



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 hesitance behavior, demographics were key predictors of beliefs. Our findings suggest pro-vaccination messaging strategies previously proposed by anthropologists and others not previously considered.

INTRODUCTION

Parental hesitance to vaccinate their children is a major concern for public health. Vaccine hesitancy occurs internationally (Larson et al. 2016), including the US, where some communities exhibit less than the 95% compliance with the evidence-based schedule for vaccinations that is needed to maintain herd immunity. Here 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). Nationally in the US, more than 27% of children under 35 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 root origins of vaccine hesitancy. Does it arise from

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2²⁸ understandings/misunderstandings of science, from dis/trust of the medical establishment or
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4²⁹ government, historically rooted experiences of oppression, outright viral misinformation? It is
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6³⁰ easy, absent considering empirical data, to postulate many such seemingly plausible single-cause
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8³¹ explanations.
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11³² From a research process standpoint, these null and backfire findings suggest the public
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13³³ health community may have moved too quickly to experimental techniques that can establish
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16³⁴ causal inference without observational research needed to induce (rather than deduce) data-driven
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18³⁵ hypotheses about how beliefs and experiences surround vaccination behaviors. Perspectives from
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20³⁶ social science might help inform vaccination policy by bringing stronger theory and/or broader
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23³⁷ empirical findings from studies that focus on observational rather than experimental research
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25³⁸ methods. Findings from these studies, however, vary dramatically by academic discipline.
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28³⁹ Upon reviewing the social science literature on vaccine hesitance, it becomes clear that
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30⁴⁰ although socio-cultural anthropology and psychology have both investigated the phenomenon,
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32⁴¹ they have arrived at radically different explanations for it. Anthropological studies have
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35⁴² emphasized multiple dimensions of parental concerns, understandings, and confidences that
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37⁴³ encompass relative trust and distrust of medical systems, sources of information, and parent's
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39⁴⁴ tendencies to accept social norms. In a manner typical of anthropologists, these studies have
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42⁴⁵ employed diverse and mostly qualitative methods tailored to each study context (Leach and
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44⁴⁶ Fairhead 2007; Brunson 2013; Soby 2015; Brunson and Sobo 2017). In contrast, multiple
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46⁴⁷ observational studies from psychological research have employed standardized survey
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49⁴⁸ instruments to find that decisions about vaccination are determined by individuals' positions on
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51⁴⁹ two unidimensional and inter-related scales: rejection of scientific consensus (e.g. rejection of
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53⁵⁰ evolution, global warming, etc.) and conspiracy ideation (e.g. moon landing faked, CDC hides
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55⁵¹ vaccine side effects) (Healy and Pickering 2011; Jarrett et al. 2015; Teoh et al. 2019; Nyhan et al.
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2⁵² 2014; Oliver and Wood 2014; Jolley and Douglas 2014; Lewandowsky, Gignac, and Oberauer
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4⁵³ 2013).

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7⁵⁴ This leads to a focus of our study, which was to bring anthropological theory to bear in a
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9⁵⁵ nationally representative survey study. While many anthropologists may hold such quantitative
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13⁵⁶ techniques suspect, much of American governmental policy is guided by quantitative analysis.
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18⁵⁷ We think anthropological theories can improve these quantitative analyses, but that without some
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23⁵⁸ effort at quantification, full policy impacts for anthropological praxis are unlikely (Roberts 2021).
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Prior Research

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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 non-vaccination arose from deficits of scientific understanding, trust in doctors, or other rational thought process. They noted the following:

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. p. 4

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2 76 Anthropological studies in the United States similarly have emphasized multiple dimensions
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4 77 of parental concerns, understandings, and confidences that encompass relative trust and distrust of
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6 78 medical systems, sources of information, and parent's tendencies to accept social norms. In a
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8 79 study of 15 mothers and 3 couples in Washington state, Brunson (2013) described parental
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10 vaccination decisions as arising from three general approaches to processing vaccine information.
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12 These approaches included acceptors who follow general social norms, reliers who accept advice
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14 from people they know, and searchers who seek out published expert information. Brunson
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16 (2013) suggested vaccination decisions arise from these alternative modes of interrogating
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18 information, and given this, that public health messages need to be tailored to each of these
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20 modes.
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25 Sobo (2015) observed somewhat different aspects of the processes surrounding
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27 vaccination decisions in a study of 36 parents of students at a Waldorf school in the US. Sobo
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29 (2015) identified how the Waldorfian anti-vaccination stance arose from mutually reinforcing
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31 local social relationships.
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34 *According to these findings, the anti-vaccination stereotype becomes increasingly accurate as*
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36 *the duration of a family's enrollment increases and the number of one's enrolled children*
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38 *grows—and as the number of people in one's people network who disfavor vaccination*
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40 *expands (see). This increased frequency of vaccine refusal, and the equation between non-*
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42 *vaccination, the independence of mind that it is taken to signify, and Waldorfian identity make*
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44 *it harder and harder to contravene the norm without threatening one's sense of group*
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46 *membership...*
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50 The process Sobo (2015) describes is consistent both with Brunson (2013) notion of
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52 "reliers" but also with a broader set of cultural theory that has hypothesized beliefs and rituals
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54 with little immediate utilitarian consequence are central to signaling membership within a social
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56 group. Religious belief and ritual have been a focal examples of this process. The beliefs and
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1 rituals are useful indexes of group identity because their proper expression can be learned only
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4 through social participation within the group (Matthews 2012; Bulbulia 2012). Because religious
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6 or other non-evidentiary beliefs can be learned only through interaction with the social group,
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8 humans quite sensibly attend to these beliefs as valid indexes of group belonging by feeling
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10 bonded to others who express the same traits, a process known in network science as homophily.
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13 These studies from socio-cultural anthropology raise compelling hypotheses that
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15 vaccination beliefs and behaviors could arise from multiple dimensions and even “jagged” edges
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17 formed by social interactions and beliefs that cocreate each other (Brunson and Sobo 2017).
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19 Their small sample sizes, however, beg the question as to whether these are general enough
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21 findings to inform vaccination policy in the US. Although Waldorf schools have a demonstrably
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23 higher rate of personal belief exemptions to vaccines than do public schools (Sobo 2015), because
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25 Waldorf schools encompass a small percentage of American students they cannot possibly
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27 account for most non-vaccination (National Center for Education Statistics 2020). Concomitantly,
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29 it is unclear whether the social and belief mechanisms among the Waldorf community have a
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31 strong correspondence to these processes among the majority of American parents.
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37 In contrast to the perspective of sociocultural anthropology just discussed, multiple
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39 observational studies from psychological research have suggested decisions about vaccination are
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41 determined by individuals’ positions on two unidimensional and inter-related scales: rejection of
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43 scientific consensus (e.g. rejection of evolution, global warming, etc.) and conspiracy ideation
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45 (e.g. moon landing faked, CDC hides vaccine side effects) (Healy and Pickering 2011; Jarrett et
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47 al. 2015; Teoh et al. 2019; Nyhan et al. 2014; Oliver and Wood 2014; Jolley and Douglas 2014;
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49 Lewandowsky, Gignac, and Oberauer 2013). Conspiracy beliefs figure prominently in these
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51 psychological explanations for anti-vaccination beliefs and behavior, and most have examined
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53 only false conspiracy beliefs. They did not include in their surveys beliefs in conspiracies that are
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55 true such as the Tuskegee Syphilis event or the CIA’s use of a fake vaccination campaign to find
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2 26 Osama bin Laden. Consistent with the “deficit model” described by Leach and Fairhead (2007),
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4 27 much psychological research implicitly assumes that false and true beliefs about conspiracies rely
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6 28 on distinct cognitive processes in the minds of individuals, but in this paper we consider that true
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8 29 and false conspiracy beliefs may instead rely on processes common to both. Throughout this
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11 30 paper we refer to conspiracy beliefs to mean mental representations (i.e. beliefs) with conspiracy
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13 31 content. We do not use conspiracy theories because this phrase implies the beliefs are false. We
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15 32 do not prejudge false or true conspiracy beliefs to be distinct ontological categories (Grimes
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17 33 2016), and instead sought to let the data determine how beliefs, both true and false, were
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20 34 interconnected (or not).

