Evaluating the Effects of Vaccine Messaging on Immunization Intentions and Behavior: Evidence from Two Randomized Controlled Trials in Vermont*

Katherine Clayton
Department of Political Science
Stanford University

Christine Finley
Immunization Program
Vermont Department of Health

D.J. Flynn
School of Global and Public Affairs
IE University

Meredith Graves
Immunization Program
Vermont Department of Health

Brendan Nyhan
Department of Government
Dartmouth College

***Corresponding Author:** Katherine Clayton, kpc14@stanford.edu. Christine Finley was the Immunization Program director and Meredith Graves was an epidemiologist at the Vermont Department of Health at the time this study was conducted. We gratefully acknowledge funding support from the National Academy of Sciences and the Rita Allen Foundation and assistance from Jessie Hammond, Bridget Ahrens, and Nick Pain at the Vermont Department of Health. All conclusions and any errors are, of course, our own.

Abstract

The effectiveness of vaccines in reducing child morbidity and mortality worldwide relies on public acceptance. However, relatively little is known about the effects of vaccine communication on vaccine attitudes and immunization behavior. Previous research suggests that common communication approaches may be ineffective or even counterproductive, especially among vaccine-hesitant parents. However, these studies typically rely on observational data or self-reported measures of vaccination intention. Using novel research designs, we tested the attitudinal and behavioral effects of messages encouraging vaccination in both a survey experiment conducted among a large sample of parents in Vermont who expressed hesitancy about childhood immunizations and a field experiment among parents whose children were overdue for vaccines. We find that neither a message promoting immunization as a social norm nor a message correcting common misperceptions about vaccines was measurably more effective than a standard public health message at improving parents' attitudes toward vaccines, intention to vaccinate their children, or compliance with the recommended vaccine schedule. Our results highlight the need for more research on approaches to successfully reducing vaccine hesitancy among parents.

Keywords: vaccine hesitancy, childhood vaccines, public health, misperceptions, myths, facts, norms

Introduction

The recent resurgence in measles and subsequent COVID-19 pandemic underscore the need for more effective vaccine communication strategies. Although vaccine compliance is high in the United States, many states do not meet Healthy People 2020 goals for kindergarten vaccination rates. The proportion of kindergarteners with at least one exemption from state immunization requirements was 2.5% in 2018–2019, up from 2.1% in 2016–2017, and as high as 7.7% at the state level (Seither et al. 2019). Coverage remains below Healthy People 2020 targets for a number of vaccines, including DTaP, Hepatitis A, and Hepatitis B (Office of Disease Prevention and Health Promotion 2020).

Despite widespread agreement on the goal of increasing vaccine compliance, relatively little is known about how to most effectively promote vaccines to hesitant parents (Sadaf et al. 2013), who are often confused by unscientific information they encounter from anti-vaccine activists (Kata 2012; Ruiz and Bell 2014). Some approaches that are used to promote vaccination to parents may be ineffective or even counterproductive, though results vary. For instance, Nyhan et al. (2014) find that corrective information debunking the vaccine-autism myth reduced parents' self-reported intention to vaccinate relative to a control condition, but Zhang et al. (2020) find that exposure to fact-checking labels improves attitudes toward vaccines relative to people who see only misinformation.

The vaccine communication challenge is especially acute in Vermont, a state where vaccine hesitancy was identified as a contributing factor to non-medical exemptions years before it became a national concern. Although Vermont was the first state to eliminate the philosophical exemption for school entry in 2015 in response to high exemption rates (6.1% among kindergartners in the 2014–2015 school year compared to a median of 1.7% among states nationally; Seither et al. 2015), maintaining high rates of immunization remains an ongoing challenge, especially given the prevalence of misinformation both locally and nationally (e.g., Ghorayshi 2017; Noyes 2017). After Vermont eliminated the philosophical exemption, for instance, it saw a seven-fold increase in the percentage of kindergartners with religious exemptions, a group that grew from 0.5% in

2011–2012 to 3.5% in 2019–2020 (Vermont Department of Health 2020; Williams et al. 2019). Assuring Vermont parents that vaccines are safe and effective thus remains a major public health objective in the state.

This project responds to the call for more systematic research on how to best promote vaccination (e.g., Bloom, Marcuse, and Mnookin 2014). We conducted two preregistered studies testing the efficacy of two communication strategies that are frequently used to promote vaccination. First, we tested a message emphasizing the social norm around vaccination that reminded parents of the consensus in favor of vaccination to prevent disease in Vermont. A second message took the approach of refuting common myths about vaccines using facts and science. Our study compared the effects of each of these messages with standard messaging currently used by the Vermont Department of Health (VDH).

The first study, which we refer to as the general parent study, was conducted among a sample of Vermont residents who are parents or guardians of one or more children age ten or younger who completed survey measures of their vaccine beliefs and attitudes and self-reported intent to vaccinate their children. We specifically focused on parents who expressed hesitancy about childhood immunizations as measured by the PACV outcome scale (Opel et al. 2011, 2013). The second study, which is referred to as the non-compliance study, was conducted on a sample of Vermont residents who are parents or guardians of 8-month old and/or 20-month-old children who were overdue for recommended vaccines. In both studies, data from the Vermont immunization registry were collected several months later to assess the effect of public health messaging on parents' vaccination decisions.

Our results showed no effect of either message on parents' attitudes and beliefs about vaccines, their intention to vaccinate their children, or their subsequent compliance with the immunization schedule (relative to a control condition with no information). Contrary to expectations, we also find no measurable difference in vaccine attitudes, intention to vaccinate, or a behavioral measure of vaccine compliance for either treatment compared to standard messaging used by the Vermont Department of Health. These findings suggest that vaccine attitudes are not easily changed by public health messaging and suggest the need for additional research on strategies to improve attitudes and compliance among hesitant parents. They also highlight the need to study the effects of these interventions on larger samples, as such an approach may be more likely to provide evidence of small but measurable differences in the population (e.g., Chen et al. 2020).

Hypotheses

We preregistered a series of hypotheses at the Center for Open Science prior to launching our study (URL: `https://bit.ly/307MhgS`). First, we expect the social norm treatment to improve vaccination attitudes and behavior. Studies of the effects of social norms in other domains demonstrate that emphasizing social norms can motivate environmental conservation, reduce prejudice and harassment, and even increase people's likelihood of voting (e.g., Goldstein, Cialdini, and Griskevicius 2008; Gerber, Green, and Larimer 2008; Paluck and Green 2009). The social norms treatment in our study is designed to work via two mechanisms (Cialdini, Kallgren, and Reno 1991). First, it increases the salience of the descriptive norm that most Vermont parents vaccinate. Second, it highlights the injunctive norm that they should vaccinate to protect their children and others from communicable disease. Bicchieri and Dimant (2019) define this combination as a social norm and argue that it is generally most successful at affecting behavior. We therefore expect the following:

> H1: Reminders of the social norm in favor of vaccination will increase vaccine-hesitant parents' favorability toward vaccines (H1a), their self-reported intention to vaccinate (H1b), and their children's vaccination compliance (H1c) compared to a control condition.

We also expect that correcting myths about vaccine safety will increase the accuracy of people's beliefs about vaccines. Several survey experiments have demonstrated that corrections can lower the perceived accuracy of false statements about immunizations (e.g., Cameron et al. 2013; Reavis et al. 2017). For example, Nyhan and Reifler (2015) find that corrective information significantly reduced parents' (false) belief that the flu vaccine can give you the flu. We therefore hypothesize the following:

> H2: Correcting myths about vaccine safety will increase the accuracy of beliefs about the effects of vaccines among vaccine-hesitant parents compared to a control condition.

However, findings are mixed for whether or how corrections affect intent to vaccinate or immunization behavior. Nyhan et al. (2014) and Nyhan and Reifler (2015) find that corrective information actually decreased intent to vaccinate among parents with the least favorable vaccine attitudes. By contrast, Pluviano, Watt, and Della Sala (2017) and Reavis et al. (2017) find no effects on intention to vaccinate and Horne et al. (2015) find positive effects on vaccine attitudes.

Research examining effects on actual immunization behavior is more sparse, but Glanz et al. (2017) find that a web-based social media intervention administered during pregnancy can improve the likelihood that women vaccinate their infants. Similarly, Chen et al. (2020) find a small increase in overall vaccination rates among seniors who received postcards from the Louisiana Department of Health reminding them to get the influenza, tetanus, shingles, and pneumonia vaccines. Because our theoretical expectations are not clear, however, we offer a research question about the influence of correcting myths on vaccination outcomes.[1]

> RQ1: Does correcting myths about vaccine safety affect vaccine-hesitant parents' favorability toward vaccines (RQ1a), their self-reported intention to vaccinate (RQ1b), or their children's vaccination compliance (RQ1c) compared to a control condition?

