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# Belief correlations with parental vaccine hesitancy: Results from a national survey

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## Abstract

We conducted a nationally representative survey of parents' beliefs and self-reported behaviors regarding childhood vaccinations. Using Bayesian selection among multivariate models, we found that beliefs, even those without any vaccine or health content, predicted vaccine-hesitant behaviors better than demographics, social network effects, or scientific reasoning. The multivariate structure of beliefs combined many types of ideation that included concerns about both conspiracies and side effects. Although they are not strongly related to vaccine-hesitant behavior, demographics were key predictors of beliefs. Our results support some of the previously proposed pro-vaccination messaging strategies and suggest some new strategies not previously considered.

KEYWORDS
vaccination, survey, cumulative culture, Bayesian

## Resumen

Realizamos una encuesta nacionalmente representativa sobre las creencias y comportamientos autodeclarados por los padres con relación a la vacunación infantil. Usando selección bayesiana entre modelos multivariados, encontramos que las creencias, aun aquellas sin ningún contenido sobre vacunas o salud, predijeron comportamientos indecisos sobre la vacuna mejor que las características demográficas, los efectos de las redes sociales o el razonamiento científico. La estructura multivariada de las creencias combinó muchos tipos de ideación que incluyó preocupaciones tanto sobre conspiraciones como efectos secundarios. Aunque no están relacionados fuertemente con los comportamientos de indecisión, las características demográficas fueron predictores centrales de las creencias. Nuestros resultados apoyan algunas de las estrategias de mensajes pro-vacunación propuestas previamente y sugieren algunas nuevas estrategias no consideradas anteriormente. [*vacunación*, *encuesta*, *cultura acumulativa*, *bayesiana*]

  

## INTRODUCTION

Parental hesitance to vaccinate their children is a major concern for public health. Vaccine hesitancy occurs internationally (Larson et al. 2016), including in the United States, where some communities exhibit less than the 95 percent compliance with the evidence-based schedule for vaccinations that is needed to maintain herd immunity. Herd immunity occurs when a pathogen can no longer spread consistently to the susceptible because its transmission is broken up by the intervening immune individuals (Rosentrater, Finlayson, and Peddecord 2018). In the United States, more than 27 percent of children under thirty-five months are not fully vaccinated (Hill et al. 2016; Olive et al. 2018). The literature on best practices around vaccine messaging and communication is complex and varies by vaccine. While some experts call for the use of personal stories and visual images of patients and parents affected by vaccine-preventable diseases (Healy and Pickering 2011; Jarrett et al. 2015; Teoh et al. 2019), the use of dramatic narratives and/or graphic images of vaccine-preventable diseases may have no effect (Teoh et al. 2019) or may backfire by reinforcing already entrenched concerns about vaccine safety (Opel et al. 2019; Nyhan et al. 2014). These findings should lead us to question the origins of vaccine hesitancy. Does it arise from understandings/misunderstandings of science, from dis/trust of the medical establishment or government, historically rooted experiences of oppression, or outright viral misinformation? It is easy, absent considering empirical data, to postulate many such seemingly plausible single-cause explanations.

From a research-process standpoint, these null and backfire findings suggest the public-health community may have moved too quickly to experimental techniques that can establish causal inference without observational research needed to induce (rather than deduce) data-driven hypotheses about how beliefs and experiences influence vaccination behaviors. Perspectives from social science might help inform vaccination policy by bringing stronger theory and/or broader empirical findings from studies that focus on observational rather than experimental research methods. Findings from these studies, however, vary dramatically by academic discipline.

Upon reviewing the social science literature on vaccine hesitancy, it becomes clear that although sociocultural anthropologists and psychologists have both investigated the phenomenon, they have arrived at radically different explanations for it. Anthropological studies have emphasized multiple dimensions of parental concerns, understandings, and confidences that encompass relative trust and distrust of medical systems, sources of information, and parents' tendencies to accept social norms. In a manner typical of anthropology, these studies have employed diverse and mostly qualitative methods tailored to each study context (Brunson 2013; Brunson and Sobo 2017; Leach and Fairhead 2007; Sobo 2015; ). In contrast, multiple observational studies from psychological research have employed standardized survey instruments to find that decisions about vaccination are determined by individuals' positions on two unidimensional and interrelated scales: rejection of scientific consensus (e.g., rejection of evolution, global warming, etc.) and conspiracy ideation (e.g., moon landing faked, CDC hides vaccine side effects) (Healy and Pickering 2011; Jarrett et al. 2015; Jolley and Douglas 2014; Lewandowsky, Gignac, and Oberauer 2013; Nyhan et al. 2014; Oliver and Wood 2014; Teoh et al. 2019).

This leads to a focus of our study: to bring anthropological theory to bear in a nationally representative survey study. While many anthropologists may hold such quantitative techniques to be suspect, much of US governmental policy is guided by quantitative analysis. We think anthropological theories can improve these quantitative analyses, but that without some effort at quantification, full policy impacts for anthropological praxis are unlikely (Roberts 2021). In part, policymakers require somewhat concrete forms of analysis to justify what can be highly contentious public-health decisions. We approached this project with the idea that more quantitative forms of analysis from nationally representative survey data could yet give equal opportunity to find empirical support for anthropological theories for human behavior as they can psychological ones. In our analyses, we strove to use methods that put predictions derived from all the theories we investigated on an equal playing field that let the data determine which were most predictive of the vaccine-hesitancy outcome of interest to us.

### Prior Research

In a major comparative study of UK and West African populations, anthropologists Leach and Fairhead (2007) characterized most approaches to vaccine policy as operating under a deficit model in which nonvaccination arose from deficits of scientific understanding, trust in doctors, or other rational thought process. They noted:

> It [the deficit approach] obscures why what they do think might make sense, as part of their everyday lives and experiences, values and conceptualizations of the issues involved. It misses the opportunity to identify the "framings"—forms of knowledge, value and social commitment—that people bring to an issue, and which shape their anxieties about it, whether positive or negative. (4)

Anthropological studies in the United States similarly have emphasized multiple dimensions of parental concerns, understandings, and confidences that encompass relative trust and distrust of medical systems, sources of information, and parents' tendencies to accept social norms. In a study of fifteen mothers and three couples in Washington state, Brunson (2013) described parental vaccination decisions as arising from three general approaches to processing vaccine information. These approaches included acceptors (who follow general social norms), reliers (who accept advice from people they know), and searchers (who seek out published expert information). Brunson suggested vaccination decisions arise from these alternative modes of interrogating information, and given this, that public-health messages need to be tailored to each of these modes.

Sobo (2015) observed somewhat different aspects of the processes surrounding vaccination decisions in a study of thirty-six parents of students at a Waldorf school in the United States. Sobo identified how the Waldorfian anti-vaccination stance arose from mutually reinforcing local social relationships.

> According to these findings, the anti-vaccination stereotype becomes increasingly accurate as the duration of a family's enrollment increases and the number of one's enrolled children grows—and as the number of people in one's people network who disfavor vaccination expands (see Brunson 2013). This increased frequency of vaccine refusal, and the equation between non-vaccination, the independence of mind that it is taken to signify, and Waldorfian identity make it harder and harder to contravene the norm without threatening one's sense of group membership.