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23 35 We also note that we use the term “beliefs” in its somewhat technical philosophical sense
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25 36 of cognitions that are mental representations of some reality external to the believer. Beliefs,
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27 37 defined in this manner, could be true or false (i.e. correspond to external reality or not). As a
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29 38 separate matter from truth, beliefs could be well-justified or poorly-justified (i.e. have good
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31 39 reasons/evidence that support them or not) (Moser, Mulder, and Trout 1998). When describing
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33 40 and discussing beliefs, we are making no judgements as to their truth or justification. We are
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35 41 interested in them because people have them, and potentially they are a very important form of
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37 42 culture (socially learned information) that influences policy-relevant decisions (like getting
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39 43 vaccinated).

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42 44 The contrasting conclusions of socio-cultural anthropology and psychology are striking.
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44 45 They have arrived at radically different explanatory systems for ostensibly the same object of
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46 46 study. Many anthropologists see vaccination decisions as arising from a multidimensional jagged
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48 47 interface of social relationships, beliefs, and societal norms, while many psychologists see
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50 48 individuals as arrayed along a relatively unidimensional scale from evidence-based scientific
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52 49 understanding on one end to (*false*) conspiracy ideation on the other. These different explanations
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2 150 for vaccine hesitancy imply very different means for engagement with the public to promote safe
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4 151 and effective vaccines.
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7 152 We sought to investigate these alternative explanatory visions by incorporating aspects of
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9 153 both into a single study with sampling and measurement methods that could discern between
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11 154 them. Consistent with the anthropological tradition, we constructed survey items not through
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13 155 deduction from theorized mental mechanisms but from an inductive approach that begins with
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15 156 qualitative research on what people generally say about vaccines. Consistent with this approach,
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17 157 we analyzed the data with principal component analysis (PCA), an exploratory analysis technique
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19 158 for summarizing variation, rather than factor analysis which is generally employed in psychology
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21 159 to focus on confirming or disconfirming theorized scales. Consistent with psychometric studies,
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23 160 however, we employed reasonably large and nationally representative sampling, and quantified
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25 161 variation such that we then could statistically examine whether the resulting covariations among
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27 162 beliefs and behaviors were multi- or uni-dimensional, and whether they were strongly related to
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29 163 conspiratorial views or evidence.
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35 164 To achieve these ends, we divided the study into two research questions. One that
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37 165 examined self-reported vaccination *behavior* as the outcome in the regressions, and one that
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39 166 examined self-reported *beliefs* as the outcome in the regressions.
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42 167 **Research question 1.** How is covariation across multiple beliefs related to self-reported
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44 168 vaccination behavior? We applied principal components analysis to summarize covariation across
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46 169 multiple beliefs in the survey belief items and then tested whether the main axis of variation was
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48 170 predictive of vaccination behavior. We tested the predictive efficacy of beliefs against other
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50 171 predictors including demographics, network effects, an attitudinal trust toward governments and
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52 172 media.
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55 173 **Research Question 2.** What is the best way to describe and conceptualize covariation
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57 174 across multiple beliefs? We characterized the principal component structure of the beliefs and
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2 175 tested the wholly inductive analysis of this structure against several constructs theorized by prior
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4 176 literature. We then examined which non-belief variables (e.g. demographics, social networks,
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6 177 attitudes) were most closely associated with PCA belief scores.
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8 9 178 10 11 179 **SOCIAL SCIENCE THEORIES FOR BEHAVIOR**

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13 180 Here we briefly summarize the prior social science theory that we operationalized in our survey.
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15 16 181 17 18 182 *Secondary Bias*

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20 183 Several research traditions from anthropology propose that learned cultural notions
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22 184 influence individuals' subsequently adopted beliefs and behaviors. (Durham 1991) expressed this
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24 185 concept as "secondary bias," defined as any process by which one socially-learned belief or
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26 186 behavior altered the probability of other beliefs and behaviors being learned. Evolutionary
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28 187 anthropology similarly hypothesized "cumulative culture" to undergird much human behavior
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30 188 (Dean et al. 2014). Cumulative culture is similar to secondary bias but with the added stipulation
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32 189 that the cultural process results in an evolutionary ratcheting of complexity and adaptiveness
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34 190 (Kamilar and Atkinson 2014). Another related concept is behavioral scaffolding, whereby social
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36 191 learning creates cultural complexes among individually learned items that build in a particular
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38 192 direction (Caporael et al. 2013).
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45 194 *Demographics*

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47 195 Prior research has supported that conspiracy beliefs are more common among groups who
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49 196 experience lower social status in a society and may have been victims of actual conspiracies. This
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51 197 could occur from people attending to status as a feature in itself or from quite rational calculation
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53 198 that their material risks and benefits differ due to their demographic affiliations whether from
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55 199 status or other processes (Uscinski and Parent 2014). In one specific example, Westergaard et al.
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200 (2014) observed that African Americans were simultaneously more willing to take a hypothetical
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401 HIV vaccine but also were more likely to believe in health conspiracies about HIV. Both
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602 observations are quite reasonable reactions since African Americans suffer disproportionately
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803 from HIV as compared to Whites, and African Americans have been victims of actual health
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1004 conspiracies by medical-governmental systems (e.g. Tuskegee syphilis event). Thus, for a variety
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1305 or reasons, we might expect demographic variables that index social status, such as income,
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1506 education, gender, and race, to associate with vaccination beliefs and behaviors.

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1807 We would also note at this point that our research design allowed for the possibility that
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2008 true and false conspiracy beliefs might correlate positively, meaning that individuals being aware
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2209 of a true conspiracy like the Tuskegee syphilis event might be associated with them also believing
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2400 that moon landings were faked or that a deep state controlled the U.S. government. Our methods,
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2601 however, also could have found these to be negatively correlated, if indeed that were the
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2902 empirical pattern. We have found that leaving this matter open to the empirical findings makes
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3103 some researchers uncomfortable; we believe this discomfort arises from two factors. One, it
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3304 allows for an empirical equivalence between ontological categories (truth and falsehood, what
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3605 exists and what doesn't exist) that are totally distinct in the minds of most researchers. Two, our
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3806 methods allow the observations to find an empirical equivalency between social groups that
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4007 researchers tend to view as justified in their mistrust of the establishment due to histories of real
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4208 victimization (e.g. African Americans) and those groups that researchers tend to see merely as
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4509 victims of misinformation (e.g. low income Whites).