Methods

Our studies received approval from the Vermont Agency of Human Services Institutional Review Board and two university IRBs, the Committee for the Protection of Human Subjects at Dartmouth

[1] We detail three additional preregistered research questions in the Online Appendix.

College, and the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS). The Commissioner of the Vermont Department of Health (VDH) approved use of VDH data for the project under a Data Use Agreement. We followed slightly different protocols for the general parent and the non-compliance studies and describe each below.

General parent study: Recruitment

In the general parent study, we used Vermont immunization registry data to identify parents or legal guardians of at least one child 10 years old or younger who was a Vermont resident. We then sent one recruitment mailing per household via a mail firm inviting those parents or guardians to participate in an initial pre-treatment survey (Wave 1).

The list of eligible participants for Wave 1 was constructed as follows. After excluding children who were deceased, VDH identified records of 75,638 children whose parents met these criteria. VDH completed an initial address de-duplication to limit recruitment to a single child per household, retaining only the youngest child when there were multiple children with the same address. Records of 65 children in state custody were removed as well as one child who was deceased since the original record pull. A professional mailing firm working under secure conditions performed an additional address de-duplication and removed those with a documented out-of-state change of address. A trial mailing was sent to 550 randomly selected addresses a few days in advance of the main mailing. These households accordingly had additional time to complete the survey. A total of 52,565 recruitment letters were sent to households with at least one parent or guardian of a child who met the aforementioned criteria in the main mailing, with 44,797 of these delivered. The Wave 1 survey remained open for 14 days from the final day on which the letters arrived.

The letters invited parents to participate in a "Vermont Parental Study" online by navigating to a URL provided in the letter and entering a unique access code (see Figure A1 in the Online Appendix for a sample mailing). Parents were also offered incentives in the form of a $5.00 gift card to encourage survey participation. Upon navigating to the online survey, parents who chose to participate completed a series of questions on their children's names and birth dates (which we used to match them to VDH immunization registry data), their own demographics (see Table 1), and their attitudes toward vaccines. To measure vaccine attitudes, we used the Parent Attitudes about Childhood Vaccines (PACV) scale (Opel et al. 2011, 2013). More details on the composition of this scale and how we constructed our outcome measures are included in the Online Appendix. The survey also asked parents to provide their email address if they were interested in being re-contacted to participate in the Wave 2 study.

A total of 2,332 parents completed Wave 1 of the survey for a response rate of 5.2%, which is comparable to other studies that recruit participants by mail (e.g., Carey et al. 2020). After closing the Wave 1 survey, we calculated PACV scores as a measure of vaccine hesitancy among parents. Those whose PACV score was in the top two-thirds of the distribution (a score of 6.7 or higher on the 100-point PACV scale[2] and corresponding to higher vaccine hesitancy)[3] were then re-contacted via email and invited to participate in the second survey (Wave 2), which contained our vaccine messages and survey outcome measures. Parents were again offered a gift card as an incentive to participate. In order to hold the lag between Waves 1 and 2 constant across participants, we sent individual invitations approximately 14 days after each participant completed Wave 1. After seven days, we sent one additional email reminder. The Wave 2 survey remained open for 14 days. A total of 940 parents completed Wave 2 of the survey, which represented 59.9% of the Wave 1 participants we invited to the second wave.[4] We then merged these data with the available data from the immunization registry and were left with a final sample size of 678 parents corresponding to 1,070 children. We were unable to match 262 parents to child immunization registry data, explaining

[2] Responses to the PACV scale in Wave 1 were skewed heavily to the right, indicating that the majority of participants were not very vaccine-hesitant. The exact tercile splits for the 100-point PACV scale were scores of approximately 0–6.7 for the lowest tercile ($N = 761$, which were not invited to Wave 2), 6.7–16.7 for the middle tercile ($N = 799$), and 16.7–100 ($N = 770$) for the top tercile. Other studies find slightly higher average PACV scores (e.g., Opel et al. 2011; Henrikson et al. 2015; Glanz et al. 2017). A possible explanation is that a mailed survey invitation from the Vermont Department of Health might have been more appealing to parents with pro-vaccine attitudes than to vaccine-hesitant parents who may distrust public health institutions.

[3] An alternative approach would be to focus on parents who stated that they had ever delayed giving their child a required immunization (PACV1) or declined to do so (PACV2). However, this behavior is relatively rare (see Table 1 for summary statistics), so we opted to conduct our study among the broader group of parents who scored in the top two-thirds of hesitancy on the PACV composite scale.

[4] After downloading the raw data, we removed participants with missing outcome data. For a small number of participants who took the survey twice using the same code (perhaps on different devices), we kept only the first response.

the drop in sample size for the behavioral outcomes.[5] Due to data privacy concerns, we cannot definitively identify the source(s) of the failed matches, but a likely explanation is discrepancies between the names and/or birthdays of the children reported in the survey and the corresponding records in the immunization registry.

Table 1 summarizes how the demographics of participants in the general parent study compare to the Vermont population as a whole. As Table 1 shows, our sample closely matches Vermont's racial composition (94% white). Further analysis shows that it also closely approximates the geographic distribution of people across Vermont, including the percentage of the population living in an urban area (58.6% versus 59.8% in Census data) and in our coverage of zip codes (responses were recorded from 90.4% of zip codes in Vermont). Overall, the distribution of participants by zip code in our sample is correlated with the Vermont population by zip code ($r = 0.86$). See the Online Appendix (Table A1 and Figure A5) for more details on the geographic representation of our sample.

The sample differed from the Vermont population in three respects. First, as parents of young children, our participants were unsurprisingly more likely to be ages 25–44 than Vermonters as a whole. The individuals who responded to the survey were also overwhelmingly female (though our invitations did not specify which parent or guardian). Participants reported higher levels of educational attainment than Vermonters as a whole, though a substantial fraction reported using Medicaid and/or SCHIP, suggesting that the sample remains economically diverse. Finally, vaccine-hesitant behaviors were relatively rare among the sample despite our use of PACV scores to determine eligibility for Wave 2; less than a quarter of respondents reported ever having delayed or declined to give their child a required shot.

[5] Since this data cleaning process removed a sizable portion of our sample, we conducted an exploratory analysis of the effect of messaging on the survey outcomes alone without any control variables derived from immunization registry data among the larger sample of 940 parents. These results, which we report in Table A4 and Figure A6 in the Online Appendix, are substantively identical to those reported in the main text.

Table 1: General parent study participant demographics

	Wave 1	Wave 2	VT pop.
Age			
Under 25	3.6%	3.2%	14.2%
25-34	38.9%	38.1%	11.7%
35-44	47.2%	48.4%	11.3%
45-54	9.5%	9.5%	13.8%
55-64	0.6%	0.3%	15.5%
65 or older	0.3%	0.4%	18.2%
Sex			
Male	16.5%	13.6%	49.0%
Female	83.4%	86.4%	51.0%
Other	0.1%	-	-
Education			
Less than high school diploma	1.7%	1.0%	7.4%
High school diploma	11.9%	10.9%	29.2%
Some college	13.8%	15.5%	17.6%
Associate's degree	7.4%	8.1%	8.5%
Bachelor's degree	26.4%	26.7%	22.1%
Some professional or graduate school but no degree	5.8%	7.2%	-
Professional or graduate degree	32.9%	30.5%	15.3%
Race			
White	96.8%	97.2%	96.1%
Black or African American	0.4%	0.1%	1.8%
American Indian or Alaska Native	0.3%	0.3%	1.3%
Asian	1.6%	1.8%	2.2%
Other	0.9%	0.6%	0.6
Medicaid			
Yes	33.4%	37.6%	23.7%
No	66.6%	62.4%	76.3%
SCHIP			
Yes	38.9%	43.2%	51.5%
No	61.1%	56.8%	48.5%
Ever delayed shot (PACV1)			
Yes	16.6%	23.7%	-
No	83.4%	76.3%	-
Ever declined shot (PACV2)			
Yes	10.2%	14.2%	-
No	89.8%	85.8%	-
Total	2,332	678	624,977

Source for population demographics: 2018 American Community Survey (Tables DP02 and DP05). Source for Medicaid and SCHIP enrollment: https://www.medicaid.gov/medicaid/program-information/medicaid-and-chip-enrollment-data/report-highlights/index.html. There were no Native Hawaiian/Other Pacific Islander individuals in our sample, so we grouped individuals in those categories into the "Other" category for the Vermont population data (where they comprise 0.1% of the population). The full wording for the PACV1 and PACV2 items is included in the Online Appendix.