The process Sobo (2015) describes is consistent both with Brunson's (2013) notion of "reliers" but also with a broader set of cultural theory that has hypothesized beliefs and rituals with little immediate utilitarian consequence as central to signaling membership within a social group. Religious belief and ritual have been focal examples of this process. The beliefs and rituals are useful indexes of group identity because their proper expression can be learned only through social participation within the group (Bulbulia 2012; Matthews 2012). Because religious or other non-evidentiary beliefs can be learned only through interaction with the social group, humans quite sensibly attend to these beliefs as valid indexes of group belonging by feeling bonded to others who express the same traits, a process known in network science as homophily.

These studies from sociocultural anthropology raise compelling hypotheses that vaccination beliefs and behaviors could arise from multiple dimensions and even "jagged" edges formed by social interactions and beliefs that cocreate each other (Brunson and Sobo 2017). Their small sample sizes, however, raise the question as to whether these are general enough findings to inform vaccination policy in the United States. Although Waldorf schools have a demonstrably higher rate of personal-belief exemptions to vaccines than do public schools (Sobo 2015), because Waldorf schools encompass a small percentage of American students, they cannot possibly account for most nonvaccination (National Center for Education Statistics 2020). Concomitantly, it is unclear whether the social and belief mechanisms among the Waldorf community have a strong correspondence to these processes among the majority of American parents.

In contrast to the anthropological perspectives just discussed, multiple observational studies from psychological research have emphasized two unidimensional and interrelated scales: rejection of scientific consensus (e.g., rejection of evolution, global warming, etc.) and conspiracy ideation (e.g., moon landing faked, CDC hides vaccine side effects) (Healy and Pickering 2011; Jarrett et al. 2015; Jolley and Douglas 2014; Lewandowsky, Gignac, and Oberauer 2013; Nyhan et al. 2014; Oliver and Wood 2014; Teoh et al. 2019). Conspiracy beliefs figure prominently in these psychological explanations for anti-vaccination beliefs and behavior, and most studies have examined only false conspiracy beliefs. They did not include in their surveys any beliefs in conspiracies that are true, such as the Tuskegee syphilis event or the CIA's use of a fake vaccination campaign to find Osama bin Laden. Consistent with the "deficit model" described by Leach and Fairhead (2007), much psychological research implicitly assumes that false and true beliefs about conspiracies rely on distinct cognitive processes in the minds of individuals, but in this article, we consider that true and false conspiracy beliefs may instead rely on processes common to both. Throughout this article, we refer to "conspiracy beliefs" to mean mental representations (i.e., beliefs) with conspiracy content. We do not use "conspiracy theories" because this phrase implies the beliefs are false. We do not prejudge false or true conspiracy beliefs to be distinct ontological categories (Grimes 2016) and instead seek to let the data determine how beliefs, both true and false, are correlated (or not).

We also note that we use the term "beliefs" in its somewhat technical philosophical sense meaning cognitions that are mental representations of some reality external to the believer. Beliefs, defined in this manner, could be true or false (i.e., correspond to external reality or not). As a separate matter from truth, beliefs could be well justified or poorly justified (i.e., have good reasons/evidence that support them or not) (Moser, Mulder, and Trout 1998). When describing and discussing beliefs, we are making no judgments as to their truth or justification. We are interested in them because people have them, and potentially they are a very important form of culture (socially learned information) that influences policy-relevant decisions (like getting vaccinated).

The contrasting conclusions of sociocultural anthropology and psychology are striking. They have arrived at radically different explanatory systems for ostensibly the same object of study. Many anthropologists see vaccination decisions as arising from a multidimensional jagged interface of social relationships, beliefs, and societal norms, while many psychologists see individuals as arrayed along a relatively unidimensional scale from evidence-based scientific understanding, on one end, to (false) conspiracy ideation, on the other. These different explanations for vaccine hesitancy imply very different means for engagement with the public to promote safe and effective vaccines.

We investigate these alternative explanatory visions by incorporating aspects of both into a single study with sampling and measurement methods that could discern between them. Consistent with the anthropological tradition, we constructed survey items not through deduction from theorized mental mechanisms but from an inductive approach that begins with qualitative research on what people generally say about vaccines. Consistent with this approach, we analyzed the data with principal component analysis (PCA), an exploratory analysis technique for summarizing variation, rather than factor analysis, which is generally employed in psychology to focus on confirming or disconfirming theorized scales. Consistent with psychometric studies, however, we employed reasonably large and nationally representative sampling and quantified variation such that we then could statistically examine whether the resulting covariations among beliefs and behaviors were multi- or unidimensional and whether they were strongly related to conspiratorial views or evidence.

To achieve these ends, we divided the study into two research questions. One that examined self-reported vaccination *behavior* as the outcome in the regressions, and one that examined self-reported *beliefs* as the outcome in the regressions.

**Research question 1**. How is covariation across multiple beliefs related to self-reported vaccination behavior? We applied principal components analysis to summarize covariation across multiple beliefs in the survey belief items and then tested whether the main axis of variation was predictive of vaccination behavior. We tested the predictive efficacy of beliefs against other predictors, including demographics, network effects, and an attitudinal trust toward governments and media.

**Research Question 2**. What is the best way to describe and conceptualize covariation across multiple beliefs? We characterized the principal component structure of the beliefs and tested the wholly inductive analysis of this structure against several constructs theorized by prior literature. We then examined which nonbelief variables (e.g., demographics, social networks, attitudes) were most closely associated with PCA belief scores.

## SOCIAL SCIENCE THEORIES FOR BEHAVIOR

Here, we briefly summarize the prior social science theory that we operationalized in our survey.

### Secondary Value Selection

Several research traditions from anthropology propose that learned cultural notions influence individuals' subsequently adopted beliefs and behaviors. Durham (1991) expressed this concept as "secondary value selection," defined as any process by which one socially learned belief or behavior altered the probability of other beliefs and behaviors being learned. Evolutionary anthropology similarly hypothesized "cumulative culture" to undergird much human behavior (Dean et al. 2014). Cumulative culture is similar to secondary value selection but with the added stipulation that the cultural process results in an evolutionary ratcheting of complexity and adaptiveness (Kamilar and Atkinson 2014). Another related concept is behavioral scaffolding, whereby social learning creates cultural complexes among individually learned items that build in a particular direction (Caporael et al. 2013).

### Demographics

Prior research has supported that conspiracy beliefs are more common among groups who experience lower social status in a society and may have been victims of actual conspiracies. This could occur from people attending to status as a feature in itself or from quite rational calculation that their material risks and benefits differ due to their demographic affiliations, whether from status or other processes (Uscinski and Parent 2014). In one specific example, Westergaard et al. (2014) observed that African Americans were simultaneously more willing to take a hypothetical HIV vaccine but also were more likely to believe in health conspiracies about HIV. Both observations are quite reasonable reactions since African Americans suffer disproportionately from HIV compared to white Americans, and African Americans have been victims of actual health conspiracies by medical-governmental systems (e.g., Tuskegee syphilis event). Thus, for a variety of reasons, we might expect demographic variables that index social status, such as income, education, gender, and race, to associate with vaccination beliefs and behaviors.