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4800 With our methods, we are trying to go beyond the ontologies that researchers want people
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5001 to use (truth/falsehood, justification/shoddy reasoning) and instead take in how people do
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5202 associate various beliefs with other beliefs. We also wish to transcend the easy narratives of
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5403 oppression/victimization that would seek to define empirical reality of what people think and do
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5604 by the moral realities and/or moral perceptions of what various people do or do not deserve.
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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 (Christakis and Fowler 2007; Centola 2010). 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 (Luke J. Matthews 2017; Bulbulia 2012). Sobo (2015) proposed a similar mechanism as underpinning anti-vaccination stances among Waldorf parents. Assuming such social-group benefits of antivaccine beliefs present greater marginal benefit for those who participate less in traditional social groups like religion or politics, then individuals that are lacking in affiliation to traditional identity groups may endorse more antivaccine 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

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250 Kavanagh 2018). This idea predicts that directly measuring levels of trust toward secular
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451 institutions that promote vaccines (doctors, the government, the mainstream media) would predict
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652 vaccination decisions.
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8 9 10 *Scientific Reasoning*

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135 Prior research has shown that scientific reasoning ability, as measured through survey
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156 questions assessing actual proficiency with the scientific method, is predictive of acceptance of
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177 scientific consensus views (Drummond and Fischhoff 2015). Based on this, we predicted that
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208 greater scientific reasoning might be associated with less vaccine hesitancy.
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22 23 24 **METHODS**

25 26 261 **Induction of Belief Survey Items**

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203 To develop belief items, we conducted a systematic literature review of peer reviewed
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264 articles that included open-ended questions about vaccine beliefs. We supplemented this with an
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345 ad hoc review of important antivaccine and conspiracy belief websites. We have previously
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366 published comprehensive documentation of findings from the systematic literature review
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387 (Gidengil et al. 2019). We identified 71 articles that used open-ended questions to elicit vaccine
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418 beliefs. As a result of this focus on open-ended questions, our literature review resulted in the
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439 inclusion of questions that might not be traditionally asked in surveys, but which offer the
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450 potential to identify concerns that the general public has about vaccines but which the medical
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471 and research communities may have neglected.
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49 50 51 52 53 **Survey Sample**

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554 We surveyed members of the RAND American Life Panel (ALP), which is a nationally
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575 representative panel of the American population. The ALP enlists individuals through a range of
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276 probability-sampling approaches, so that the resulting sample represents the U.S. population for
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477 race, age, gender, income, education, and region. The average attrition rate from the panel over
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678 the past 10 years has been 13% per year. From the ALP, we invited 716 individuals with children
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879 under 21 to take a survey about vaccine related beliefs and decisions. We employed no other
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110 inclusion/exclusion criteria for participation in the current survey. The ALP has advantages over
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131 most other survey platforms, both because it uses probability-based sampling method and it
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152 captures the US population that is not already online (PEW Research Center 2020). Individuals
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183 without regular internet access are provided it as part of their participation in the ALP. Because
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204 participants are empaneled for multiple years in the ALP, with demographic variables regularly
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225 collected on all panelists, we are able to field longer surveys about a specific topic, like vaccines,
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256 without using up time collecting demographic information. Full panel recruitment and survey
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277 methods are available at <https://alpdata.rand.org/>.

289 **Survey Measures**

290 *Secondary Bias*

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361 We operationalized secondary bias by evaluating whether self-reported vaccination
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382 decisions were statistically associated with PCA reductions of beliefs (i.e., principle component
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413 scores) on a range of topics. We elicited Likert-style disagree-to-agree responses for 35 belief
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434 items that we developed through our inductive literature review described above. The scale was
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455 anchored at 0 = “strongly disagree is true” and 6 = “strongly agree is true, with 3 = “Undecided or
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486 not sure”. To extract a dimension of belief from these items, we applied scaled and centered
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507 principal components analysis (function `prcomp` in R) and used the scores from the first principal
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528 component. We repeated this procedure for three subsets of the beliefs: 1) false conspiracy beliefs
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559 2) beliefs supported by evidence, and 3) false vaccine side effects. To test robustness and guard
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570 against the possibility that the 0-6 scales introduced false precision, we repeated all these PCAs
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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 > 95% 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, whether their connections had autism or children with autism.

Political and Religious Affiliations

We operationalized this hypothesis by asking individuals their religious and political affiliation and by asking the same affiliation 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 affiliation, 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 8 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% of variance) of these 8 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 4 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 hesitance. This was an assumption we found problematic and were unwilling to make. Another analytic option would be to fully model the transition probabilities amongst the questions (e.g. 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

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

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9 We compared the differently-specified regressions using the Bayesian Information
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11 Criterion (BIC), which enabled us to compare the non-nested hypotheses while allowing for
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13 multiple predictor variables in each model. Comparison of BIC values has become a common
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15 practice in parts of social science and ecology because theories often suggest regression models
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17 whose predictors are not nested subsets of each other (Mesoudi, Magid, and Hussain 2016; Luke J
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19 Matthews et al. 2011; Towner and Luttbeg 2007). BIC allows for direct comparisons of
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21 regression models to each other and to a null model (lower BIC is better). Differences in BIC
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23 values are interpretable as Bayes Factors, which express the ratio of predictive utility of one
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25 model over another. Most applications of Bayes Factors follow the interpretive scale of relative
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27 support originally proposed by Kass and Raftery (1995): differences 0-2 weak, 2-6 positive, 6-10
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29 strong, >10 very strong. Simulation studies have generally validated BIC selection methods
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31 across a range of contexts (Brewer, Butler, and Cooksley 2016; Karimov and Matthews 2016).

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

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56 *Analysis of belief structure*
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1
2 We wished to examine the principal component structure of the belief items to ascertain
3
4 how they might best be described. To test the construct validity of the total dataset and belief
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6 subsets (false conspiracy beliefs, evidence-supported beliefs, putative side effects), we calculated
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8 the unstandardized Cronbach alpha for the total set and all subsets (function alpha in the psych
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10 package in R). During this calculation we reverse coded any beliefs that loaded negatively on the
11
12 1st principal component of that subset.
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15 We assessed whether the subsets theorized by prior literature (beliefs in conspiracies or
16
17 supported by evidence) and generated by our qualitative literature review (false side effects) had
18
19 Cronbach alphas better than any random subset of the total 35 beliefs. To test this, we pulled
20
21 random combinations for the same number of beliefs as in each subset, calculated Cronbach's
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23 alpha, and then compared this null distribution from 1000 random pulls to the observed alpha of
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25 the actual belief subsets.
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28 29 *Predictors of beliefs as outcomes*

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31 The analysis of belief structure speaks to the internal structure of the 35 belief items,
32
33 which is one aspect of internal validity. Another form of validity is derived by examining the
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35 correspondence of the PCA output to other variables not entered into the PCA in the first place. If
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37 those variables correspond to the PCA output in theoretically expected ways then this can be
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39 taken to indicate there is some external validity to the PCA output; that is, the output reflects at
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41 least something about the external thing in the world it was trying to describe. This form of
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43 validity has been called nomological validity in some literature (Nunnally and Bernstein 1994).
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45 We assess the nomological validity of the component scores by using them as outcomes in
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47 regression models specified in the same manner as for modeling self-reported vaccination
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49 decisions.
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52 53 *Nestedness analysis of the belief scaffold hypothesis*

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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).

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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.