General parent study: Vaccine messages

Wave 2 of the survey included our vaccine messages. Participants were randomly assigned into one of four treatment conditions that varied whether or not they read a letter from VDH and the content of the letter. In the first condition, which served as a pure control, participants did not read any information from VDH. In the second (standard pro-vaccine message) condition, participants read a standard message from VDH about the importance of getting vaccinated that includes information on how to find a provider. In the third (social norm treatment) condition, participants read a message that included the text from the standard message but also reminded parents of the social consensus in Vermont to vaccinate to protect everyone from disease. In the final (myths and facts treatment) condition, participants read a message that included text from the standard message but also refuted common myths about vaccines with information from experts. The full text of each vaccine message is provided in the Online Appendix (see Figures A2–A4). After the treatment messages, participants were again asked a series of outcome questions that are described in the next section.

General parent study: Outcomes

Our analysis includes three survey outcome measures and two behavioral outcome measures. The survey outcome measures tap three different dimensions of parents' attitudes toward vaccines in Wave 2: their PACV outcome score (recoded such that higher values indicate lower vaccine hesitancy), which is comprised of a subset of questions from the PACV scale; their factual beliefs about vaccines, which is measured using two post-treatment survey questions about whether vaccines are safe and whether they have serious side effects; and their vaccine behavioral intentions, a measure based on two post-treatment survey questions about whether parents would follow the vaccination schedule if they were to have another child. We confirmed that each scale is unidimensional using principal components factor analysis and created composite measures for each after confirming that they did. More details on these questions and the indices we created are included in the Online Appendix.

With parental consent, we created the behavioral outcome measures based on VDH immunization registry data. These data were measured at the child level for each qualifying child in the household. For each child, we calculated a binary up-to-date measure which recorded if each child was up to date on the recommended seven-vaccine series of childhood vaccines (DTap, IPV, MMR, Hib, HepB, Var, and PCV) for their age group, and a continuous measure of the proportion of required doses they have received of the recommended vaccines, which adjusts for variation in the number of series and doses that are recommended for children of different ages.[6] The latter quantity was calculated as the total number of vaccine doses received in the recommended series over the maximum number that would be required for completion of all of the recommended series for the child's age group (a standard measure in the Vermont immunization program). The total number of vaccine doses required ranged from one to 24 depending on each child's age group (see the Online Appendix for more details on the vaccines required for each age group). We measured both of these behavioral outcomes six months following the close of the second survey wave.[7]

Non-compliance study

The non-compliance study was conducted on a separate sample of parents after closing Wave 2 of the general parent study.[8] This study tested the effect of similar social norms and myths and facts treatments on immunization status changes among children who were out of compliance with the recommended vaccine schedule. We randomized the content of letters sent from VDH to parents of non-up-to-date (UTD) 8-month-old and 20-month-old children on (approximately) the first of each month. These ages were selected following established practice for the routine

[6] An alternative continuous outcome measure is the number of days a child is under-vaccinated (e.g., Glanz et al. 2017); we chose to measure the proportion of vaccines received because we viewed it as the most direct public health outcome and the easiest to interpret, but future research might consider both indicators.

[7] Data privacy limitations preclude us from identifying what factors (declined vaccines, delayed vaccines, etc.) or which vaccines were most consistently associated with non-compliance.

[8] Due to an administrative error, we neglected to remove participants in the general parent study from the mailing lists for the non-compliance study as indicated in our preregistration. We therefore ended up with nine parents who participated in the general parent study and also received mailings for the non-compliance study. Because of potential spillover effects of the general parent study onto the non-compliance study, we excluded these individuals from both sets of analyses.

recall/reminder letters that VDH sends on a monthly basis.

The planned follow-up period was six months, but the study was terminated early due to changes in access and lower primary care utilization rates associated with COVID-19. The follow-up period for households who received the mailing ranged from one to four months depending on the mailing month. VDH conducted the randomization at the household level and mailed letters mid-month. Specifically, parents were randomly assigned to receive one of three versions of the letter: (1) the standard pro-vaccine message currently in use, which serves as the baseline; (2) a version that includes an additional social norms treatment; or (3) a version that includes an additional myths and facts treatment. These mirrored the treatments in the general parent study (see Figures A2–A4 in the Online Appendix).

Behavioral outcome measures mirroring those described above were measured at recruitment and follow-up. Immunization histories were provided by the Vermont immunization registry. VDH calculated up-to-date status at baseline (the start of each month in which the letter was sent) and at follow-up in mid-March. A total of 808 households, including 815 children, were randomized. Follow-up data was available for 618 of the children, corresponding to 613 households.[9] VDH provided a de-identified dataset for analysis.

Results

Our analyses employ Ordinary Least Squares regression (OLS) with robust standard errors clustered by household for all child-level immunization registry outcomes. In the Online Appendix, we also present regression results for our binary dependent variable in both the general parent study and the non-compliance study (proportion up to date on all vaccines) using probit models (see Table A3). In each model, outcome variables are constructed such that higher values indicate more positive vaccine attitudes, more accurate vaccine beliefs, greater intent to vaccinate, or higher levels of vaccine compliance.

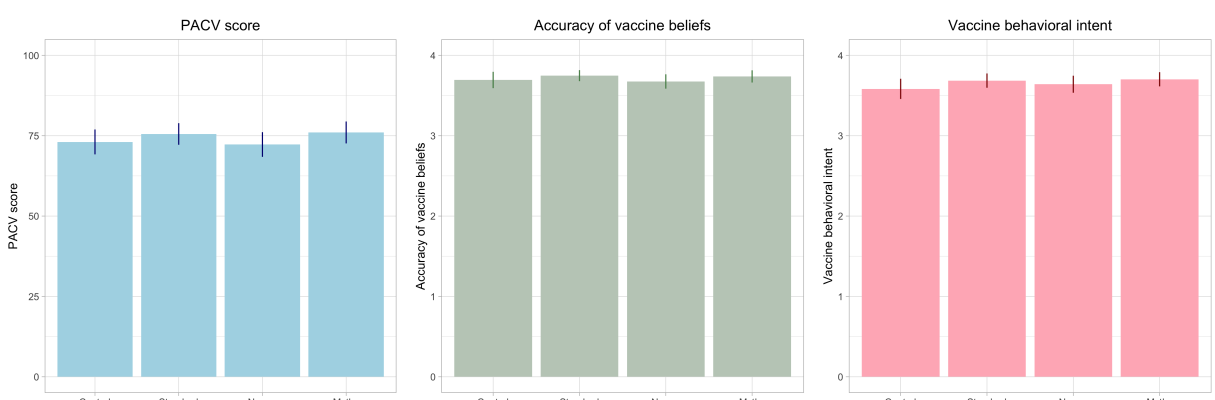
[9] We excluded 30 children whose parents received letters in March, since they likely would not have had time to get vaccinations before we terminated the study and collected outcome data.

To examine the precision of these results, we also conduct a series of equivalence tests. The goal of equivalence tests is to explicitly test whether meaningful effects are plausible by defining the bounds of the confidence interval that contains the estimate (e.g., Lakens, Scheel, and Isager 2018). Specifically, we examine if we can rule out large effects by measuring whether we can reject effects larger than a given effect size. To run this analysis, we use the `TOSTER` package in R (Lakens 2017), setting the significance level to $p < 0.05$ (equivalent to two one-sided tests with 90% confidence intervals) and selecting tests with unequal variances.

General parent study: Outcomes

We begin with the survey outcomes for the general parent study. These results are presented in the first three columns (Models 1–3) of Table 2 and graphically in Figure 1. The statistical models we report in Table 2 control for Wave 1 (pre-treatment) PACV outcome score (recoded such that higher values indicate lower vaccine hesitancy) and mean proportion up to date on all vaccines at the household level before treatment. As the results show, we do not find support for Hypothesis 1 or 2. Neither the social norms message nor the myths and facts message had a significant effect on parents' attitudes toward vaccines, the accuracy of their beliefs about vaccines, or their intent to vaccinate a future child. Effects for the standard message were similarly null.

Figure 1: General parent study survey outcomes



Mean PACV outcome score (recoded; left), accuracy of vaccine beliefs (middle), and vaccine behavioral intent (right) by treatment group for the general parent study.

