitive biases in this study in greater depth. Such studies could determine whether these biases can form a cognitive phenotype for vaccine-hesitant participants, and if so, if this phenotype has influence on vaccine-related behaviors, such as vaccination of self or one's children. Previous research has shown that social networks play an important role in parents' vaccination decision-making, and that vaccine-hesitant parents create social networks together and deviate from the norm of vaccination (45). Thus, consequent studies should investigate whether these networks of vaccine-hesitant parents display similar cognitive biases and, if so, whether these biases have influence on their vaccine attitudes and intentions.

Conclusions

Several cognitive biases may be associated with vaccine hesitancy, including conjunction fallacy, sunk cost bias, present bias, and information bias. Additionally, intent to vaccinate is lower among participants who are susceptible to information avoidance. These results suggest that cognitive biases play a role in both the development of parental vaccine hesitancy and vaccine-related behavior. Future studies should be conducted to further investigate how these human decision-making processes influence vaccine hesitancy, especially among a variety of vaccines and populations.

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Tables

Table 1
Definitions for Cognitive Biases

Cognitive Bias	Definition
Base Rate Neglect	Individuals focus more on specific information and ignore general information about events (17)
Conjunction Fallacy	Occurs when an individual thinks a specific condition is more likely than a general condition (20)
Sunk Cost Fallacy	Individuals are compelled to continue a behavior or efforts towards a goal because they have previously invested resources (time, money, etc.) that cannot be recovered (24)
Present Bias	The tendency to give stronger weight to more-immediate payoffs than long-term payoffs (25)
Risk Aversion	The preference to invest in an opportunity with lower returns and known risks rather than an opportunity with higher returns, but greater or unknown risk (29)
Information Avoidance	The preference to not to obtain knowledge that is freely available, especially if that knowledge is unwanted or unpleasant (32)

Table 2
Demographic Characteristics of Study Sample

	n	Mean (SD) or %*
Participant Gender		
Male	388	27.46
Female	1012	71.62
Prefer Not to Answer	13	0.92
Participant Age, Years		39.4 (7.3)
Participant Race/Ethnicity		
White	1047	74.1
African American	102	7.2
Asian	78	5.5
Hispanic	54	3.8
American Indian/Alaska Native	23	1.6
Hawaiian/Pacific Islander	3	0.2
Other/Multi-racial	106	7.5
Participant Marital Status		
Single, Never Married	127	9.0
Married	1064	75.3
Widowed/Divorced/Separated	222	15.7
Household Income		
Less than $25,000	170	12.0
$25,000-$34,999	188	13.3
$35,000-$49,999	215	15.2
$50,000-$74,999	307	21.7
$75,000-$99,999	262	18.5
Over $100,000	271	19.2
Number of children in household		
1 child	222	15.7
2 children	558	39.5
3 children	325	23.0
4 or more children	308	21.8
Participant Education Level		
High School or GED	159	11.3
College Degree	953	67.5
Graduate or Professional Degree	301	21.3
Daughter's Age		
9-11 years old	488	34.5
12-14 years old	457	32.3
15-17 years old	468	33.1

Table 3

Sensitivity Analysis for the Association of Individual Cognitive Biases with Vaccine Confidence Scale Score

Variable	VCS Score	OR	95% CI	
Base Rate Neglect	Low	1.07	0.79	1.44
	Medium	1.10	0.84	1.45
	High	1.00	-	-
Conjunction Fallacy	Low	0.65	0.47	0.90
	Medium	0.88	0.64	1.20
	High	1.00	-	-
Sunk Cost Bias	Low	0.78	0.58	1.05
	Medium	0.97	0.74	1.27
	High	1.00	-	-
Present Bias	Low	2.95	1.69	5.14
	Medium	1.55	0.862	2.77
	High	1.00	-	-
Risk Aversion	Low	1.02	0.75	1.38
	Medium	0.98	0.74	1.30
	High	1.00	-	-
Base Rate Neglect	Low	1.07	0.79	1.44
	Medium	1.10	0.84	1.45
	High	1.00	-	-

Note: VCS Scores were divided between Low (VCS ≤ 6), Medium (6 < VCS ≤ 8), and High (VCS > 8). Lower scores indicate greater vaccine hesitancy. Odds ratios indicate the odds of susceptibility to each cognitive bias between levels of vaccine hesitancy, modeled using multinomial logistic regression with "High" vaccine confidence scores as the reference group. Information avoidance uses z-scores; the remaining biases are measured dichotomously.