36 **RESULTS**

37 **Induction of Belief Items for Survey**

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Although antivaccine 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-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 71 articles that included primary data collection using open-ended questions about beliefs related to childhood vaccines that are currently in use in the

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446 United States, and were published in 1999 or later and indexed in PubMed, Embase, or
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447 PsycINFO.
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448 Our systematic literature review pointed to a potentially prominent role for beliefs in
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449 putative vaccine side effects wholly independent from conspiracy, evidentiary, or other health and
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450 political beliefs. We therefore included questions in our survey that asked about various side
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451 effects mentioned in articles.
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452 Understanding of vaccination science, or misunderstandings, was another theme from our
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453 literature review. For example, one belief expressed by parents who chose to vaccinate was that
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454 vaccines work by killing viruses in the body (Downs, de Bruin, and Fischhoff 2008). This
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455 incorrect belief appears to confuse the action of vaccines with that of antibiotics, but it was
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456 associated with parents who did vaccinate, rather than the vaccine hesitant. This suggested
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457 understanding of vaccine science may have a relationship to vaccine hesitancy, but potentially
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458 one that has no direct concordance with how scientists would intuit that relationship. We therefore
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459 included questions that assessed correct and incorrect understandings of vaccine science.
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460 While reviewing prominent websites associated with conspiracy beliefs, we were
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461 surprised by the extensive overlap of conspiratorial and non-conspiratorial views presented. Even
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462 sites like *Infowars* presented verifiably true events that were reported by mainstream journalism
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463 alongside demonstrably false conspiracy beliefs. Thus, we included non-conspiratorial views and
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464 even those supported by evidence when we saw the potential for them to be associated with
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465 conspiracy beliefs in our inductive research process. Examples of such beliefs would be the
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466 notion that historic declines in vaccine preventable illness in developed countries were not caused
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467 by vaccines but were caused by other public health measures. Although we disagree with the
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468 policy interpretation given to this belief by anti-vaccine individuals, there is some evidence that
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469 supports this idea that has been published in peer-reviewed journals (E.H. Kass 1971; McKinlay
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470 and McKinlay 1977; Greenwood). The belief is in some sense true and is not itself inherently
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2 471 conspiratorial in nature, but may be consistent with or bolster conspiratorial ideation. Similarly,
3
4 472 there is evidence that the immunity acquired by disease exposure is a more effective immunity
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6 473 than that acquired by vaccines (Childrens' Hospital of Philadelphia 2018). Also, HIV likely was
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8 474 spread to some degree by sleeping sickness vaccination programs in Africa during the mid-20th
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10 475 century (Carlsen 2001; Gürtler and Eberle 2017). These types of true beliefs, however, are
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12 476 intermixed with conspiratorial interpretations and outright falsehoods in anti-vaccine media.
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16 477 A final product of the literature review process was a 35-item list of beliefs about political,
17
18 478 scientific, and health topics (Table 2). The list included true items, (e.g. During the Tuskegee
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20 479 syphilis event, government-funded scientists decided to not treat African Americans for syphilis)
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22 480 as well as false items (e.g. Barack Obama was not born in the U.S.).
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25 481 **Statistical Analyses**

26 27 482 *Predictors of self-reported vaccination behavior*

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30 483 We applied an inclusive three-fold criterion to define vaccine hesitance behavior as
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32 484 delaying a vaccine, declining a vaccine, or knowingly using a doctor that recommends an
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34 485 alternative vaccination schedule. Using this criterion, 42% of parents in the data without
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36 486 incompletes are vaccine hesitant (N = 526), which is consistent with findings from the National
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38 487 Immunization Survey (Hill et al. 2016). Of that 42%, 9% reported not declining or delaying
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40 488 vaccines but that they used a doctor who followed an alternative vaccine schedule. As a
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42 489 robustness check and for a subset of analyses, we also modeled a more constrained definition for
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44 490 hesitancy as only when the respondent affirmed declining a vaccine (*Constrained Hesitancy*
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46 491 below).
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51 492 We modeled vaccine hesitancy behavior as the outcome in a set of logistic regressions that
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53 493 had combinations of variables as specified by alternative social science theories. To
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55 494 operationalize the secondary bias theory, we used scores on the first principal component from a
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57 495 PCA of different sets of the belief items: (a) all 35 items, (b) only the false vaccine side effects,
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(c) only the false conspiracy beliefs unrelated to vaccines, and (d) only the items supported by evidence. In addition, and as described above, we consider 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 than 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 2 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% (16% for the more constrained definition of vaccine hesitancy). Alternatively, one could state that a 1 point increase in agreement across 10 beliefs results in the same 20% 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.E. Kass and Raftery 1995). Comparisons of BIC from binarized belief data were qualitatively the same (S1).

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 Bias, general	Adoption of some beliefs alters the	PC1 from 35 inductively determined belief items	683	554

	probability that other beliefs and behaviors area adopted			
Secondary Bias, false conspiracy beliefs		PC1 from 11 false conspiracy beliefs not about vaccines	713	
Secondary Bias, false side effects		PC1 from 8 false vaccine side effects	669	
Secondary Bias, evidence supported beliefs		PC1 from 10 beliefs supported by evidence	679	
Demographics	Vaccination beliefs and behaviors vary by demographics	Race (<i>White (reference), Black, Am. Indian or AK Native, Asian or Pac. Isl., Other</i>); Hispanic (<i>Y/N</i>); Education (<i>Less than high school (reference), High school, Associate's degree, Bachelor's degree, Professional degree or doctorate</i>), gender (<i>M/F</i>), 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	750	597

		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		
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 (<i>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</i>); Self Political Party (<i>Republican (reference), Democrat, Independent, Other</i>)	801	643
Institutional trust	Beliefs reflect an attitude of trust or distrust toward societal institutions (government,	Two principal components from 8 institutional trust items; religious service attendance (<i>Never</i>	750	595

	organized religion, journalism)	<i>(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)</i>		
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)

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 hesitant 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.

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. Notes, path analysis or SEM that makes not qualitative assumptions 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 advantages of removing any constraints on how we the researchers bucketed variables together, and they avoid then 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 hesitant behavior, and with the same estimated odds ratio (Table 2, performed in the MASS package in R, (Venables and Ripley 2002).

TABLE 2. *Results from backward-forward search for predictors of vaccine hesitant behavior*

	Odds Ratio
Beliefs PC1	1.20***
Female parent	1.67**
Voted in 2016	2.08**

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557 Friends not vaccinate 1.40*
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358 ***p < 0.001, **p < 0.01, *p < 0.05, N = 526
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860 *Analysis of belief structure*
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11 The strong association of beliefs with vaccine hesitancy motivates understanding the
12 internal structure of the beliefs measured, and how they relate to other variables external to them.
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15 The strong association is consistent with some degree of secondary bias occurring in parents'
16 decisions of whether or not to vaccinate their children. We present only analysis of the 0-6 Likert
17 responses, as the results above using binarized data were qualitatively similar while appearing to
18 suffer from the loss of information due to the binarization.
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25 From the PCA of all 35 beliefs, we found that the first principal component (PC1)
26 captured 35% of the original variation. This component dwarfed the variation described by the
27 next largest components (PC2 = 8%, PC3 = 6%). Most standard approaches to PCA would
28 therefore only analyze the first principal component due to the quite substantial drop off in
29 variation described by the other PCs in this analysis (Jolliffe 2002). Loadings for the PCAs of the
30 theorized variable subsets considered separately (false conspiracy beliefs, false vaccine side
31 effects, evidence supported beliefs) are higher than when the beliefs are considered together but in
32 the same direction (Table 3).
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445 TABLE 3. *Loadings for beliefs on first principal component of overall PCA and belief subset*
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<u>Short Description*</u>	Percent Agree	PC1 Loadings for Variable Subsets		
		All Variables (35% variance)	False Conspiracy Beliefs without Vaccine Element (47% variance)	False Vaccine Side Effects (56% variance)
-		<i>False Conspiracy Beliefs without Vaccine Element</i>		

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		
<i>Beliefs Supported by Evidence</i>					
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-Barre	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
<i>False Vaccine Side Effects</i>					

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	
	<i>Other</i>				
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

Cronbach's alpha for the total set of 35 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 Chronbach's alpha, but researchers suggest alpha basic research should exceed 0.8 and for applied research exceed 0.9 (Lance et al. 2006). Because Chronbach'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% and 0.99% 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% 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 antiestablishment 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- vs. 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 SES 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 antiestablishment thinking.