We would also note at this point that our research design allowed for the possibility that true and false conspiracy beliefs might correlate positively, meaning that individuals being aware of a true conspiracy like the Tuskegee syphilis event might be associated with them also believing that moon landings were faked or that a deep state controlled the US government. Our methods, however, also could have found these to be negatively correlated, if indeed that were the empirical pattern. We have found that leaving this matter open to the empirical findings makes some researchers uncomfortable; we believe this discomfort arises from two factors. One, it allows for an empirical equivalence between ontological categories (truth and falsehood, what exists and what doesn't exist) that are totally distinct in the minds of most researchers. Two, our methods allow the observations to find an empirical equivalency between social groups that researchers tend to view as justified in their mistrust of the establishment due to histories of real victimization (e.g., African Americans) and those groups that researchers tend to see merely as victims of misinformation (e.g., low-income whites).

With our methods, we are trying to go beyond the ontologies that researchers want people to use (truth/falsehood, justification/shoddy reasoning) and instead take in how people associate various beliefs with other beliefs. We also wish to transcend the easy narratives of oppression/victimization that would seek to define the empirical reality of what people think and do by the moral realities and/or moral perceptions of what various people do or do not deserve.

### Network Effects

Network studies from anthropology and sociology have emphasized the role of each individual's direct social connections in cocreating their beliefs and behaviors (Centola 2010; Christakis and Fowler 2007). These observed "network effects" likely arise from a combination of social influence, in which the traits of social connections influence each other, and homophily, in which individuals with similar traits preferentially form social connections. Both social influence and homophily predict that the perceived similarity of one's social connections will correlate with each individual's own beliefs and behaviors.

### Political and Religious Affiliations

Another tradition in anthropology and cognitive science of religion has emphasized the role of culture as a means for signaling

membership in a social group (Bulbulia 2012; Matthews 2017). Sobo (2015) proposed a similar mechanism as underpinning anti-vaccination stances among Waldorf parents. Assuming such social-group benefits of anti-vaccine beliefs present greater marginal benefit for those who participate less in traditional social groups like religion or politics, then individuals who are lacking in affiliation to traditional identity groups may endorse more anti-vaccine beliefs.

### Trust in Institutions

Scholars in psychology have proposed that the specific semantic content of beliefs is not important to behaviors but rather the "gist"/take-home point or mere attitudinal disposition is what underlies behavior (Reyna 2004). Semantic content is seen as a more surface-level phenomenon. Recent research has proposed changing general attitudes toward trust in experts and institutions may underlie the decline of value for evidence in public discourse (Rich and Kavanagh 2018). This idea predicts that directly measuring levels of trust toward secular institutions that promote vaccines (doctors, the government, the mainstream media) would predict vaccination decisions.

### Scientific Reasoning

Prior research has shown that scientific-reasoning ability, as measured through survey questions assessing actual proficiency with the scientific method, is predictive of acceptance of scientific consensus views (Drummond and Fischhoff 2015). Based on this, we predicted that greater scientific reasoning might be associated with less vaccine hesitancy.

## METHODS

### Induction of Belief Survey Items

To develop belief items, we conducted a systematic literature review of peer-reviewed articles that included open-ended questions about vaccine beliefs. We supplemented this with an ad hoc review of important anti-vaccine and conspiracy-belief websites. We have previously published comprehensive documentation of findings from the systematic literature review (Gidengil et al. 2019). We identified seventy-one articles that used open-ended questions to elicit vaccine beliefs. As a result of this focus on open-ended questions, our literature review resulted in the inclusion of questions that might not be traditionally asked in surveys but that offer the potential to identify concerns that the general public has about vaccines that the medical and research communities may have neglected.

### Survey Sample

We surveyed members of the RAND American Life Panel (ALP), which is a nationally representative panel of the US population. The ALP enlists individuals through a range of probability-sampling approaches so that the resulting sample represents the US population for race, age, gender, income, education, and region. The average attrition rate from the panel over the past ten years has been 13 percent per year. From the ALP, we invited 716 individuals with children under twenty-one years old to take a survey about vaccine-related beliefs and decisions. We employed no other inclusion/exclusion criteria for participation in the current survey. The ALP has advantages over most other survey platforms, both because it uses probability-based sampling methods and it captures the US population that is not already online (PEW Research Center 2020). Individuals without regular internet access are provided it as part of their participation in the ALP. Because participants are empaneled for multiple years in the ALP, with demographic variables regularly collected on all panelists, we are able to field longer surveys about a specific topic, like vaccines, without using up time collecting demographic information. Full panel recruitment and survey methods are available at https://alpdata.rand.org/.

### Survey Measures

#### Secondary Value Selection

We operationalized secondary value selection by evaluating whether self-reported vaccination decisions were statistically associated with PCA reductions of beliefs (i.e., principal component scores) on a range of topics. We elicited Likert-style disagree-to-agree responses for thirty-five belief items that we developed through our inductive literature review described above. The scale was anchored at 0 = "strongly disagree is true" and 6 = "strongly agree is true," with 3 = "Undecided or not sure." To extract a dimension of belief from these items, we applied scaled and centered principal components analysis (function prcomp in R) and used the scores from the first principal component. We repeated this procedure for three subsets of the beliefs: (1) false conspiracy beliefs, (2) beliefs supported by evidence, and (3) false vaccine side effects. To test robustness and guard against the possibility that the 0–6 scales introduced false precision, we repeated all these PCAs with binarized data that coded belief agreement (4–6) as a 1 and disagreement or unsure (0–3) as a 0. Our use of PCA means we did not adjust the components to have variables load more strongly or weakly on them. This type of adjustment, called "rotation," is common for many implementations of Factor Analysis. Instead, our unrotated PCA attempts to describe variance across all the items on a set of components that load the majority of total variance on the first few components. PCA as we implemented it should be viewed as an exploratory data analysis technique used to describe data. Further validation of the belief structure we find in this study would require new data collected in another sample but with similar questions.

#### Demographics

We included income, education level, race, ethnicity, age, and gender as variables that past research suggested could affect attitudes about

vaccines. The use of a survey panel like the ALP enabled us to include these items without adding to our survey time because these features are collected regularly as part of ALP panel management.

### Network Effects

We tested for network effects by eliciting individuals' social networks and then asking follow-up questions about experiences closely related to vaccination decisions, as similarity in such experiences might indicate the presence of social contagion or homophily processes. We first elicited the social network using a validated approach from social network analysis that asks respondents to name up to ten individuals with whom they have "discussed important matters" in the last six months. Asking up to ten named individuals is sufficient because more than 95 percent of Americans have six or fewer "discuss important matters" relationships (Marsden 1987). The same respondents then reported their perceptions of whether the network connections had experienced specific vaccine-preventable illnesses like measles and polio, whether the connections typically vaccinated their own children, or whether their connections had autism or children with autism.

### Political and Religious Affiliations

We operationalized this hypothesis by asking individuals their religious and political affiliations and by asking the same affiliations of their social ties. The latter was conducted as follow-up questions to the "discuss important matters" relationships. In the same manner as just described for network effects, we asked these questions of the panelists about their perceptions of their social ties. We included these variables as predictors of vaccine hesitancy under the expectation that weaker religious or political affiliations, and more homogenous social networks on these features, would be associated with greater use of vaccine hesitancy as a surrogate for traditional identity groups based on religious denomination or political party. Without affiliation to traditional groups and without diversity in these groups, they might function less well to produce group-membership signaling functions, which suggests they might be replaced by other signals such as anti-vaccine beliefs.