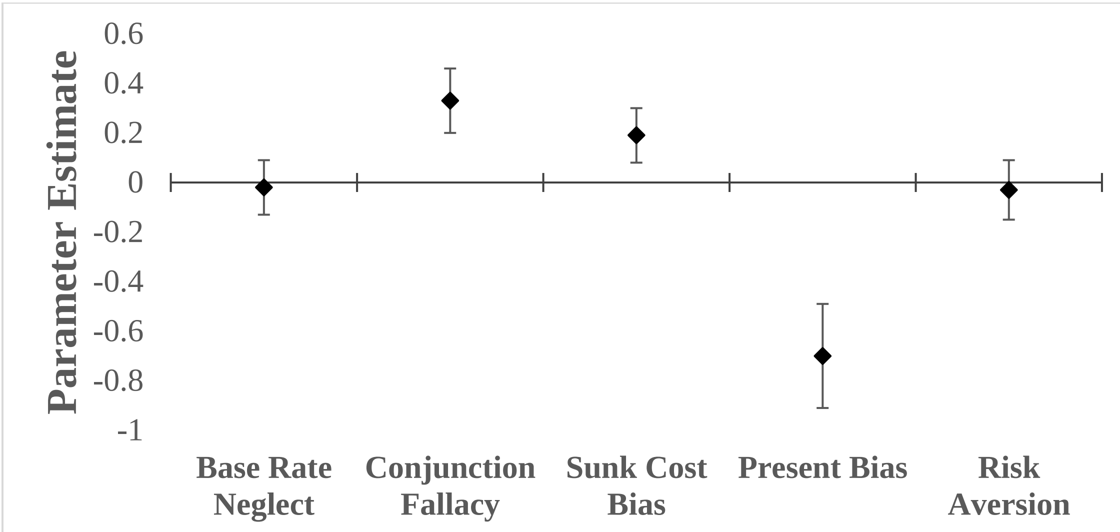
Table 4
Estimated Odds Ratios and 95% Confidence Intervals for the Association of Individual Cognitive Biases with Intent to Vaccinate

Variable	OR	95% CI	
Base Rate Neglect	0.99	0.77	1.26
Conjunction Fallacy	0.90	0.69	1.18
Sunk Cost Bias	1.02	0.80	1.30
Information Avoidance	0.87	0.78	0.98
Present Bias	1.20	0.77	1.88
Risk Aversion	0.85	0.66	1.09

Note: Information avoidance uses z-scores; the remaining biases are measured dichotomously.