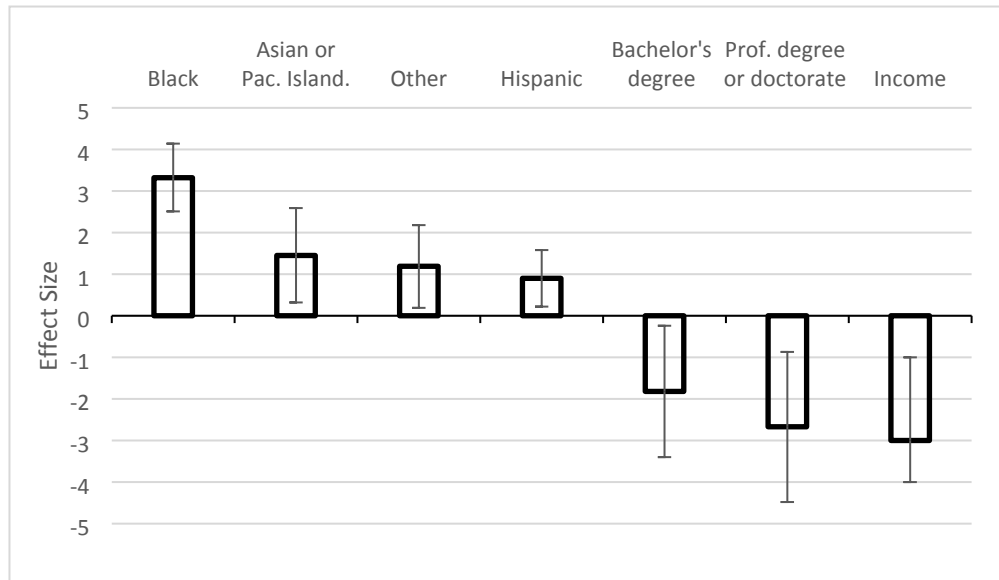
TABLE 4. *Comparison of a priori regression models to explain scores on PC1 from all variables*

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).

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 antiestablishment views, minority status, lower education, and lower income all significantly predicted higher scores on PC1 for beliefs (Figure 1).

FIGURE 1. *Statistically significant demographic predictors of antiestablishment views*



Note: Effect sizes are coefficients from linear regression with PC1 scores as the outcome. Error bars show 95% confidence intervals.

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 3). 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 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-Barre syndrome (S4). On average, greater scientific reasoning is associated with *disbelief* of these beliefs despite their being supported by

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2 639 empirical evidence (ave. $r = -0.13$, $p = 0.03$, $N = 6$, one sample t-test). Greater scientific reasoning
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4 640 was associated with greater *disbelief* of true events that involved conspiracies (CIA fake
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6 641 vaccination) even though this event was widely reported, including in the journal *Nature* and by
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8 642 the BBC (S4). Scientific reasoning is associated with *disbelief* of non-conspiratorial events that
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10 643 logically would lead to distrust of the establishment (e.g. HIV spread in Africa by vaccination
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12 644 programs, other public health measures besides vaccines causes declines in vaccine preventable
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14 645 illness) and *disbelief* of actual vaccine sides effects like Guillian-Barre. It is difficult to explain
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16 646 these findings as simply lack of awareness. Given these findings, the pro-establishment end of
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18 647 PC1 appears also to describe a tendency toward a *credulous scientism* that contrasts with critical
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20 648 scientific thinking. By credulous scientism we mean a tendency to endorse pro-science views
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22 649 when one actually does not know the evidence base or choses to ignore it.
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28 650 Of these six beliefs supported by evidence, only belief in the Tuskegee syphilis event
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30 651 correlates positively with scientific reasoning. This correlation likely arises because the history of
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32 652 Tuskegee syphilis event is a standard part of many scientific curricula that also teach people to
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34 653 reason scientifically, meaning that individuals who learned to reason scientifically simultaneously
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36 654 learned the veracity of this particular event.
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41 656 *Nestedness analysis of the belief scaffold hypothesis*

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44 657 We employed an analysis of the individual by belief matrix, using two measures indicative
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46 658 of how much a matrix can be “packed” into an upper triangular matrix indicative of a belief
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48 659 scaffold compared to a variety of null assumptions. The observed level of packing was significant
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50 660 ($p < 0.001$) under any of the several specifications for null models used for this metric (see
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52 661 Methods). The five beliefs lowest down in the nesting structure (i.e. at the bottom of the scaffold
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54 662 and supporting the other beliefs) are: Vaccines kill viruses, Flu vaccine causes flu, 2016 Votes
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56 663 Manipulated, JFK Assassination, Tuskegee Syphilis. The scaffolding theory for culture would
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1 interpret these as precursors to beliefs higher in the scaffold. The five beliefs highest in the
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465 nesting structure (i.e. supported by other beliefs) are: Vaccines cause SIDS, HIV Spread Vaccine
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666 Africa, CIA created HIV, Chemtrails, Immigration Plot (full nesting shown in Supplement).
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For Review Only

DISCUSSION

We used an inductive approach to generate 35 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 hesitant 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 35 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- vs 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 35 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 socio-cultural 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 American society like scientists, public health authorities, and the government (Brunson 2013; Sobo 2015; Brunson and Sobo 2017). In contrast to this prior research, however, we find no evidence for a hyper-

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2 multi-dimensional ‘jaggedness’ to this belief structure; rather, roughly a third of the variation in
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4 these pro- vs anti-establishment beliefs is arrayed along a single axis of variation, and the low
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6 variance on the other axes suggests these may just be random noise rather than signal.
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9 We also offer another interpretation of PC1 that we believe is unprecedented in either the
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11 psychology or socio-cultural anthropology literature. This interpretation is that there is no attitude
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13 or gist of “antiestablishment-ness” that underlies PC1; instead, all that exist are the individual
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15 beliefs, but these are interlinked in a mutually supportive way. This interpretation derives from
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17 the scaffolding model for cultural learning, whereby culture is conceived as a multitude of
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19 individually learned cognitive items that are interlinked just as the individual bars of a scaffold
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21 are interlinked to create a vertical structure. Ultimately the vertical support of a physical scaffold
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23 arises merely from the interlinkages among the bars; there exists no hidden dark matter of
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25 “scaffold-ness” supporting it.
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30 We found some support for this interpretation in that the beliefs are hierarchically nested
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32 much more than expected under any of several null models. This is suggestive of a scaffolding
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34 process in which some beliefs sit at the bottom of the scaffold and become precursors for beliefs
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36 layered on top of them.
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39 Assuming that an underlying “antiestablishment-ness” accounts for PC1 implies radically
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41 different communication policies toward vaccination than does the scaffold interpretation. Under
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43 the antiestablishment-ness interpretation, effective messages would validate the anti-
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45 establishment disposition while simultaneously endorsing vaccines. Physician spokespersons
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47 likely could be found who are anti-establishment in aspects of their lives other than their medical
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49 practice.
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54 The scaffolding interpretation predicts that these types of antiestablishment-validating
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56 messages will be ineffective, because in the minds of people there is no hidden antiestablishment-
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58 ness to validate. Instead, there are only individual beliefs interlinked in their minds. The
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1 scaffolding interpretation suggests messages should address individual belief items near the
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4 bottom of the scaffold; i.e., those that are lower down in the belief hierarchy and thus more
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6 supportive of the overall belief structure. The nestedness analysis points to specific beliefs to be
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8 addressed, which cut across scientific understandings of vaccination and political or health
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10 conspiracy beliefs.
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13 Addressing these beliefs during communication about childhood vaccination need not
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15 mean refuting them in all cases. Some might be usefully refuted as they may reflect simple
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17 misunderstandings of vaccine science: vaccines do not work by killing viruses (antibiotics work
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19 this way) and although the flu vaccine may cause some mild flu symptoms, it is a dead virus and
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21 so cannot give anyone the flu. Some other beliefs should be acknowledged, and not refuted in the
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23 least in vaccine messaging. The Tuskegee syphilis event is an example of an actual health
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25 conspiracy perpetrated against African Americans. Acknowledging specific true conspiracies like
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27 Tuskegee may be an important component of pro-vaccine messaging.
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33 This research was conducted before the onset of the COVID-19 pandemic, and we
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35 therefore do not have any direct measures for COVID-19 hesitancy. We note, however, that many
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37 of our results may generalize to the current situation for COVID-19 vaccination in the U.S.,
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39 which is far too low (~50% vaccinated) to stop the spread of the infection. The observed
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41 emerging plateau at 50% vaccination is remarkably similar to the ~50% vaccination the U.S.
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43 generally achieved for adult seasonal flu vaccination (Centers for Disease Control and Prevention
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45 2021). This similar overall vaccination rate in context of dramatically publicized risks of COVID-
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47 19 infection underscores our findings that assessment of scientific evidence, or even plainer
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49 perceptions of actual disease risk (e.g. freezer trucks rolling up to hospitals), may play little role
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51 in vaccination decisions. Instead, vaccination decisions are made based on socially learned beliefs
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53 that are tied up in individual's experiences of whether society is on their side (indexed in our
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55 study by race, education, income). In this study we did not measure access to healthcare because,
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2 43 *specifically for children* in the U.S., this access, although not without disparities, generally is
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4 44 excellent and equitably available. For example, Hispanic Americans have higher childhood
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6 45 vaccination rates than do non-Hispanic White Americans, while Black Americans are usually
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8 46 within 0-4 percentage points of the childhood vaccination rate for Whites, depending on the
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11 47 vaccine (Kulkarni et al. 2021; Hill et al. 2018; Hill et al. 2020). Education and income variation,
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13 48 mostly among Whites, are more substantial drivers of low vaccination for childhood vaccines
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15 49 than is race/ethnicity (Kulkarni et al. 2021). In short, when the American healthcare system has
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17 50 provided good access, as is the case of childhood vaccinations, minority groups show similar
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20 51 vaccination rates to Whites, or even higher in some cases.