Table 2: General parent study message effects on survey and behavioral outcomes

	Vaccine attitudes (1)	Vaccine beliefs (2)	Vaccine intent (3)	Vaccines up to date (binary) (4)	Share of vaccinations (5)
Standard	0.785	0.023	0.044	0.022	−0.004
	(1.362)	(0.048)	(0.045)	(0.025)	(0.003)
Norms	−1.730	−0.035	0.027	0.011	−0.003
	(1.469)	(0.054)	(0.051)	(0.027)	(0.004)
Myths	1.177	0.014	0.065	0.017	0.000
	(1.361)	(0.049)	(0.048)	(0.027)	(0.004)
Norms − standard	−2.515	−0.058	−0.017	−0.010	0.001
	(1.410)	(0.049)	(0.046)	(0.025)	(0.002)
Myths − standard	0.392	−0.010	−0.021	−0.005	0.004
	(1.327)	(0.046)	(0.043)	(0.025)	(0.003)
Norms − myths	-2.907^*	−0.049	−0.038	−0.006	−0.003
	(1.414)	(0.049)	(0.046)	(0.027)	(0.004)
Controls	✓	✓	✓	✓	✓
Clustered by household	No	No	No	Yes	Yes
Number of parents	678	678	678	-	-
Number of children	-	-	-	1,070	1,070

$^*p < 0.05$. OLS regression models with standard errors shown in parentheses. Estimates are relative to the control group, which was exposed to no information. Control variables include Wave 1 PACV score and baseline proportion up to date on all vaccines at the household level for the vaccine attitudes, beliefs, and intent outcomes and baseline proportion up to date on all vaccines at the child level for the vaccines up-to-date and share of vaccines outcome measures. For each outcome, higher values indicate more positive vaccine attitudes (lower hesitancy), more accurate beliefs about vaccines, higher intent to vaccinate, and higher vaccine compliance. See Methods section and Online Appendix for details on variable construction.

The fourth row of Table 2 shows the estimated difference in effects between the myths and facts treatment and the social norms treatment. As the first column of that row shows, the myths and facts treatment was significantly more effective at improving attitudes toward vaccines than the social norms treatment. Average Wave 2 attitudes toward vaccines were about three percentage points higher (on the 100-point PACV scale) among participants who read the myths and facts message than among those who read the social norms message. However, this difference is the only significant effect we observed; there were no other significant differences between any of the treatments we tested in effectiveness at changing attitudes toward vaccines, accuracy of vaccine beliefs, or intent to vaccinate.

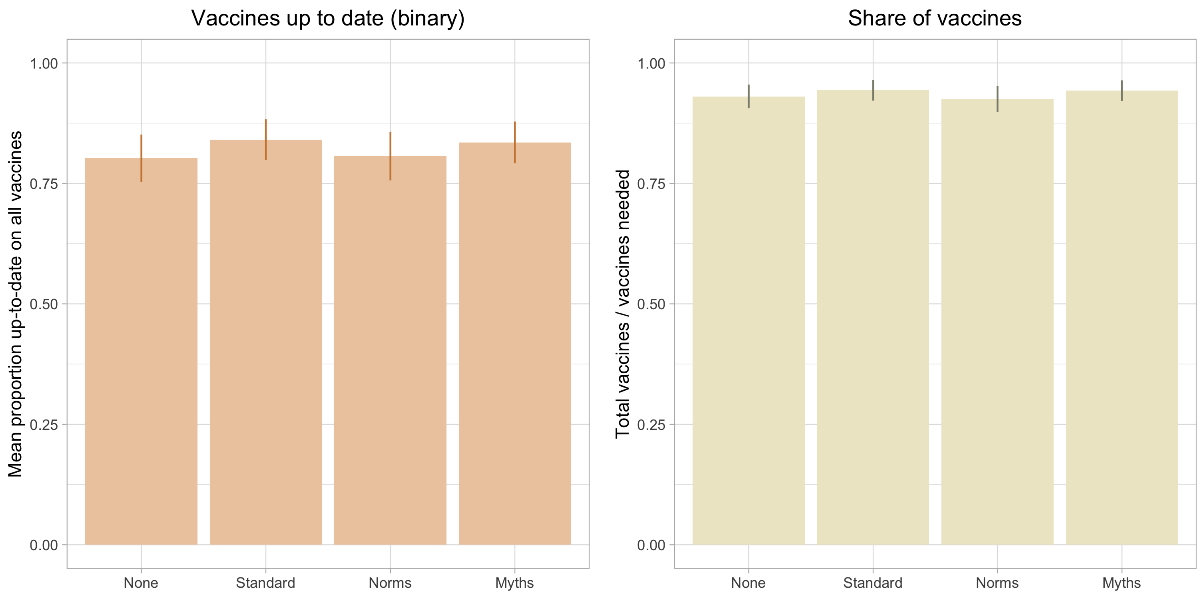
Equivalence tests allow us to examine the precision of these null results. Because we hypothesized that the treatments would have positive effects, we focus on estimating the size of the positive effects that we can confidently reject. For example, we can reject positive effects greater than 1.8 percentage points for the effects of the standard message on the PACV score measure of vaccine attitudes (out of 100). We can also reject PACV effects greater than 5.4 percentage points and 1.4 percentage, respectively, for the social norms and myths and facts messages relative to the control condition. In other words, we can be statistically confident that the treatments did not improve vaccine attitudes by more than 1.8, 5.4, or 1.4 percentage points for the respective treatments on the 100-point PACV scale. For the vaccine beliefs outcome, we can reject effects larger than 0.05 on a 1–4.5 scale for the standard message, 0.13 for the social norms message, and 0.06 for the myths and facts message. Finally, for the intent to vaccinate outcome, we can reject effects larger than 0.03 on a 1–4 scale for the standard message, 0.08 for the social norms message, and 0.01 for the myths and facts message.

Substantively, these results illustrate that we can confidently rule out large positive effects of the treatments on all of our survey outcomes. While small effects remain possible, they would very likely be smaller than the values reported above and as such would not represent fundamental changes in attitudes, beliefs, or vaccination intentions. For instance, an increase of 0.13 on the vaccine beliefs outcome would not change a parent's rating of a true statement about vaccine safety from "not at all accurate" to "not very accurate."

We now turn to the behavioral outcomes for the general parent study, which are shown graphically in Figure 2 and in columns 4–5 of Table 2. These models control for mean proportion up to date on all vaccines at the child level before treatment. We consider two behavioral outcome measures: a binary indicator of whether or not a child is up to date on all of the recommended vaccines for their age group and a continuous measure that divides the total number of vaccines a child has by the total number he or she should have at a given age. Both are measured six months after parents took the Wave 2 survey with the vaccine messages.

We find no significant effects of any treatment on either our binary indicator of being up to date

Figure 2: General parent study behavioral outcomes



Mean proportion of children who are up to date on all recommended vaccines (left) and mean number of vaccines a child has divided by the total number of vaccines recommended for his or her age group (right) by treatment group six months post-treatment in the general parent study.

on vaccines or our continuous measure of vaccination status.[10] The effects of the standard message, the social norms message, and the myths and facts condition were not statistically different from the control condition with no information, nor were they measurably different from each other.

We again conduct equivalence tests to evaluate the effect sizes we can confidently rule out. Relative to a control condition with no information, we can confidently reject *any* increase in the probability of a child being up to date on all of their vaccines for the standard message. Similarly, we can reject increases in the probability of being up to date larger than 0.05 for the social norms message and 0.04 for the myths and facts message. Finally, we can reject any increase in vaccine share for the standard message for the number of vaccines a child has over the number he or she needs as well as increases in vaccine share larger than 0.02 and 0.01 for the social norms and myths and facts messages, respectively. In substantive terms, these findings indicate that none of

[10] In the Online Appendix, we also evaluate the accuracy of parents' past reports of vaccine compliance by regressing our binary and continuous measures of vaccination status on past vaccine behavior (see Table A2). Consistent with Opel et al. (2013), the results suggest that self-reported non-compliance is a strong indicator of actual non-compliance, alleviating concerns about social desirability bias in vaccine behavior reporting.

the treatments would lead to more than one additional shot for a child of any eligible age in the general parent study compared to receiving no information.

Non-compliance study: Outcomes

We next turn to the non-compliance study conducted among parents of children who were out of compliance with the CDC's recommended vaccine schedule.[11] We use the same two behavioral outcomes as in the general parent study. Both are measured between one and four months after the child's parents were sent a letter depending on when the letter was received. Consistent with our preregistration, there are no control variables in these models.

Unlike the general parent study, there is not a pure control condition in the non-compliance study in which some parents see no information. All parents whose children were out of compliance with the recommended vaccine schedule received a mailing. As a result, the baseline condition in our analyses is the standard message used by VDH. Each coefficient thus represents the difference in effects attributable to the social norms or myths and facts treatment relative to the standard message.

Our results, which are presented in Table 3 and graphically in Figure 3, indicate that social norms treatment had no statistically significant effect on vaccination behavior for either the binary up-to-date measure or the continuous measure of vaccination status relative to the standard message used by VDH. There was also no significant effect of the myths and facts treatment on either outcome relative to the standard message, and the difference between the social norms treatment and the myths and facts treatment was not significant. These results provide no evidence that the treatment messages changed vaccine behavior among parents of non-compliant children.