### Trust in Institutions

We elicited conscious trust in institutions by asking eight questions about individuals' levels of trust (0 to 6 scale) in social and media institutions (e.g., local state and federal government, local and national newspapers, social media). We extracted the scores on the first two principal components (68 percent of variance) of these eight questions to make variables for trust in institutions.

### Scientific Reasoning

We used four true/false questions from a previously validated measure of scientific-reasoning ability (Drummond and Fischhoff 2015). Following prior research, we summed the number of correct responses across four items to create a single variable for scientific-reasoning ability.

### Vaccine Hesitancy Behaviors

We categorized parents as vaccine hesitant *in their behavior* if they answered "yes" to any of the following questions: (1) For any of your children, have you ever chosen not to get a vaccine that was recommended by their doctor other than the flu vaccine? (2) Have you ever chosen to delay a vaccine for your child, other than flu vaccine, past when was recommended by their doctor? (3) Do the physicians who treat your children encourage vaccination recommendations that are different from the standard recommendations?

We chose to model an affirmative answer to any of these questions as a binary (0/1) outcome because modeling them as an ordinal or continuous outcome with a simplistic model would enforce an assumption that having affirmative answers to two of the questions statistically constitutes twice as much vaccine hesitancy. This was an assumption we found problematic and were unwilling to make. Another analytic option would be to fully model the transition probabilities among the questions—for example, transition from Q1(0), Q2(0), Q3(1) to Q1(0), Q2(1), Q3(1)—but our sample size would be insufficient to fit such a parameter-rich outcome model. As a further robustness check, we modeled a (0/1) binary outcome for affirmation only that a parent declined a recommended vaccination (question 1).

The full survey instrument and survey data are available on the ALP website (https://www.rand.org/research/data/alp/data-access.html).

## Statistical Analyses

### Predictors of Self-Reported Vaccine Hesitancy Behavior

We modeled vaccine hesitancy as a binary outcome across a set of logistic regression models. We specified six *a priori* models that combined different predictors to cover the social science theories discussed above.

We compared the differently specified regressions using the Bayesian information criterion (BIC), which enabled us to compare the nonnested hypotheses while allowing for multiple predictor variables in each model. Comparison of BIC values has become a common practice in parts of social science and ecology because theories often suggest regression models whose predictors are not nested subsets of each other (Matthews et al. 2011; Mesoudi, Magid, and Hussain 2016; Towner and Luttbeg 2007). BIC allows for direct comparisons of regression models to each other and to a null model (lower BIC is better). Differences in BIC values are interpretable as Bayes factors, which express the ratio of predictive utility of one model over another. Most applications of Bayes factors follow the interpretive scale of relative support originally proposed by R. Kass and Raftery (1995): differences 0–2 weak, 2–6 positive, 6–10 strong, >10 very strong. Simulation

studies have generally validated BIC selection methods across a range of contexts (Brewer, Butler, and Cooksley 2016; Karimov and Matthews 2017).

BIC is derived from a model's likelihood, which is the probability of the observed data given the model. Models with more parameters (e.g., predictors in a regression) always increase likelihood at least a little bit. The BIC deals with this by adding a penalty for each additional parameter. In theory, this might prevent the BIC from preferring parameter-rich models, but in our empirical results below for beliefs as outcomes, we show that the BIC actually preferred one of the most parameter-rich models. This suggests overconservatism by the BIC was not a problem in this particular study.

### Analysis of Belief Structure

We wished to examine the principal component structure of the belief items to ascertain how they might best be described. To test the construct validity of the total data set and belief subsets (false conspiracy beliefs, evidence-supported beliefs, putative side effects), we calculated the unstandardized Cronbach alpha for the total set and all subsets (function alpha in the psych package in R). During this calculation we reverse coded any beliefs that loaded negatively on the first principal component of that subset.

We assessed whether the subsets theorized by prior literature (beliefs in conspiracies or supported by evidence) and generated by our qualitative literature review (false side effects) had Cronbach alphas better than any random subset of the total thirty-five beliefs. To test this, we pulled random combinations for the same number of beliefs as in each subset, calculated Cronbach's alpha, and then compared this null distribution from one thousand random pulls to the observed alpha of the actual belief subsets.

### Predictors of Beliefs as Outcomes

The analysis of belief structure speaks to the internal structure of the thirty-five belief items, which is one aspect of internal validity. Another form of validity is derived by examining the correspondence of the PCA output to other variables not entered into the PCA in the first place. If those variables correspond to the PCA output in theoretically expected ways, then this can be taken to indicate there is some external validity to the PCA output—that is, the output reflects at least something about the external thing in the world it was trying to describe. This form of validity has been called nomological validity in some literature (Nunnally and Bernstein 1994). We assess the nomological validity of the component scores by using them as outcomes in regression models specified in the same manner as for modeling self-reported vaccination decisions.

### Nestedness Analysis of the Belief Scaffold Hypothesis

Finally, we examined whether the patterns in the survey were consistent with a scaffolding process in which beliefs build upon themselves as the bars of a scaffold are arranged to create a vertical structure. To do this, we used the nestedness calculation based on the "Overlap and Decreasing Fill" (NODF) metric drawn from ecology and anthropology (Atmar and Patterson 1993), as well as the "temperature" metric, which is a measure of how much a matrix differs from a perfectly packed matrix with an upper triangular structure. Lower temperatures indicate a more packed matrix. We used the nestedness function from the bipartite package (Formann, Gruber, and Fründ 2008) in R to calculate the temperature (Rodríguez-Gironés and Santamaría 2006). The NODF metric provides an alternative and potentially more robust test of the null hypothesis for matrix packing, and we calculated the NODF test in the ANINHADO software (Almeida-Neto et al. 2008; Guimarães and Guimarães 2006).

We performed all statistical analyses in R version 3.5.0 (The R Foundation 2018; Almeida-Neto et al. 2008), with the exception of the NODF analysis, which we performed in ANINHADO.

## RESULTS

### Induction of Belief Items for Survey

Although anti-vaccine beliefs have existed since the beginning of vaccination programs, we started our systematic review of peer-reviewed literature at 1999 because it covers a substantial length of time and marks the first full year after the publication of the now-retracted 1998 article by Andrew Wakefield that linked the measles, mumps, and rubella (MMR) vaccine to autism. We used results from both the systematic review and the scan of prominent websites to inform the development of a list of vaccine and conspiracy beliefs (Gidengil et al. 2019). We identified and abstracted information from seventy-one articles that included primary data collection using open-ended questions about beliefs related to childhood vaccines that are currently in use in the United States, were published in 1999 or later, and indexed in PubMed, Embase, or PsycINFO.

Our systematic literature review pointed to a potentially prominent role for beliefs in putative vaccine side effects wholly independent from conspiracy, evidentiary, or other health and political beliefs. We therefore included questions in our survey that asked about various side effects mentioned in articles.

Understanding of vaccination science, or misunderstandings, was another theme from our literature review. For example, one belief expressed by parents who chose to vaccinate was that vaccines work by killing viruses in the body (Downs, de Bruin, and Fischhoff 2008). This incorrect belief appears to confuse the action of vaccines with that of antibiotics, but it was associated with parents who did vaccinate, rather than the vaccine hesitant. This suggested understanding of vaccine science may have a relationship to vaccine hesitancy, but potentially one that has no direct concordance with how scientists would intuit that relationship. We therefore included questions that assessed correct and incorrect understandings of vaccine science.