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23 52 We would suggest, therefore, that disparities in access to healthcare might largely account
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25 53 for the Black-White racial disparity in adult vaccination for seasonal flu of 12 percentage points
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27 54 and the disparity for COVID-19 of 10 percentage points (Melillo 2021; Centers for Disease
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29 55 Control and Prevention 2021). Also, while these are substantial disparities, they are much less
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32 56 than the overall problem that roughly half the adult population (of any race) does not get
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34 57 vaccinated for flu or COVID-19. We suggest that the problem of the U.S. having a far too low
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36 58 overall COVID-19 vaccination rate likely is driven by socially learned beliefs similar to the ones
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39 59 we included in this study, although disparities in vaccination may largely arise from disparities in
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41 60 healthcare access.

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44 61 In conclusion, by taking a systematic and inductive approach to belief measurement we
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46 62 found support for prior socio-cultural research that the beliefs surrounding vaccination crisscross
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48 63 topically-focused categories like conspiracy ideation, health side effects, and scientific
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51 64 understanding. Our results, however, fail to support substantial multidimensional “jaggedness” of
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53 65 the arrangement of beliefs. Instead, about a third of variation in the items correlates with a single
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55 66 dimension of co-variation, and other dimensions look less substantial. The nestedness analysis
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58 67 further suggests the belief dimension may be usefully viewed as a scaffold of individual beliefs
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that are interlinked into a supportive structure. Vaccination communications could consider engaging the key beliefs that are most supportive of the overall belief scaffold.

REFERENCES CITED

- Almeida-Neto, Mário, Paulo Guimarães, Paulo R. Guimarães Jr, Rafael D. Loyola, and Werner Ulrich. 2008. "A consistent metric for nestedness analysis in ecological systems: reconciling concept and measurement." *Oikos* 117 (8): 1227-1239.
<https://onlinelibrary.wiley.com/doi/10.1111/j.0030-1299.2008.16644.x>.
- Atmar, Wirt, and Bruce D. Patterson. 1993. "The measure of order and disorder in the distribution of species in fragmented habitat." *Oecologia* 96 (3): 373-382.
<https://link.springer.com/article/10.1007/BF00317508>.
- Brewer, Mark J., Adam Butler, and Susan L. Cooksley. 2016. "The relative performance of AIC, AICC and BIC in the presence of unobserved heterogeneity." *Methods in Ecology and Evolution* 7 (6): 679-692.
<https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12541>.
- Brunson, Emily K. 2013. "How parents make decisions about their children's vaccinations." *Vaccine* 31 (46): 5466-5470.
<https://www.sciencedirect.com/science/article/pii/S0264410X13012462>.
- Brunson, Emily K., and Elisa J. Sobo. 2017. "Framing Childhood Vaccination in the United States: Getting Past Polarization in the Public Discourse." *Human Organization* 76 (1): 38-47. <https://meridian.allenpress.com/human-organization/article-abstract/76/1/38/71266/Framing-Childhood-Vaccination-in-the-United-States?redirectedFrom=PDF>.
- Bulbulia, Joseph. 2012. "Spreading order: religion, cooperative niche construction, and risky coordination problems." *Biology & philosophy* 27 (1): 1-27.
<https://www.ncbi.nlm.nih.gov/pubmed/22207773>.
- Caporael, Linnda R., James R. Griesemer, William C. Wimsatt, Stuart A. Newman, James Allen Evans, Jeffrey C. Schank, Christopher J. May, Sanjay Joshi, Pamela Lyon, Georg Theiner, Christophe Heintz, Colin Allen, Sergio F. Martinez Muñoz, Elihu M. Gerson, Johann Peter Murmann, Iddo Tavory, Simona Ginsburg, Eva Jablonka, Shu-Chen Li, and Barbara Horberg Wimsatt. 2013. *Developing Scaffolds in Evolution, Culture, and Cognition*. Vol. 17 *Vienna Series in Theoretical Biology*: The MIT Press.
- Carlsen, William. 2001. "Did Modern Medicine Spread an Epidemic? After decades, and millions of injections, scientists are asking the chilling question." SF Gate. Last Modified January 15. <https://www.sfgate.com/health/article/Did-Modern-Medicine-Spread-an-Epidemic-After-2964707.php>.
- Centers for Disease Control and Prevention. 2021. "New CDC Analysis of Flu Hospitalization Data." Last Modified July 6. <https://www.cdc.gov/flu/highrisk/disparities-racial-ethnic-minority-groups.html?web=1&wdLOR=cB1FC8FD7-B97A-47CD-A649-21AE736907A6>.