Our equivalence test results again rule out the possibility of large effects. Relative to the standard message, we can confidently reject increases in the probability of a non-compliant child being

[11] The non-compliance study data provided by VDH included a small number of children (n = 71) whose registry information indicates that they were up to date on all of their vaccines before the study. In the interest of transparency, we include these children in the analyses reported in the main text, but we also report analyses that exclude them in Table A5 and Figure A7 in the Online Appendix. The conclusions we draw from those results are substantively identical to those reported in the main text.

Table 3: Non-compliance study effects on vaccine behavior

	Vaccines up to date (binary) (1)	Share of vaccinations (2)
Norms	−0.016	−0.006
	(0.042)	(0.031)
Myths	−0.055	0.045
	(0.040)	(0.028)
Norms − myths	0.039	−0.050
	(0.041)	(0.030)
Controls	✗	✗
Clustered by household	Yes	Yes
Number of children	618	618

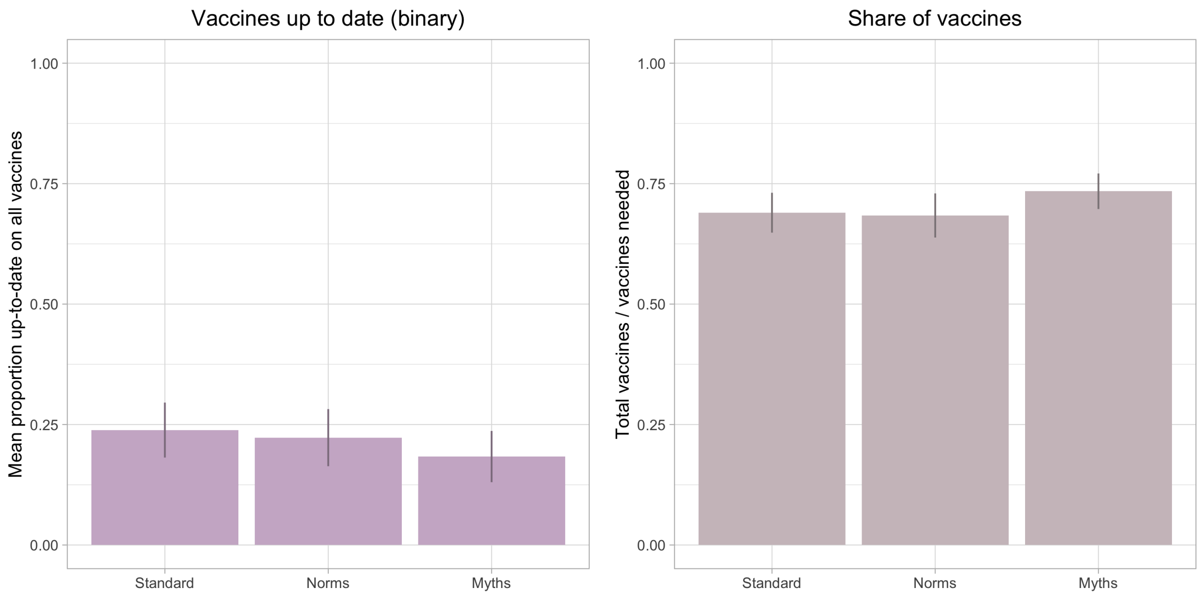
$^{*}p < 0.05$. OLS regression models with standard errors shown in parentheses. Estimates are relative to the standard message used by VDH. No control variables. For each outcome, higher values indicate higher vaccine compliance.

up to date on all of their vaccines larger than 0.08 for the social norms message and larger than 0.12 for the myths and facts message. Moreover, we can reject increases larger than 0.06 for the social norms message and can rule out any significant positive effects for the myths and facts message on the total number of vaccines a child at a given age has divided by the number the child is supposed to have. In substantive terms, we again have no evidence that either treatment would lead to more than one additional shot for a child in the non-compliance study compared to the standard message used by VDH.

Discussion

The results of our study suggest that pro-vaccine messaging strategies may fail to improve vaccine attitudes, intentions, and behavior among parents of children in Vermont. Across two studies and five different outcomes, we find no significant effects of messages emphasizing social norms around vaccination or refuting myths about vaccines with scientific evidence relative to either a pure control condition with no information or standard pro-vaccine messaging used by public health officials. In contrast to findings suggesting that standard pro-vaccine reminder messages can increase compliance (e.g., Jacob et al. 2016), we also found that the message currently in

Figure 3: Non-compliance study outcomes



Mean proportion of children who are up to date on all recommended vaccines (left) and mean number of vaccines a child has divided by the total number of vaccines recommended for his or her age group (right) by treatment group in the non-compliance study.

use was ineffective relative to a no-information condition — a result worth revisiting in future research. These findings corroborate previous research finding limited evidence that messaging strategies change how people think about emotionally charged health issues like vaccinations (e.g., McCaul, Johnson, and Rothman 2002; Gerend and Shepherd 2007; Erceg-Hurn and Steed 2011).

Our results do have some important limitations. First, we were only able to test two novel messages in addition to the messaging currently used by the Vermont Department of Health. Other approaches, such as those that effectively invoke potential risks, losses, or fear, could have different effects (e.g., Rothman and Salovey 1997; Witte and Allen 2000; Bartels, Kelly, and Rothman 2010), although these types of framing have also been shown to have counterproductive effects in certain circumstances (Nyhan et al. 2014). The effectiveness of message that incorporate insights from marketing and advertising could also be explored (Eisend and Tarrahi 2016; Rosengren et al. 2020). Especially in the context of the COVID-19 pandemic, research should continue to test other messages that could improve vaccine attitudes and compliance (Facher 2021). Additionally, our partnership with VDH meant that we could not test the effects of messages originating from other sources. Given concerns about low trust in the government and public health organizations (e.g., Cooper, Larson, and Katz 2008), perhaps other message sources would be more effective.

Third, participants in the control condition in the general parent study were exposed to no information. Future studies should verify that providing information about an unrelated topic in a placebo condition does not produce a different pattern of results. Fourth, we were only able to test the influence of pro-vaccine messages in Vermont, a state that is not very representative of the United States, particularly with respect to racial diversity and urbanization. Future research should examine the effectiveness of vaccine messaging strategies on more diverse and representative samples. Fifth, in focusing on the core survey and behavioral outcomes, we are unable to identify the mechanisms by which messages could change vaccine attitudes and behavior — another important area for future research.

Finally, vaccine attitudes at baseline in the general parent study were more favorable than expected, which meant that our sample included many people who were not very hesitant toward vaccines even after we excluded the third of our sample that was least hesitant. Potential ceiling effects resulting from the presence of these individuals in the sample could help explain why we failed to change vaccine attitudes, beliefs, and intentions with our vaccine messages. Future studies should seek to recruit larger participant samples of individuals with high vaccine hesitancy (as measured by composite PACV score) and/or a history of having delayed or declined vaccines for their children in the past.

Despite these limitations, our study makes important theoretical and research design contributions. To our knowledge, this is the first study examining the effects of vaccine messaging strategies on vaccine attitudes, beliefs, intent (as measured in a survey), and real immunization behavior among both parents and children. By combining a survey with public health data, we identify a fruitful approach for future research on vaccine attitudes and behavior, which should more frequently evaluate the effects of interventions using experimental designs and behavioral outcome data. More broadly, these findings suggest that approaches to changing vaccine behavior should be tested carefully before being implemented by any public health organization.

Conclusion

Our results have important implications for both public health strategies and the design of future studies on vaccine attitudes and behavior. First, we demonstrate that two important strategies that are frequently used to try to improve vaccine attitudes and compliance — a social norms message and a myths and facts message — do not improve vaccination outcomes among a large sample of parents and their children. These results illustrate the need for further testing of these and other types of messages (e.g., Nowak, Shen, and Schwartz 2017). It is possible that the effects of messages promoting immunization are similarly effective (e.g., Hallsworth, Mirpuri, and Toth 2021) and that both scholars and practitioners focus too much on differences between messages rather than, e.g., reaching the individuals who may be most likely to change their behavior in response to credible messages.

Absent large-scale evaluations on state populations (e.g., Chen et al. 2020), our results also indicate that messaging interventions may be unlikely to generate measurable effects on behavior. Immunization programs seeking to test the effects of such messages will need thousands of participants to detect small but potentially meaningful effects on behavioral outcomes. We therefore recommend that future research on vaccine messaging be deployed among larger participant samples and/or delivered in higher dosages that are more likely to affect vaccine attitudes, intentions, and behavior. Indeed, our findings indicate that reducing vaccine hesitancy is a significant challenge that may require new and innovative approaches among advocates and policymakers.

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Online Appendix

Evaluating the Effects of Vaccine Messaging on Immunization Intentions and Behavior

Additional pre-registered research questions

In addition to the hypotheses and research question that we reported in the main text, we offered four additional research questions that we describe below.