Figures

(a) Binary Cognitive Biases



(b) Standardized Interval Cognitive Biases

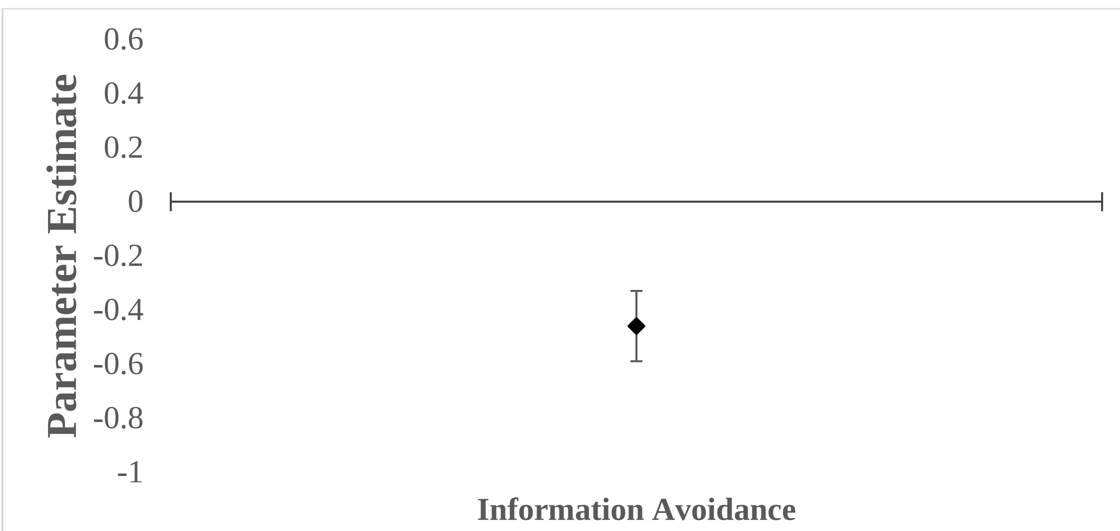


Figure 1a-b. Parameter estimates indicating the relationship between Vaccine Confidence Scale (VCS) score and individual cognitive biases, modeled with multivariate linear regression. A positive parameter estimate indicates less vaccine hesitancy, while a negative parameter estimate indicates greater vaccine hesitancy. (a) Binary cognitive biases were coded dichotomously (Bias present vs. not present); the parameter estimates indicate the change in VCS score if the bias is present, compared to if the bias is absent. (b) Standardized cognitive biases were coded as linear scales, then standardized to ensure comparability; the parameter estimates indicate the change in VCS score for each standard deviation of change in the bias score.

<u>Chapter III</u>: Summary, Implications, and Future Directions

The aim of this study was to investigate how vaccine hesitancy and intent to vaccinate (with the HPV vaccine) among participants are associated with six decision-making factors—base rate neglect, conjunction fallacy, sunk cost bias, present bias, risk aversion, and information avoidance—in a sample of parents of adolescent daughters. Our goal was to identify some of the cognitive processes through which individuals develop vaccine attitudes, in order to develop improved tactics to combat false beliefs about vaccines and to modify perceptions of risk about vaccination.

We found that parental susceptibility to established cognitive biases is associated with both vaccine hesitancy and intent to vaccinate. We found that conjunction fallacy and sunk cost bias were associated with more positive attitudes towards vaccines. Information avoidance and present bias were associated with greater vaccine hesitancy. Parental susceptibilities to optimism bias and information avoidance were associated with lower intent to vaccinate.

As the decision to vaccinate largely falls to parents, there is a need for continued research investigating how cognitive factors can be utilized to improve vaccine uptake among vaccine-hesitant individuals. Since vaccination mandates are subject to controversy and backlash, some public health researchers have recommended "nudges", or strategies that direct people to behave in a specific way, without significantly limiting their options. Nudges fall under the assumption that unfavorable decisions are caused by biases and errors; thus, nudges work to set the context for making favorable health choices, instead of demanding a particular decision (6).

Our results suggest that vaccine hesitancy (the unfavorable decision in this scenario) are indeed affected by biases. Therefore, nudges designed with specific cognitive biases in mind may be more effective in causing behavioral change among vaccine-hesitant individuals. For example, financial or tax incentives could be used for present-biased vaccine-hesitant individuals; such incentives could add to the current value of seeking vaccination, outweighing the perception of risk or inconvenience. For vaccine-confident individuals, a potential nudge to complete a vaccine series could be appointment reminders that emphasize the sunk costs associated with previous doses.