While reviewing prominent websites associated with conspiracy beliefs, we were surprised by the extensive overlap of conspiratorial

and nonconspiratorial views presented. Even websites like Infowars presented verifiably true events that were reported by mainstream journalism alongside demonstrably false conspiracy beliefs. Thus, we included nonconspiratorial views and even those supported by evidence when we saw the potential for them to be associated with conspiracy beliefs in our inductive research process. Examples of such beliefs would be the notion that historic declines in vaccine-preventable illness in developed countries were not caused by vaccines but were caused by other public-health measures. Although we disagree with the policy interpretation given to this belief by anti-vaccine individuals, there is some evidence that supports this idea that has been published in peer-reviewed journals (Greenwood 2014; E. Kass 1971; McKinlay and McKinlay 1977). The belief is in some sense true, and is not itself inherently conspiratorial in nature, but may be consistent with or bolster conspiratorial ideation. Similarly, there is evidence that the immunity acquired by disease exposure is a more effective immunity than that acquired by vaccines (Childrens' Hospital of Philadelphia 2018). Also, HIV likely was spread to some degree by sleeping sickness vaccination programs in Africa during the mid-twentieth century (Carlsen 2001; Gürtler and Eberle 2017). These types of true beliefs, however, are intermixed with conspiratorial interpretations and outright falsehoods in anti-vaccine media.

A final product of the literature review process was a thirty-five-item list of beliefs about political, scientific, and health topics (Table 3). The list included true items (e.g., during the Tuskegee syphilis event, government-funded scientists decided to not treat African Americans for syphilis) and false items (e.g., the belief Barack Obama was not born in the United States).

## Statistical Analyses

### Predictors of Self-Reported Vaccination Behavior

We applied an inclusive three-fold criterion to define vaccine hesitancy behavior as delaying a vaccine, declining a vaccine, or knowingly using a doctor that recommends an alternative vaccination schedule. Using this criterion, 42 percent of parents in the data without incompletes are vaccine hesitant (N = 526), which is consistent with findings from the National Immunization Survey (Hill et al. 2016). Of that 42 percent, 9 percent reported not declining or delaying vaccines but that they used a doctor who followed an alternative vaccine schedule. As a robustness check and for a subset of analyses, we also modeled a more constrained definition for hesitancy as only when the respondent affirmed declining a vaccine ("Constrained Hesitancy" section, below).

We modeled vaccine hesitancy behavior as the outcome in a set of logistic regressions that had combinations of variables as specified by alternative social science theories. To operationalize the secondary value selection theory, we used scores on the first principal component from a PCA of different sets of the belief items: (a) all thirty-five items, (b) only the false vaccine side effects, (c) only the false conspiracy beliefs unrelated to vaccines, and (d) only the items supported by evidence. In addition, and as described above, we considered operationalizations that use the original response scale, as well as one binarized for disagreement/agreement. We found that all versions of the belief PCA scores were more associated with vaccine hesitancy that were the other models from other social science theories (Table 1). However specified, regressions that used belief data all were better than a null model; none of the other regressions outperformed the null.

By examining the loadings of individual survey items on the PC1 scores, we can calculate that the estimated odds ratio for the PC1 belief score (1.2) means that every additional two beliefs that go from a full disagree (0) to an agreement of 5 on the 6-point scale raises the probability of a parent not vaccinating their children by 20 percent (16 percent for the more constrained definition of vaccine hesitancy). Alternatively, one could state that a 1-point increase in agreement across ten beliefs results in the same 20 percent increase in the probability of not vaccinating.

Among the beliefs sets, the scores most closely associated with vaccine hesitancy behaviors were those from vaccine side effects, followed by scores from evidence-supported beliefs and then by the conspiracy beliefs. Differences from null model BIC were all strong or very strong (R. Kass and Raftery 1995). Comparisons of BIC from binarized belief data were qualitatively the same (S1).

Clearly, the finding that beliefs are associated with vaccine hesitancy could arise by reverse causation, such that individuals make a vaccination decision and then adopt a corresponding set of beliefs. This is one plausible explanation for why beliefs in vaccine side effects are more related to vaccine hesitancy than are the other types of beliefs. The notion that the entire association of beliefs with vaccine hesitancy is reverse causation is mitigated, however, by the diversity of beliefs that spans political conspiracies in addition to various health beliefs. Notably, the scores from the PCA of false conspiracy beliefs that specifically did not involve vaccination still predicted vaccine hesitancy better than the null model and better than all alternative social science theories. This does not mean conspiracy ideation is the best description of the data variance, but it does suggest reverse causation does not fully account for the findings (e.g., it feels implausible that individuals' decisions not to vaccinate their children induce them to believe the moon landings were faked or that Barack Obama was not born in the United States).

At this point, some researchers would perform a mediation analysis to assess how much the putative effects of some predictors on vaccine hesitancy behaviors, like demographics, are mediated by beliefs as an intermediary. Closely related analysis could involve path analysis or structural equation modeling (SEM). We somewhat disagree with the use of mediation and SEM in wholly observational data, which has become commonplace in some disciplines like economics, because ultimately the quantitative results are driven by (usually untested) qualitative decisions about what variables would be presumed to mediate others. For example, rather than demographic effects being mediated by beliefs, perhaps belief effects are mediated by demographics? The original formulation of mediation analysis was in experimental contexts in which some variables could be held constant to ensure a mediation effect could be estimated with some certainty.

**TABLE 1** BIC Comparisons of Logistic Regressions Specified by Social Science Theories to Predict Vaccination Behavior

| Regression Model Name | Theoretical Basis | Predictor Variables | BIC Hesitancy | BIC Constrained Hesitancy |
|---|---|---|---|---|
| Null | | Intercept only | 723 | 574 |
| Secondary Value Selection, general | Adoption of some beliefs alters the probability that other beliefs and behaviors area adopted | PC1 from 35 inductively determined belief items | 683 | 554 |
| Secondary Value Selection, false conspiracy beliefs | | PC1 from 11 false conspiracy beliefs not about vaccines | 713 | |
| Secondary Value Selection, false side effects | | PC1 from 8 false vaccine side effects | 669 | |
| Secondary Value Selection, evidence-supported beliefs | | PC1 from 10 beliefs supported by evidence | 679 | |
| Demographics | Vaccination beliefs and behaviors vary by demographics | Race (*white (reference), Black, Am. Indian or AK Native, Asian or Pac. Isl., Other*); Hispanic (*Y/N*); Education (*Less than high school (reference), High school, Associate's degree, Bachelor's degree, Professional degree or doctorate*), gender (*M/F*), age, education, income at 10k increments up to 100k, income over 100k | 777 | 644 |
| Network Effects | Personal and social exposures interact with belief formation | Number social ties; Number of ties w/ experience vaccine-preventable illness; Self experience w/ vaccine-preventable illness; Number of ties with autism; Number of ties with children; Number of ties with autistic children; Number of ties not vaccinate children for flu; Number of ties delay or decline childhood vaccines other than flu | 750 | 597 |
| Political and Religious Affiliations | Beliefs are an alternative mechanism for identity groups | Number of social ties, Number of ties with a different religion; Number of ties with a different political party; Self religion (*Catholic (reference), Mainline Protestant; Evangelical/Pentecostal; Christian unspecified or nondenominational, Mormon, Jehovah's Witness/Adventist, Jewish, Muslim, Hindu/Buddhist/Other, None/don't know, Agnostic/Atheist*); Self Political Party (*Republican (reference), Democrat, Independent, Other*) | 801 | 643 |
| Institutional Trust | Beliefs reflect an attitude of trust or distrust toward societal institutions (government, organized religion, journalism) | Two principal components from 8 institutional trust items; religious service attendance (*Never (reference), A few times year/not sure, 1–3 times a month, Every/nearly every week, More than weekly*); Voted in 2016 election (*Y/N*) | 750 | 595 |
| Scientific Reasoning | Beliefs reflect individuals' capacity to reason scientifically | Scientific reasoning scale (scored 1–4) based on number of correct answers to published True/False science reasoning questions | 724 | 579 |