Our design tests the effects of a standard pro-vaccine message used by the Vermont Department of Health. We do not have strong theoretical priors about how this message will affect vaccine attitudes and behavior but are interested in measuring its effects and how they compare to both the social norms treatment and the myths and facts treatment. We therefore offer the following research questions:

> RQ2: Does a standard pro-vaccine message affect vaccine-hesitant parents' favorability toward vaccines (RQ2a), their self-reported intention to vaccinate (RQ2b), or their children's vaccination compliance (RQ2c) compared to a control condition?
>
> RQ3: Does providing reminders of the social norm in support of vaccination affect vaccine-hesitant parents' favorability toward vaccines (RQ3a), their self-reported intention to vaccinate (RQ3b), or their children's vaccination compliance (RQ3c) compared to a standard pro-vaccine message?
>
> RQ4: Does correcting myths about vaccine safety affect vaccine-hesitant parents' favorability toward vaccines (RQ4a), their self-reported intention to vaccinate (RQ4b), their children's vaccination compliance (RQ4c), or the accuracy of their beliefs about the effects of vaccines (RQ4d) compared to a standard pro-vaccine message?

We also offer a research question about the effects of our social norm treatment on reported misperceptions about vaccine side effects. Unlike the myths and facts treatment, the social norms treatment is not explicitly designed to reduce perceived accuracy of false information, but we are interested in whether social pressure represents an alternative route by which people might report more accurate vaccine beliefs.

> RQ5: Do reminders of the social norm in support of vaccination affect reported misperceptions about vaccine side effects among vaccine-hesitant parents compared to a control condition (RQ5a) or a general pro-vaccine message (RQ5b)?

Sample survey materials

Figure A1: Sample general parent study mailing

VERMONT PARENTAL SURVEY

UNIVERSITY OF MICHIGAN

1*1*2***********ALL FOR AADC 050
Parent/Guardian of [redacted]

Dear Vermont Parent or Guardian:

I am writing to invite one parent or guardian in your household to participate in a survey about public health issues in Vermont. This research project is being conducted by Professor Brendan Nyhan at the University of Michigan in collaboration with the Vermont Department of Health and Dartmouth College.

Your participation is voluntary. Participation involves completing a brief survey, which will take about 15 minutes. You may choose to not answer any or all questions. **If you complete today's survey by August 7, 2019, we will send you a $5 gift card to Amazon, Walmart, or another retailer of your choice.**

The information collected during this survey will be maintained confidentially. On the survey, we will ask you to share your views on public health issues. We will also request basic information about you and your child(ren), including name and age. There is a chance that your information could accidentally be disclosed, but we have put stringent data security procedures in place to minimize this risk. Names and other identifying information of participants will not be disclosed publicly by the researchers or used in any presentation or paper written about this project.

To participate, please navigate to this website and enter the following access code:

Link: www.vtsurvey.org
Access Code: hubcap18

Please note that only one parent or guardian in your household may participate.

Thank you for considering our request. If you have questions about your rights as a research participant, please contact the University of Michigan HSBS Institutional Review Board at (866) 936-0933 or irbhsbs@umich.edu. For other questions about the project or to obtain a translation of this document, please contact Professor Nyhan at bnyhan@umich.edu or Meredith Graves at the Vermont Department of Health at (800) 464-4343; AHS.VDHPublicCommunication@vermont.gov (please type "Parent Study" in the subject line of the email).

Sincerely,

Brendan Nyhan
Professor of Public Policy and Principal Investigator
University of Michigan

Figure A1 shows a sample mailing that parents invited to participate in Wave 1 of the general parent study received. Identifying information has been redacted. Brendan Nyhan, one of the researchers, was affiliated with the University of Michigan at the time the survey was launched.

Figure A2: General parent study standard message treatment

VERMONT
DEPARTMENT OF HEALTH

Division of Health Surveillance
Immunization Program
P.O. Box 70
Burlington, VT 05401
http://healthvermont.gov

Dear Parent or Guardian:

We are writing to encourage you to make sure your child's immunizations are up to date. Vaccines have saved millions of lives by preventing diseases such as polio and measles and reducing dangerous infections. With the help of health care providers in our state, my colleagues and I at the Vermont Department of Health are working to help babies and toddlers get all the shots they need.

It's important to make sure that your child is up to date on his or her immunizations. If you're not sure if your child is fully vaccinated, call your child's health care provider to find out if they are due for any vaccinations. If you don't have a provider, visit http://www.healthvermont.gov/local to locate a public clinic near you.

Thank you for your attention to this important issue.

Sincerely,

Christine Finley

Christine Finley, APRN, MPH
Immunization Program Manager
Vermont Department of Health

Figure A2 shows the standard pro-vaccine message experimental condition in Wave 2 of the general parent study. This is a standard message from VDH about the importance of getting vaccinated that includes information on how to find a provider. 186 participants who completed the survey were randomly assigned to this treatment group (163 were randomly assigned to the control condition, in which no letter was shown). A similar message was shown for the standard pro-vaccine message experimental condition in the non-compliance study (with 218 participants randomly assigned to the standard pro-vaccine message experimental condition).

Figure A3: General parent study social norms treatment

VERMONT
DEPARTMENT OF HEALTH

Division of Health Surveillance
Immunization Program
P.O. Box 70
Burlington, VT 05401
http://healthvermont.gov

Dear Parent or Guardian:

We are writing to encourage you to make sure your child's immunizations are up to date. Vaccines have saved millions of lives by preventing diseases such as polio and measles and reducing dangerous infections. With the help of health care providers in our state, my colleagues and I at the Vermont Department of Health are working to help babies and toddlers get all the shots they need.

As a parent, you carefully consider each decision you make that impacts your child's health. If you're feeling uncertain, it can help to learn more about the safety and effectiveness of vaccines. This information is from the Centers for Disease Control and Prevention.

What do most parents in Vermont think about vaccines? Here in our state, most parents decide that the benefits of vaccination are greater than the risks and follow expert recommendations to get their children immunized.

- Nearly three quarters (75%) of Vermont children under age three are fully vaccinated and 90 percent are up to date on all vaccines by the time they enter kindergarten.

How do parents' decisions to vaccinate affect public health in Vermont? Vaccines protect your child from preventable diseases. They also protect other people in our community who come into contact with your child.

- If too many Vermont parents choose not to vaccinate their children, the risk of a disease outbreak in our state increases.

Which Vermonters are put at greatest risk if vaccination rates decline? People with weaker immune systems are more likely to become ill from vaccine-preventable diseases.

- Newborns, elderly adults, and sick children in Vermont are at greatest risk from vaccine-preventable disease outbreaks.

It's important to make sure that your child is up to date on his or her immunizations. If you're not sure if your child is fully vaccinated, call your child's health care provider to find out if they are due for any vaccinations. If you don't have a provider, visit http://www.healthvermont.gov/local to locate a public clinic near you.

Thank you for your attention to this important issue.

Sincerely,

Christine Finley

Christine Finley, APRN, MPH
Immunization Program Manager
Vermont Department of Health

Figure A3 shows the social norms experimental condition in Wave 2 of the general parent study. This message includes the text from the standard message but also reminds parents that the social consensus in Vermont in favor of vaccination is strong and that vaccinations protect people in the state from disease. 146 participants were randomly assigned to this treatment group. A similar message was shown for the social norms experimental condition in the non-compliance study (with 193 participants randomly assigned to the social norms experimental condition).

Figure A4: General parent study myths and facts treatment

VERMONT
DEPARTMENT OF HEALTH

Division of Health Surveillance
Immunization Program
P.O. Box 70
Burlington, VT 05401
http://healthvermont.gov

Dear Parent or Guardian:

We are writing to encourage you to make sure your child's immunizations are up to date. Vaccines have saved millions of lives by preventing diseases such as polio and measles and reducing dangerous infections. With the help of health care providers in our state, my colleagues and I at the Vermont Department of Health are working to help babies and toddlers get all the shots they need.

As a parent, you carefully consider each decision you make that impacts your child's health. If you're feeling uncertain, it can help to learn more about the safety and effectiveness of vaccines. This information is from the Centers for Disease Control and Prevention.

Vaccines are extremely safe. If vaccine side effects occur, they are almost always mild and go away within a few days. Research shows that serious side effects after vaccination are very rare. If they occur, doctors and clinic staff are trained to deal with them.

- An analysis of more than 1,000 studies found that few health problems are caused by or clearly associated with vaccines.

Children's immune systems can easily handle vaccines. Every day, a healthy child's immune system successfully fights off thousands of germs. Researchers agree that immunizing children is safe and does not harm their immune systems.

- Studies show that vaccines do not damage, weaken, or overload the immune system. Vaccines boost the immune system.

Vaccination protects your child from risk. If your child gets a vaccine-preventable disease, you can't predict whether or not they will only experience a mild illness or become very sick.