Future research should also investigate whether certain cognitive biases join together to form a "phenotype" among vaccine-hesitant participants, and if so, whether this phenotype has influence on vaccine uptake. Additionally, previous research has shown that social networks play an important role in parents' vaccination decision-making, and that vaccine-hesitant parents tend to create networks together (30). Future studies should investigate whether these networks of vaccine-hesitant parents share cognitive biases and, if so, whether these biases have influence on vaccine uptake within a group. Accordingly, nudges and targeted messaging could be developed to address the biases leading to vaccine refusal or delay within networks or clusters of vaccine-hesitant parents.

Appendix A

Cognitive Bias Measures

Base rate neglect was measured with a question developed by Kahneman and Tversky (17). The prompt describes a group of 100 women, in which 70 are supermarket cashiers and 30 are librarians, followed by a description of a detail-oriented and quiet woman in the group named Ashley. Participants rate the chances of Ashley being a supermarket cashier using a slider from 0% to 100%. Base rate neglect was coded as present if the response was <70%.

Conjunction fallacy was also measured with a question developed by Kahneman and Tversky and modified for this study, where a woman named Brittany is described as outspoken and social-justice-oriented (20). Participants rank the probability of 5 scenarios related to Brittany from 1 to 5, with 1 as “Most probable” and 5 as “Least probable”. Conjunction fallacy was coded as present if, within these 5 scenarios, the participant ranks “Brittany is a bank teller and active in the feminist movement” as more probable than “Brittany is a bank teller”.

Sunk cost fallacy was measured with two related questions (24). Both prompts refer to a scenario where the participant imagines watching 5 minutes of a boring movie in a hotel and must decide whether to continue watching the movie or to switch channels on the television. In the first scenario, the participant has paid $6.95 for the movie; in the second scenario, the movie was free. Sunk cost fallacy is coded as present if the participant indicates that they would continue watching if they paid to watch the movie but would switch channels if the movie were free. This suggests that the participant would choose to continue a behavior due to having made a previous investment, even if continuing that behavior is not beneficial and requires continued investment of time and resources. In other cases, including if the participant indicates they would switch if they paid but would continue watching if the movie were free, participants were not considered to be susceptible to the sunk cost fallacy.

Present bias was measured with a 7-item questionnaire, each question presenting two choices about receiving money now or receiving money later, i.e. would the participant prefer to "Receive a $5 gift card today or a $15 gift card in five days" (25). Consecutive questions increased the "current" payout from $5 to $17 in increments of $2, while the money received in five days remained stable at $15. Susceptibility to present bias tends to be greater if participants prefer to receive less money now instead of more money later. We coded present bias as a dichotomous variable due to non-normal distribution of responses. In this study, the bias was present if participants preferred less than half the maximum payout now than $15 in five days, indicating that the participant has a preference for immediate payoffs at the expense of better long-term outcomes

Risk aversion was measured by presenting a list of six gambles, each with two potential equally likely payoffs (e.g. a coin flip) (29). The first gamble presented two equal payoffs of $10, with subsequent gambles having gradually more unequal payoffs, up to "Heads: $2.50, Tails: $24". Participants chose which gamble to take. Risk aversion scores tend to be greater in participants preferring more equal payoffs than riskier, but potentially greater, payoffs. We coded risk aversion as a dichotomous variable due to the non-normal distribution of responses in our sample. Risk aversion was present if participants chose either of the two least risky gambles (Heads: $10, Tails: $10 and Heads: $9.50, Tails: $11). Risk averse participants were not willing to pay a risk premium for a potentially higher pay out.

Information avoidance was measured with a 6-item questionnaire relating to whether the participant would want to avoid potentially distressing knowledge (e.g. "I would avoid learning whether my partner is cheating on me") (32). The original health-related items in this questionnaire were modified by replacing them with items relating to HPV and cervical cancer. The responses to each statement are scaled from 1 ("Strongly Disagree") to 5 ("Strongly

Agree"). Information avoidance scores were calculated by reverse coding the responses for the two "want to know" questions, then calculating the sum of the scores for all 6 questions. The information avoidance scores were z-score standardized for easier comparability to the other interval measured biases, with greater scores indicating greater susceptibility to information avoidance.