N = 526, BIC should be compared down columns for the same outcome (not across rows)

An alternative to mediation analysis that we think is more appropriate to observational data is a stepwise regression that allows patterns in the data to ascertain which variables have the strongest effects versus which appear mediated by others; the latter are dropped from the final model because their mediators account for them. Note, path analysis, or SEM that makes no qualitative assumptions about which variables should be included or which causal paths shut off, will converge on stepwise regression results for the main predictors.

Results from stepwise regressions must be taken with caution because they are prone to findings of false significance, but they have the advantages of removing any constraints on how we, the researchers, bucketed variables together, and they avoid the

**TABLE 2** Results from Backward-Forward Search for Predictors of Vaccine Hesitancy Behavior

| Predictor Variable | Odds Ratio |
|---|---|
| Beliefs PC1 | 1.20*** |
| Female parent respondent | 1.67** |
| Voted in 2016 | 2.08** |
| Number of social ties delay or decline childhood vaccines other than flu | 1.40* |

***p < 0.001, **p < 0.01, *p < 0.05, N = 526.

researcher assumptions inherent to mediation analyses of observational data.

The results from a backward-forward stepwise regression fitted across all the variables still incorporated beliefs as among the most important predictors of vaccine hesitancy behavior, and with the same estimated odds ratio (Table 2, performed in the MASS package in R) (Venables and Ripley 2002).

## Analysis of Belief Structure

The strong association of beliefs with vaccine hesitancy motivates understanding the internal structure of the beliefs measured and how they relate to other variables external to them. The strong association is consistent with some degree of secondary value selection occurring in parents' decisions to vaccinate their children. We present only analysis of the 0–6 Likert responses, as the results above using binarized data were qualitatively similar while appearing to suffer from the loss of information due to the binarization.

From the PCA of all thirty-five beliefs, we found that the first principal component (PC1) captured 35 percent of the original variation. This component dwarfed the variation described by the next largest components (PC2 = 8 percent, PC3 = 6 percent). Most standard approaches to PCA would therefore only analyze the first principal component due to the quite substantial drop-off in variation described by the other PCs in this analysis (Jolliffe 2002). Loadings for the PCAs of the theorized variable subsets considered separately (false conspiracy beliefs, false vaccine side effects, evidence-supported beliefs) are higher than when the beliefs are considered together but in the same direction (Table 3).

Cronbach's alpha for the total set of thirty-five beliefs is high (0.94) and is reduced for each of the variable subsets (false conspiracy beliefs alpha = 0.87, false side effects alpha = 0.88, beliefs supported by evidence alpha = 0.75). There are no exact standards for an acceptable Cronbach's alpha, but researchers suggest alpha basic research should exceed 0.8 and for applied research exceed 0.9 (Lance et al. 2006). Because Cronbach's alpha can be higher as more items are included in a scale, we conducted a comparison to randomly picked variable combinations, each with the same number of items as the theorized constructs. The false conspiracy belief and false vaccine side effect variable sets had higher than chance Cronbach alphas (exceeding 96 percent and 99 percent of null alphas, respectively), but the supported by evidence variable set had a lower Cronbach alpha than did randomly selected variable subsets (it was less than 96 percent of null alphas).

## Predictors of Beliefs as Outcomes

We assessed the nomologic validity of the belief scores from the overall PCA by modeling them as outcomes in a linear regression. First, it is important to note that, upon inspection of loadings, higher scores on the overall PC1 are associated with endorsing beliefs that are anti-establishment and/or not supported by evidence, while lower values are associated with endorsing beliefs that are pro-establishment and/or supported by evidence. Higher scores on the false conspiracy belief PC1 are associated with greater endorsement of conspiracy beliefs. Likewise, higher scores on the false vaccine side effects PC1 are associated with more endorsement of vaccine side effects. The PC1 from supported by evidence beliefs is less straightforward. Even though all the beliefs are supported by at least some evidence, they load variably on their first PC, and in a manner consistent with a pro- versus anti-establishment pattern but inconsistent with individuals evaluating evidence.

Given these observations, nomologic validity would be established if individuals have higher PC scores who are discriminated against or not treated fairly by establishment features of American society. We might logically expect such individuals (e.g., racial minorities, low-socioeconomic-status individuals) to endorse these ideas because they accord with at least some of their very real experiences of American society. We might also expect the measures of institutional trust to correlate negatively with the beliefs PCs under the interpretation that they reflect anti-establishment thinking.

The results in Table 4 show that the regression with demographic variables was the best predictor for beliefs, even though demographics were not strongly predictive of vaccine hesitancy behavior. Demographics outperforms the next best model by a Bayes factor of 73 (2951–2878 = 73, very strong support). As expected by the idea that individuals who actually are treated less well in American society would endorse more conspiratorial or anti-establishment views, minority status, lower education, and lower income all significantly predicted higher scores on PC1 for beliefs (Figure 1).

Although reverse causation can be a concern for cross-sectional studies, it seems more likely that differential experiences of demographic groups induce people to adopt beliefs that explain their experiences of high or low socioeconomic status, since income and especially race are less plausibly influenced by adopted beliefs.

The scientific reasoning regression, while inferior to demographic variables, was the next best-fitting model (Table 4). This suggests nomologically that the beliefs may reflect a relationship of reasoning ability to the interpretation of evidence. This result is surprising given that the internal validity test (Cronbach's alpha) suggested beliefs that were supported by evidence were among the least coherent belief subsets. Closer examination, however, suggests that the relationship of beliefs to scientific reasoning is not due to the role of scientific reasoning in evaluation of evidence. The data include six beliefs that are