- Travelers continue to bring measles into the U.S. from other parts of the world, where approximately 90,000 people died from the disease in 2016 — mostly children under age 5.

It's important to make sure that your child is up to date on his or her immunizations. If you're not sure if your child is fully vaccinated, call your child's health care provider to find out if they are due for any vaccinations. If you don't have a provider, visit http://www.healthvermont.gov/local to locate a public clinic near you.

Thank you for your attention to this important issue.

Sincerely,

Christine Finley

Christine Finley, APRN, MPH
Immunization Program Manager
Vermont Department of Health

Figure A4 shows the myths and facts experimental condition in Wave 2 of the general parent study. This message includes text from the standard message but also refutes common myths about vaccines with information from experts. 183 participants were randomly assigned to this treatment group. A similar message was shown for the myths and facts experimental condition in the non-compliance study (with 207 participants randomly assigned to the myths and facts experimental condition).

Outcome variable construction: Vaccine attitudes

To measure vaccine attitudes, we used the Parent Attitudes about Childhood Vaccines (PACV) scale (Opel et al. 2011). The full scale is displayed below, with overall PACV scores calculated by summing points across all questions (point values for each response are shown in brackets); note, however, that our PACV outcome variable uses a subset of these items as described below.

1. PACV1: Have you ever delayed having your child get a shot (not including seasonal flu or swine flu (H1N1) shots) for reasons other than illness or allergy?
   - Yes [2]
   - No [0]

2. PACV2: Have you ever decided not to have your child get a shot (not including seasonal flu or swine flu (H1N1) shots) for reasons other than illness or allergy?
   - Yes [2]
   - No [0]

3. PACV3: How sure are you that following the recommended shot schedule is a good idea for your child? Please answer on a scale of 0 to 10, where 0 is "not at all sure" and 10 is "completely sure."
   - 0 (Not at all sure) [2]
   - 1 [2]
   - 2 [2]
   - 3 [2]
   - 4 [2]
   - 5 [2]
   - 6 [1]
   - 7 [1]
   - 8 [0]
   - 9 [0]
   - 10 (Completely sure) [0]

4. PACV4: Children get more shots than are good for them.
   - Strongly agree [2]
   - Agree [2]
   - Not sure [1]
   - Disagree [0]
   - Strongly disagree [0]

5. PACV5: I believe that many of the illnesses that shots prevent are severe.
   - Strongly agree [2]
   - Agree [2]
   - Not sure [1]
   - Disagree [0]
   - Strongly disagree [0]

6. PACV6: It is better for my child to develop immunity by getting sick than to get a shot.
    - Strongly agree [2]
    - Agree [2]
    - Not sure [1]
    - Disagree [0]
    - Strongly disagree [0]

7. PACV7: It is better for children to get fewer vaccines at the same time.
    - Strongly agree [2]
    - Agree [2]
    - Not sure [1]
    - Disagree [0]
    - Strongly disagree [0]

8. PACV8: How concerned are you that your child might have a serious side effect from a shot?
    - Not at all concerned [0]
    - Not too concerned [0]
    - Not sure [1]
    - Somewhat concerned [2]
    - Very concerned [2]

9. PACV9: How concerned are you that any one of the childhood shots might not be safe?
    - Not at all concerned [0]
    - Not too concerned [0]
    - Not sure [1]
    - Somewhat concerned [2]
    - Very concerned [2]

10. PACV10: How concerned are you that a shot might not prevent the disease?
    - Not at all concerned [0]
    - Not too concerned [0]
    - Not sure [1]
    - Somewhat concerned [2]
    - Very concerned [2]

11. PACV11: If you had another child today, would you want him/her to get all the recommended shots?
    - Yes [0]
    - No [2]
    - Don't know [1]

12. PACV12: Overall, how hesitant about childhood shots would you consider yourself to be?
    - Not at all hesitant [0]
    - Not too hesitant [0]
    - Not sure [1]
    - Somewhat hesitant [2]

- Very hesitant [2]

13. PACV13: I trust the information I receive about shots.
    - Strongly agree [0]
    - Agree [0]
    - Not sure [1]
    - Disagree [2]
    - Strongly disagree [2]

14. PACV14: I am able to openly discuss my concerns about shots with my child's doctor.
    - Strongly agree [0]
    - Agree [0]
    - Not sure [1]
    - Disagree [2]
    - Strongly disagree [2]

15. PACV15: All things considered, how much do you trust your child's doctor? Please answer on a scale of 0 to 10, where 0 is "do not trust at all" and 10 is "completely trust."
    - 0 (Do not trust at all) [2]
    - 1 [2]
    - 2 [2]
    - 3 [2]
    - 4 [2]
    - 5 [2]
    - 6 [1]
    - 7 [1]
    - 8 [0]
    - 9 [0]
    - 10 (Completely trust) [0]

As indicated in our pre-registration, we used a subset of the PACV scale to measure participants' post-treatment attitudes towards vaccines. Specifically, we excluded questions PACV1–2 and PACV14–15, which ask about past vaccination behavior and trust in pediatricians, respectively, because they are unrelated to our experimental treatments. We also excluded PACV11 because it is part of our behavioral intent measure (described below). After excluding these elements of PACV scale, we conducted principal components factor analysis on the remaining Wave 2 PACV vaccine attitudes subscale and confirmed that the items loaded on a single dimension. The first principal component explains 48.9% of the variance, and the Cronbach's Alpha for the final scale is 0.489. We then summed the items and rescaled them on a 0–100 scale to create a PACV outcome score. For our analyses, we reverse-coded this scale by subtracting the calculated scores from 100 such that positive coefficients in our regression model would correspond to more positive attitudes towards vaccines—a deviation from Opel et al. (2011). We used this outcome to test our hypotheses about the effects of the treatments on vaccine attitudes in the general parent study.

We measured factual beliefs about vaccines with the following two questions.

1. Just based on what you know, how accurate is the following claim? *Vaccines are safe for children's immune systems.*
    - Very accurate [4]
    - Somewhat accurate [3]
    - Not very accurate [2]
    - Not at all accurate [1]

2. Just based on what you know, how likely is it that children who get a vaccine will suffer serious side effects?
    - Extremely likely [1]
    - Very likely [2]
    - Moderately likely [3]
    - Not too likely [4]
    - Not at all likely [5]

We again conducted principal components factor analysis to check whether these two items load on a single dimension. The first principal component explained 76.0% of the variance, and Cronbach's α was 0.683. We therefore created a composite measure for vaccine belief accuracy by taking an average of the two items. Higher scores indicate more accurate beliefs about vaccines.

Finally, we measured vaccine behavioral intentions with the following two questions—one that was adapted from Nyhan et al. (2014) to apply to all vaccines (rather than just MMR) and one that was adapted from the PACV scale (PACV11 but with the word "child" substituted for infant because some of the parents in our study no longer have an infant).

1. If you had another child, how likely is it that you would give him/her all of the recommended vaccines?
    - Very likely [6]
    - Somewhat likely [5]
    - Slightly likely [4]
    - Slightly unlikely [3]
    - Somewhat unlikely [2]
    - Very likely [1]

2. If you had another child today, would you want him/her to get all the recommended shots?
    - Yes [3]
    - No [1]
    - Don't know [2]

Again, we conducted principal components factor analysis to check whether these two items load on a single dimension. The first principal component explained 92.9% of the variance, and Cronbach's Alpha was 0.830. We created a composite measure for vaccine behavioral intent by taking an average of the two items. Higher scores indicate higher intent to vaccinate.

Outcome variable construction: Vaccine behavior

Our behavioral outcome measures come from the Vermont Immunization Registry. These data were measured at the child level for each qualifying child in the household; the statistical analyses reported in the results section of the manuscript cluster on households to account for dependency within families in behavior. Specifically, we measured (1) whether each child was fully up to date with the recommended vaccine series (see below) and (2) the proportion of required doses received of the recommended vaccines, which adjusts for the differing number of series and doses at different ages. Children in each age range were expected to have the vaccines listed below for that range regardless of where they fell in that range. We measured both of these behavioral outcomes six months following the close of the second survey wave for the general parent study, and between one and four months after the mailing month in the non-compliance study. The planned follow-up period for the non-compliance study was six months, but was ended early due to changes in access and avoidance of primary care associated with COVID-19.

We used the following standard to determine whether a child is up to date (standards vary depending on child's age). Children are expected to have the vaccines listed regardless of where they fall in the relevant age range. For each child, we calculated a binary up-to-date measure and a proportion of doses required to measure whether each child was compliant. We calculated the latter quantity as the total number of vaccine doses received in the recommended series over the maximum number that would be required for completion of all of the recommended series for the child's age group (a standard measure in the Vermont state immunization program). The binary up-to-date measure recorded whether or not each child was up to date on all recommended series for the relevant age group.