- Centola, Damon. 2010. "The spread of behavior in an online social network experiment." *Science* 329 (5996): 1194-7. <https://science.sciencemag.org/content/329/5996/1194>.
- Childrens' Hospital of Philadelphia. 2018. "Vaccine Safety: Immune System and Health." Last Modified March 30, 2018. <https://www.chop.edu/centers-programs/vaccine-education-center/vaccine-safety/immune-system-and-health>.
- Christakis, Nicholas A., and James H. Fowler. 2007. "The spread of obesity in a large social network over 32 years." *New England journal of medicine* 357 (4): 370-379. <https://www.nejm.org/doi/full/10.1056/NEJMsa066082>.
- Dean, Lewis G, Gill L Vale, Kevin N Laland, Emma Flynn, and Rachel L Kendal. 2014. "Human cumulative culture: a comparative perspective." *Biological Reviews* 89 (2): 284-301.
- Downs, J. S., W. B. de Bruin, and B. Fischhoff. 2008. "Parents' vaccination comprehension and decisions." *Vaccine* 26 (12): 1595-607.
- Drummond, Caitlin, and Baruch Fischhoff. 2015. "Development and Validation of the Scientific Reasoning Scale." *Journal of Behavioral Decision Making* 30 (1): 26-38. <https://onlinelibrary.wiley.com/doi/10.1002/bdm.1906>.
- Durham, William H. 1991. *Coevolution: Genes, culture, and human diversity*. Stanford University Press.
- Formann, Carsten F., Bernd Gruber, and Jochen Fründ. 2008. "Introducing the bipartite Package: Analysing Ecological Networks." *Computer Science* 8 (2).
- Gidengil, Courtney, Christine Chen, Andrew M. Parker, Sarah Nowak, and Luke Matthews. 2019. "Beliefs around childhood vaccines in the United States: A systematic review." *Vaccine* 37 (45): 6793-6802. <https://www.sciencedirect.com/science/article/pii/S0264410X19311442>.
- Greenwood, Brian. "The contribution of vaccination to global health: past, present and future." *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 369 (1645): 20130433. <https://www.ncbi.nlm.nih.gov/pubmed/24821919>.
- Grimes, David Robert. 2016. "On the Viability of Conspiratorial Beliefs." *PLOS ONE* 11 (1): e0147905. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0147905>.
- Guimarães, Paulo R., and Paulo Guimarães. 2006. "Improving the Analyses of Nestedness for Large Sets of Matrices." *Environmental Modelling & Software* 21, no. 10: 1512-1513. <https://app.dimensions.ai/details/publication/pub.1032490104>.
- Gürtler, Lutz G., and Josef Eberle. 2017. "Aspects on the history of transmission and favor of distribution of viruses by iatrogenic action: perhaps an example of a paradigm of the worldwide spread of HIV." *Medical microbiology and immunology* 206 (4): 287-293. <https://www.ncbi.nlm.nih.gov/pubmed/28434128>.
- Healy, C. Mary, and Larry K. Pickering. 2011. "How to communicate with vaccine-hesitant parents." *Pediatrics* 127 Suppl 1: S127-33. https://pediatrics.aappublications.org/content/127/Supplement_1/S127.
- Hill, Holly A., Laurie D. Elam-Evans, David Yankey, James A. Singleton, and Vance Dietz. 2016. "Vaccination Coverage Among Children Aged 19-35 Months - United States, 2015." *MMWR Morb Mortal Wkly Rep* 65 (39): 1065-1071. <https://www.cdc.gov/mmwr/volumes/65/wr/mm6539a4.htm>.
- Hill, Holly A., Laurie D. Elam-Evans, David Yankey, James A. Singleton, and Yoonjae Kang. 2018. "Vaccination Coverage Among Children Aged 19-35 Months — United States, 2017." *Morbidity and Mortality Weekly Report* 67 (40): 1123-1128. <https://www.cdc.gov/mmwr/volumes/67/wr/mm6740a4.htm>.
- Hill, Holly A., David Yankey, Laurie D. Elam-Evans, James A. Singleton, S. Cassandra Pingali, and Tammy A. Santibanez. 2020. "Vaccination Coverage by Age 24 Months Among Children Born in 2016 and 2017 — National Immunization Survey-Child, United States,

- 2017–2019." *Morbidity and Mortality Weekly Report* 69 (42): 1505-1511.
<https://www.cdc.gov/mmwr/volumes/69/wr/mm6942a1.htm>.
- Jarrett, Caitlin, Rose Wilson, Maureen O'Leary, Elisabeth Eckersberger, and Heidi J. Larson. 2015. "Strategies for addressing vaccine hesitancy - A systematic review." *Vaccine* 33 (34): 4180-90.
<https://www.sciencedirect.com/science/article/pii/S0264410X15005046?via%3Dihub>.
- Jolley, Daniel, and Karen M. Douglas. 2014. "The Effects of Anti-Vaccine Conspiracy Theories on Vaccination Intentions." *PLOS ONE* 9 (2): e89177.
<https://doi.org/10.1371/journal.pone.0089177>.
- Jolliffe, I. T. 2002. *Principal Component Analysis*. Second ed. New York, NY: Springer.
- Kamilar, Jason M., and Quentin D. Atkinson. 2014. "Cultural assemblages show nested structure in humans and chimpanzees but not orangutans." *Proceedings of the National Academy of Sciences* 111 (1): 111. <http://www.pnas.org/content/111/1/111.abstract>.
- Karimov, Rouslan, and Luke J Matthews. 2017. "A simulation assessment of methods to infer cultural transmission on dark networks." *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*: 1548512916679900.
- Karimov, Rouslan, and Luke J. Matthews. 2016. "A simulation assessment of methods to infer cultural transmission on dark networks." *The Journal of Defense Modeling and Simulation* 14 (1): 7-16. <https://journals.sagepub.com/doi/full/10.1177/1548512916679900>.
- Kass, Edward H. 1971. "Infectious Diseases and Social Change." *The Journal of Infectious Diseases* 123 (1): 110-114. <http://www.jstor.org/stable/30108855>.
- Kass, Robert E, and Adrian E Raftery. 1995. "Bayes factors." *Journal of the american statistical association* 90 (430): 773-795.
- Kulkarni, Ansh A., Raj P. Desai, Héctor E. Alcalá, and Rajesh Balkrishnan. 2021. "Persistent Disparities in Immunization Rates for the Seven-Vaccine Series Among Infants 19–35 Months in the United States." *Health Equity* 5 (1): 135-139.
<https://www.liebertpub.com/doi/10.1089/heq.2020.0127>.
- Larson, Heidi J., Alexandre de Figueiredo, Zhao Xiaohong, William S. Schulz, Pierre Verger, Iain G. Johnston, Alex R. Cook, and Nick S. Jones. 2016. "The State of Vaccine Confidence 2016: Global Insights Through a 67-Country Survey." *EBioMedicine* 12: 295-301.
<http://www.sciencedirect.com/science/article/pii/S235239641630398X>.
- Leach, Melissa, and James Fairhead. 2007. *Vaccine Anxieties*. London, UK: Routledge.
- Lewandowsky, Stephan, Gilles E. Gignac, and Klaus Oberauer. 2013. "The Role of Conspiracist Ideation and Worldviews in Predicting Rejection of Science." *PLOS ONE* 8 (10): e75637.
<https://doi.org/10.1371/journal.pone.0075637>.
- Marsden, Peter V. 1987. "Core Discussion Networks of Americans." *American Sociological Review* 52 (1): 122-131. <http://www.jstor.org/stable/2095397>.
- Matthews, Luke. 2016. *Mutualistic cooperation - why religion is common but saints are rare*. Vol. 7.
- Matthews, Luke J. 2012. "The recognition signal hypothesis for the adaptive evolution of religion." *Human Nature* 23 (2): 218-249.
- Matthews, Luke J, Jamie J Tehrani, Fiona M Jordan, Mark Collard, and Charles L Nunn. 2011. "Testing for divergent transmission histories among cultural characters: a study using Bayesian phylogenetic methods and Iranian tribal textile data." *PLoS One* 6 (4): e14810.
- Matthews, Luke J. 2017. "Mutualistic cooperation – why religion is common but saints are rare." *Religion, Brain & Behavior* 7 (3): 253-255.
<https://www.tandfonline.com/doi/full/10.1080/2153599X.2016.1156561>.
- McKinlay, John B., and Sonja M. McKinlay. 1977. "The Questionable Contribution of Medical Measures to the Decline of Mortality in the United States in the Twentieth Century." *The*