**TABLE 3** Loadings for Beliefs on First Principal Component of Overall PCA and Belief Subset PCAs

| | | PC1 Loadings for Variable Subsets | | | |
|---|---|---|---|---|---|
| Short Description* | Percent Agree | All Variables (35% variance) | False Conspiracy Beliefs without Vaccine Element (47% variance) | False Vaccine Side Effects (56% variance) | Beliefs Supported by Evidence (34% variance) |
| | *False Conspiracy Beliefs without Vaccine Element* | | | | |
| JFK Assassination | 37 | 0.16 | 0.29 | | |
| Moon Landing Faked | 10 | 0.19 | 0.27 | | |
| Masons Secret Control | 15 | 0.19 | 0.32 | | |
| 9/11 Inside Job | 17 | 0.19 | 0.36 | | |
| 2016 Votes Manipulated | 34 | 0.11 | 0.23 | | |
| Deep State | 23 | 0.19 | 0.33 | | |
| Birtherism | 19 | 0.12 | 0.2 | | |
| Immigration Plot | 9 | 0.13 | 0.22 | | |
| CIA Created HIV | 10 | 0.2 | 0.36 | | |
| Chemtrails | 9 | 0.21 | 0.36 | | |
| Pharma Tests Africa | 12 | 0.17 | 0.31 | | |
| | *Beliefs Supported by Evidence* | | | | |
| Vaccine Spread HIV Africa | 10 | 0.2 | | | 0.33 |
| CIA Bin Laden Vaccination | 11 | 0.14 | | | 0.2 |
| Tuskegee Syphilis | 29 | 0.07 | | | 0.05 |
| Vaccines Benefit Public | 78 | −0.13 | | | −0.42 |
| Drs Serve Best Interest | 73 | −0.14 | | | −0.41 |
| Guillain-Barré | 12 | 0.16 | | | 0.26 |
| Vaccines Build Immunity | 77 | −0.09 | | | −0.33 |
| Vaccines Net Benefit | 68 | −0.13 | | | −0.41 |
| Natural Immunity | 25 | 0.14 | | | 0.24 |
| Vaccines Insignificant | 15 | 0.17 | | | 0.32 |
| | *False Vaccine Side Effects* | | | | |
| HPV Vacc Causes Sterility | 13 | 0.13 | | 0.28 | |
| HPV Vacc Causes Promiscuity | 9 | 0.15 | | 0.25 | |
| Flu Vaccine Causes Flu | 43 | 0.13 | | 0.25 | |
| MMR Autism | 14 | 0.21 | | 0.41 | |
| Vaccines Cause SIDS | 10 | 0.21 | | 0.42 | |
| Vaccine Overload | 28 | 0.18 | | 0.37 | |
| Vaccines Cause Asthma | 18 | 0.21 | | 0.39 | |
| Vaccines Cause ADHD | 15 | 0.22 | | 0.41 | |
| | *Other* | | | | |
| CDC Hides Side Effects | 26 | 0.22 | | | |
| Vaccines Created to Sterilize | 16 | 0.19 | | | |
| Vaccine Profit Motive | 18 | 0.22 | | | |
| Drs Hide Side Effects | 33 | 0.2 | | | |
| Vaccines Kill Viruses | 26 | 0.1 | | | |
| Vaccines Stop Working | 12 | 0.16 | | | |

N = 615

*Full question text shown in S2.

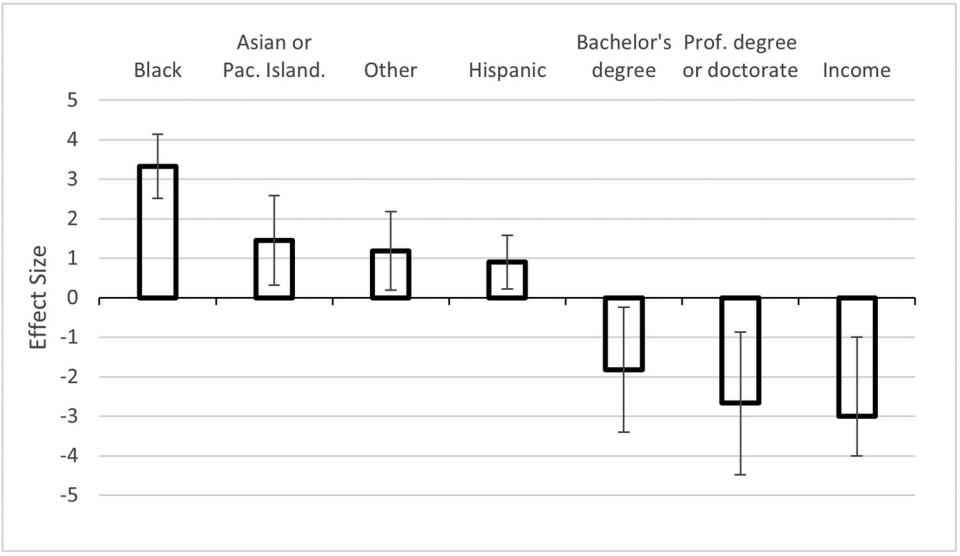


**FIGURE 1** Statistically significant demographic predictors of anti-establishment views. Note: Effect sizes are coefficients from linear regression with PC1 scores as the outcome. Error bars show 95 percent confidence intervals

**TABLE 4** Comparison of a Priori Regression Models to Explain Scores on PC1 from All Variables

| Regression Model Name | BIC |
|---|---|
| Null | 3018 |
| Demographics | 2878 |
| Network effects | 3040 |
| Political and Religious Affiliations | 3037 |
| Institutional Trust | 3004 |
| Scientific Reasoning | 2951 |

N = 564. Lower BIC values indicate better model fit. All models included some variables with $p < 0.05$ and $p < 0.01$ (S3).

anti-establishment but supported by evidence—for example, that the CIA conducted a fake vaccination program to find relatives of Osama bin Laden or that vaccines can cause Guillain-Barré syndrome (S4). On average, greater scientific reasoning is associated with *disbelief* of these beliefs despite their being supported by empirical evidence (ave. r = -0.13, p = 0.03, N = 6, one sample t-test). Greater scientific reasoning was associated with greater *disbelief* of true events that involved conspiracies (CIA fake vaccination) even though this event was widely reported, including in the journal *Nature* and by the BBC (S4). Scientific reasoning is associated with *disbelief* of nonconspiratorial events that logically would lead to distrust of the establishment (e.g., HIV spread in Africa by vaccination programs, other public-health measures besides vaccines causes declines in vaccine-preventable illness) and *disbelief* of actual vaccine sides effects like Guillain-Barré. It is difficult to explain these findings as simply lack of awareness. Given these findings, the pro-establishment end of PC1 appears also to describe a tendency toward a *credulous scientism* that contrasts with critical scientific thinking. By "credulous scientism," we mean a tendency to endorse pro-science views when one actually does not know the evidence base or chooses to ignore it.

Of these six beliefs supported by evidence, only belief in the Tuskegee syphilis event correlates positively with scientific reasoning. This correlation likely arises because the history of the Tuskegee syphilis event is a standard part of many scientific curricula that also teaches people to reason scientifically, meaning that individuals who learned to reason scientifically simultaneously learned the veracity of this particular event.

## Nestedness Analysis of the Belief Scaffold Hypothesis

We employed an analysis of the individual by belief matrix, using two measures indicative of how much a matrix can be "packed" into an upper triangular matrix indicative of a belief scaffold compared to a variety of null assumptions. The observed level of packing was significant ($p<0.001$) under any of the several specifications for null models used for this metric (see Methods). The five beliefs lowest down in the nesting structure (i.e., at the bottom of the scaffold and supporting the other beliefs) are: Vaccines Kill Viruses, Flu Vaccine Causes Flu, 2016 Votes Manipulated, JFK Assassination, Tuskegee Syphilis. The scaffolding theory for culture would interpret these as precursors to beliefs higher in the scaffold. The five beliefs highest in the nesting structure (i.e., supported by other beliefs) are: Vaccines Cause SIDS, HIV Spread Vaccine Africa, CIA created HIV, Chemtrails, Immigration Plot (full nesting shown in Supplement).