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- Milbank Memorial Fund Quarterly. *Health and Society* 55 (3): 405-428.
<http://www.jstor.org/stable/3349539>.
- Melillo, Gianna. 2021. "Disparities in COVID-19 Vaccine Rates Tarnish Swift US Rollout." *American Journal of Managed Care*. <https://www.ajmc.com/view/how-biogen-s-aduhelm-approval-marks-a-precipitous-turning-point-for-the-fda>.
- Mesoudi, Alex, Kesson Magid, and Delwar Hussain. 2016. "How Do People Become W.E.I.R.D.? Migration Reveals the Cultural Transmission Mechanisms Underlying Variation in Psychological Processes." *PLOS ONE* 11 (1): e0147162.
<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0147162>.
- Moser, Paul K., Dwayne H. Mulder, and J. D. Trout. 1998. *The Theory of Knowledge: A Thematic Introduction*. New York, NY: Oxford University Press.
- National Center for Education Statistics. 2020. "Private School Enrollment." Last Modified May.
<https://nces.ed.gov/programs/coe/indicator/cgc>.
- Nunnally, Jum C., and Ira H. Bernstein. 1994. *Psychometric Theory*. 3rd ed. *McGraw-Hill Series in Psychology*. New York: McGraw-Hill.
- Nyhan, Brendan, Jason Reifler, Sean Richey, and Gary L. Freed. 2014. "Effective messages in vaccine promotion: a randomized trial." *Pediatrics* 133 (4): e835-42.
<https://pediatrics.aappublications.org/content/133/4/e835>.
- Olive, Jacqueline K., Peter J. Hotez, Ashish Damania, and Melissa S. Nolan. 2018. "The state of the antivaccine movement in the United States: A focused examination of nonmedical exemptions in states and counties." *PLOS Medicine* 15 (6): e1002578.
<https://doi.org/10.1371/journal.pmed.1002578>.
- Oliver, J., and T. Wood. 2014. "Medical conspiracy theories and health behaviors in the united states." *JAMA Internal Medicine* 174 (5): 817-818.
<http://dx.doi.org/10.1001/jamainternmed.2014.190>.
- Opel, D. J., N. Henrikson, K. Lepere, R. Hawkes, C. Zhou, J. Dunn, and J. A. Taylor. 2019. "Previsit Screening for Parental Vaccine Hesitancy: A Cluster Randomized Trial." *Pediatrics* 144 (5).
- PEW Research Center. 2020. "Internet/Broadband Fact Sheet." Last Modified April 7.
<https://www.pewresearch.org/internet/fact-sheet/internet-broadband/>.
- Reyna, Valerie F. 2004. "How People Make Decisions That Involve Risk: A Dual-Processes Approach." *Current Directions in Psychological Science* 13 (2): 60-66.
<https://doi.org/10.1111/j.0963-7214.2004.00275.x>.
- Rich, Michael D., and Jennifer Kavanagh. 2018. *Truth Decay: An Initial Exploration of the Diminishing Role of Facts and Analysis in American Public Life*. Santa Monica, CA: RAND Corporation.
- Roberts, Elizabeth F. S. 2021. "Making Better Numbers through Bioethnographic Collaboration." *American Anthropologist*.
<https://anthrosource.onlinelibrary.wiley.com/doi/10.1111/aman.13560>.
- Rodríguez-Gironés, Miguel A., and Luis Santamaría. 2006. "A New Algorithm to Calculate the Nestedness Temperature of Presence-Absence Matrices." *Journal of Biogeography* 33 (5): 924-935. www.jstor.org/stable/3838502.
- Rosentrater, C., T. L. Finlayson, and K. M. Peddecord. 2018. "Effects of California Assembly Bill 2109 in Low Vaccination Rate Counties: Are We Looking at the Right Variables?" *J Public Health Manag Pract* 24 (2): e25-e32.
- Sobo, Elisa J. 2015. "Social Cultivation of Vaccine Refusal and Delay among Waldorf (Steiner) School Parents." *Medical Anthropology Quarterly* 29 (3): 381-399.
<https://anthrosource.onlinelibrary.wiley.com/doi/10.1111/maq.12214>.
- Teoh, Deanna, Rida Shaikh, Abigail Schnaith, Emil Lou, Annie-Laurie McRee, Rebekah H. Nagler, and Rachel I. Vogel. 2019. "Evaluation of graphic messages to promote human

1 papillomavirus vaccination among young adults: A statewide cross-sectional survey."

2 *Preventative Medicine Reports* 13: 256-261.

3 <https://www.sciencedirect.com/science/article/pii/S2211335518301700?via%3Dihub>.

4 The R Foundation. 2018. "The R Project for Statistical Computing." <https://www.r-project.org/>.

5 Towner, Mary C., and Barney Luttbeg. 2007. "Alternative statistical approaches to the use of data
6 as evidence for hypotheses in human behavioral ecology." *Evolutionary Anthropology:
7 Issues, News, and Reviews* 16 (3): 107-118.

8 <https://onlinelibrary.wiley.com/doi/abs/10.1002/evan.20134>.

9 Uscinski, Joseph E., and Joseph M. Parent. 2014. *American Conspiracy Theories*. Oxford
10 University Press.

11 Venables, W. N., and B. D. Ripley. 2002. *Modern Applied Statistics with S*. Fourth ed. New York,
12 NY: Springer.

13 Westergaard, Ryan P., Mary Catherine Beach, Somnath Saha, and Elizabeth A. Jacobs. 2014.

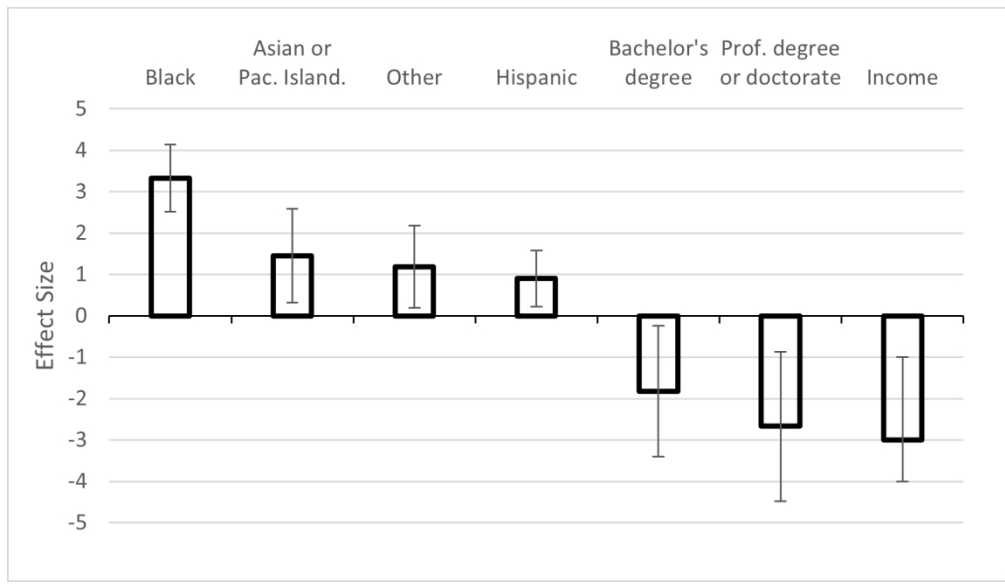
14 "Racial/Ethnic Differences in Trust in Health Care: HIV Conspiracy Beliefs and Vaccine
15 Research Participation." *Journal of General Internal Medicine* 29 (1): 140-146.

16 <https://link.springer.com/article/10.1007/s11606-013-2554-6>.

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Statistically significant demographic predictors of antiestablishment views

133x76mm (330 x 330 DPI)