## DISCUSSION

We used an inductive approach to generate thirty-five survey items from past responses to open-ended questions about vaccination.

Principal component scores based on these items were significantly associated with self-reported vaccine hesitancy behaviors, which is consistent with the idea that the adoption of some beliefs/behaviors increases the probability of adopting others. None of our measurements operationalizing alternative social science theories improved upon a null model for predicting vaccine hesitancy behavior.

The internal structure of the thirty-five-beliefs load on a single principal component accounting for just over a third of the variation. The internal structure of beliefs may reflect a pro- versus anti-establishment disposition under the interpretation that the belief covariation reflects a coherent cognitive tendency. We found some nomologic validity for this notion because individuals who are less well represented by the establishment, and at times victims of establishment prejudices, have higher scores on the overall PC1. Scientific reasoning reduced PC1 scores, but this was not driven by those with higher scientific reasoning necessarily being more likely to endorse true items. High scientific reasoners were less likely to endorse items that were supported by evidence but also ran counter to positive views of establishment entities, such as the government, scientists, and doctors.

We offer two interpretations of our findings that we cannot discriminate between fully at this time. One interpretation of the results would be that the PC1 scores on the thirty-five beliefs reflect an underlying cognitive disposition toward anti-establishment thinking, and that this disposition is associated with vaccine hesitancy. This interpretation is consistent with prior sociocultural research on vaccinations that have suggested conspiracy beliefs or health beliefs are just particular manifestations of an overall stance by parents toward establishment features of US society like scientists, public-health authorities, and the government (Brunson 2013; Brunson and Sobo 2017; Sobo 2015). In contrast to this prior research, however, we find no evidence for a hyper-multi-dimensional "jaggedness" to this belief structure; rather, roughly a third of the variation in these pro- versus anti-establishment beliefs is arrayed along a single axis of variation, and the low variance on the other axes suggests these may just be random noise rather than signal.

We also offer another interpretation of PC1 that we believe is unprecedented in either the psychology or sociocultural anthropology literature on vaccination. This interpretation is that there is no attitude or gist of "anti-establishment-ness" that underlies PC1; instead, all that exists are the individual beliefs, but these are interlinked in a mutually supportive way. This interpretation derives from the scaffolding model for cultural learning, whereby culture is conceived as a multitude of individually learned cognitive items that are interlinked, just as the individual bars of a scaffold are interlinked to create a vertical structure. Ultimately, the vertical support of a physical scaffold arises merely from the interlinkages among the bars; there exists no hidden dark matter of "scaffold-ness" supporting it. We found some support for this belief scaffold interpretation in that the beliefs are hierarchically nested much more than expected under any of several null models. This suggests a scaffolding process in which some beliefs sit at the bottom of the scaffold and become precursors for beliefs layered on top of them.

Assuming that an underlying "anti-establishment-ness" accounts for PC1 implies radically different communication policies toward vaccination than does the scaffold interpretation. Under the anti-establishment-ness interpretation, effective messages would validate the anti-establishment disposition while simultaneously endorsing vaccines. Physician spokespersons likely could be found who are anti-establishment in aspects of their lives other than their medical practice.

The scaffolding interpretation predicts that these types of anti-establishment-validating messages will be ineffective because in the minds of people there is no hidden anti-establishment-ness to validate. Instead, there are only individual beliefs interlinked in their minds. The scaffolding interpretation suggests messages should address individual belief items near the bottom of the scaffold—that is, those that are lower down in the belief hierarchy and thus more supportive of the overall belief structure. The nestedness analysis points to specific beliefs to be addressed, which cut across scientific understandings of vaccination and political or health conspiracy beliefs.

Addressing these beliefs during communication about childhood vaccination need not mean refuting them in all cases. Some might be usefully refuted as they may reflect simple misunderstandings of vaccine science: vaccines do not work by killing viruses (antibiotics work this way), and although the flu vaccine may cause some mild flu symptoms, it is a dead virus and so cannot give anyone the flu. Some other beliefs should be acknowledged, and not refuted in the least in vaccine messaging. The Tuskegee syphilis event is an example of an actual health conspiracy perpetrated against African Americans. Acknowledging specific true conspiracies like Tuskegee may be an important component of pro-vaccine messaging.

This research was conducted before the COVID-19 pandemic, and we therefore do not have any direct measures for COVID-19 vaccine hesitancy. We note, however, that many of our results may generalize to the current situation for COVID-19 vaccination in the United States, which is far too low (64 percent of total population fully vaccinated and 74 percent of 18+ ages as of January 31, 2022) to stop the spread of the infection. The observed slowing of new adult vaccination that occurred at 50 percent adult vaccination (Centers for Disease Control and Prevention 2021a) is similar to the ~50 percent vaccination rate the United States generally achieved for adult seasonal flu vaccination (Centers for Disease Control and Prevention 2021b). This similar pattern in the context of the dramatically publicized risks of COVID-19 infection underscores our findings that assessment of scientific evidence, or even plainer indicators of actual disease risk (e.g., freezer trucks rolling up to hospitals), may play little role in vaccination decisions. Instead, vaccination decisions are made based on socially learned beliefs that are tied up in an individual's experiences of whether society is on their side (indexed in our study by race, education, income). In this study, we did not measure access to health care because, specifically for children in the United States, this access, although not without disparities, generally is excellent and equitably available. For example, Hispanic Americans have higher childhood vaccination rates than do non-Hispanic white Americans, while Black Americans are usually within 0–4 percentage points of the childhood vaccination rate for white Americans, depending on the vaccine (Hill et al. 2018, 2020;

Kulkarni et al. 2021). Education and income variation, mostly among white Americans, are more substantial drivers of low vaccination for childhood vaccines than is race/ethnicity (Kulkarni et al. 2021). In short, when the American health-care system has provided good access, as is the case of childhood vaccinations, minority groups show similar vaccination rates to white Americans, or even higher in some cases.

We would suggest, therefore, that disparities in access to health care might largely account for the Black/white racial disparity in adult vaccination for seasonal flu of 12 percentage points and the disparity for COVID-19 of 10 percentage points (Centers for Disease Control and Prevention 2021a, 2021b; Melillo 2021). Also, while these are substantial disparities, they are much less than the overall problem that roughly half the adult population (of any race) does not get vaccinated for flu. We suggest that the problem of the United States having a far too low overall flu and COVID-19 vaccination rate likely is driven by socially learned beliefs similar to the ones we included in this study, although disparities in vaccination may largely arise from disparities in health-care access.

In conclusion, by taking a systematic and inductive approach to belief measurement, we found support for prior sociocultural research that the beliefs surrounding vaccination crisscross topically focused categories like conspiracy ideation, health side effects, and scientific understanding. Our results, however, fail to support substantial multidimensional "jaggedness" of the arrangement of beliefs. Instead, about a third of variation in the items correlates with a single dimension of covariation, and other dimensions look less substantial. The nestedness analysis further suggests the belief dimension may be usefully viewed as a scaffold of individual beliefs that are interlinked into a supportive structure. Vaccination communications could consider engaging the key beliefs that are most supportive of the overall belief scaffold.

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