The required vaccines for each age range are shown below:

1. Birth–2 months (1 series):
    - DTap: 0
    - IPV: 0
    - MMR: 0
    - Hib: 0
    - HepB: 1
    - Var: 0
    - PCV: 0

2. 3–4 months (5 series):
    - DTap: 1
    - IPV: 1
    - MMR: 0
    - Hib: 1
    - HepB: 2
    - Var: 0
    - PCV: 1

3. 5–6 months (5 series):

- DTap: 2
- IPV: 2
- MMR: 0
- Hib: 2
- HepB: 2
- Var: 0
- PCV: 2

4. 7–15 months (5 series):
    - DTap: 3
    - IPV: 3
    - MMR: 0
    - Hib: 3
    - HepB: 3
    - Var: 0
    - PCV: 3

5. 16–18 months (5 series):
    - DTap: 3
    - IPV: 3
    - MMR: 1
    - Hib: 4
    - HepB: 3
    - Var: 1 (or history of disease)
    - PCV: 4

6. 19 months–6 years (7 series):
    - DTap: 4
    - IPV: 3
    - MMR: 1
    - Hib: 4
    - HepB: 3
    - Var: 1 (or history of disease)
    - PCV: 4

7. 7 years–10 years (7 series):
    - DTap: 5
    - IPV: 4
    - MMR: 2
    - Hib: 4
    - HepB: 3
    - Var: 2 (or history of disease)
    - PCV: 4

Sample geographic representation

Table A1: General parent study sample vs. Vermont population representation by zip code

Zip code	Population	Population percentage	Sample	Sample percentage
05401	28913	4.65	20	1.76
05452	21444	3.45	68	5.97
05701	20031	3.22	35	3.07
05403	18695	3.01	28	2.46
05641	16382	2.63	33	2.90
05301	16341	2.63	31	2.72
05446	15892	2.55	38	3.34
05478	14802	2.38	25	2.19
05201	14197	2.28	35	3.07
05468	13694	2.20	26	2.28
05602	11785	1.89	26	2.28
05753	10444	1.68	14	1.23
05495	10148	1.63	23	2.02
05408	9512	1.53	32	2.81
05001	9303	1.50	10	0.88
05819	9145	1.47	12	1.05
05156	9112	1.46	22	1.93
05488	8239	1.32	17	1.49
05482	7799	1.25	7	0.61
05404	7232	1.16	11	0.97
05855	7147	1.15	7	0.61
05443	6930	1.11	12	1.05
05663	6597	1.06	7	0.61
05851	6491	1.04	12	1.05
05733	5933	0.95	9	0.79
05661	5832	0.94	18	1.58
05491	5803	0.93	7	0.61
05465	5414	0.87	9	0.79
05450	5136	0.83	11	0.97
05346	5111	0.82	10	0.88
05454	5051	0.81	11	0.97
05676	4862	0.78	5	0.44
05461	4633	0.74	16	1.40
05089	4552	0.73	12	1.05
05477	4504	0.72	7	0.61
05060	4495	0.72	7	0.61
05672	4436	0.71	8	0.70
05101	4401	0.71	6	0.53
05735	4211	0.68	6	0.53
05255	4022	0.65	1	0.09
05743	3862	0.62	9	0.79
05445	3839	0.62	19	1.67
05250	3605	0.58	6	0.53
05656	3587	0.58	9	0.79
05777	3436	0.55	1	0.09
05091	3391	0.55	5	0.44
05679	3388	0.54	3	0.26
05764	3333	0.54	12	1.05
05464	3306	0.53	6	0.53
05489	3290	0.53	8	0.70
05055	3219	0.52	5	0.44
05068	3192	0.51	9	0.79
05476	3182	0.51	6	0.53
05655	2932	0.47	6	0.53
05048	2912	0.47	3	0.26
05763	2652	0.43	7	0.61
05860	2584	0.42	7	0.61
05033	2577	0.41	5	0.44
05673	2525	0.41	2	0.18

05261	2522	0.41	1	0.09
05843	2484	0.40	5	0.44
05345	2383	0.38	5	0.44
05857	2357	0.38	4	0.35
05677	2328	0.37	4	0.35
05032	2308	0.37	7	0.61
05262	2308	0.37	7	0.61
05354	2303	0.37	1	0.09
05680	2277	0.37	5	0.44
05773	2255	0.36	3	0.26
05667	2200	0.35	4	0.35
05458	2193	0.35	5	0.44
05149	2090	0.34	5	0.44
05828	2041	0.33	8	0.70
05045	1889	0.30	2	0.18
05462	1864	0.30	8	0.70
05494	1823	0.29	4	0.35
05459	1737	0.28	4	0.35
05660	1716	0.28	5	0.44
05440	1707	0.27	2	0.18
05765	1696	0.27	4	0.35
05759	1692	0.27	3	0.26
05444	1685	0.27	1	0.09
05472	1675	0.27	1	0.09
05487	1672	0.27	3	0.26
05486	1666	0.27	6	0.53
05363	1644	0.26	6	0.53
05829	1631	0.26	9	0.79
05674	1613	0.26	2	0.18
05457	1592	0.26	1	0.09
05051	1565	0.25	4	0.35
05151	1542	0.25	2	0.18
05658	1518	0.24	1	0.09
05483	1512	0.24	3	0.26
05439	1484	0.24	1	0.09
05061	1447	0.23	3	0.26
05251	1440	0.23	1	0.09
05651	1420	0.23	5	0.44
05830	1415	0.23	10	0.88
05473	1414	0.23	1	0.09
05845	1319	0.21	3	0.26
05682	1226	0.20	2	0.18
05824	1220	0.20	1	0.09
05650	1213	0.19	1	0.09
05738	1197	0.19	1	0.09
05760	1196	0.19	3	0.26
05456	1190	0.19	1	0.09
05077	1179	0.19	3	0.26
05046	1137	0.18	3	0.26
05675	1136	0.18	3	0.26
05836	1111	0.18	3	0.26
05036	1089	0.18	1	0.09
05774	1035	0.17	1	0.09
05075	1032	0.17	3	0.26
05647	1024	0.16	2	0.18
05654	1023	0.16	6	0.53
05455	1021	0.16	1	0.09
05043	1009	0.16	2	0.18
05826	960	0.15	1	0.09
05474	956	0.15	5	0.44
05770	943	0.15	1	0.09
05448	941	0.15	5	0.44
05148	941	0.15	1	0.09
05737	922	0.15	1	0.09
05353	889	0.14	5	0.44
05867	885	0.14	2	0.18
05832	879	0.14	4	0.35
05155	871	0.14	1	0.09

05356	864	0.14	2	0.18
05761	844	0.14	3	0.26
05732	792	0.13	5	0.44
05839	767	0.12	2	0.18
05847	754	0.12	3	0.26
05142	741	0.12	2	0.18
05751	726	0.12	1	0.09
05471	709	0.11	6	0.53
05492	707	0.11	3	0.26
05150	702	0.11	1	0.09
05086	699	0.11	2	0.18
05866	695	0.11	2	0.18
05772	692	0.11	1	0.09
05350	684	0.11	3	0.26
05079	681	0.11	2	0.18
05873	643	0.10	1	0.09
05758	640	0.10	1	0.09
05744	636	0.10	2	0.18
05340	602	0.10	5	0.44
05778	602	0.10	2	0.18
05736	542	0.09	3	0.26
05070	526	0.08	1	0.09
05253	481	0.08	2	0.18
05059	404	0.06	1	0.09
05076	403	0.06	2	0.18
05762	367	0.06	2	0.18
05827	365	0.06	6	0.53
05649	356	0.06	2	0.18
05850	306	0.05	1	0.09
05730	279	0.04	2	0.18
05058	266	0.04	1	0.09
05678	263	0.04	3	0.26
05862	237	0.04	2	0.18
05067	191	0.03	1	0.09
05362	55	0.01	1	0.09
Other	**59750**	**9.60**	0	0.00

Table A1 shows the representation of our sample and the Vermont population by zip code. Population data by zip code are provided by the U.S. Census Bureau, Table B01001 Sex by Age, 2018 American Community Survey 5-Year Estimates (see https://www.vermont-demographics.com/zip_codes_by_population). Sample population data by zip code are provided by the Vermont Department of Health. In the final row, "Other" corresponds to all zip codes represented in the population that are not represented in our sample, whose residents correspond to 9.6% of the Vermont population. Due to data access and anonymity concerns, we were not able to exclude participants who we excluded from the main analysis in the general parent study for reasons outlined in the main text (missing survey outcome data, missing immunization registry data, administrative error leading to participation in both the general parent study and the non-compliance study for a small number of participants, etc) from our analyses of the geographic representativeness of our sample. Accordingly, the total number of participants in our sample reported in this table and the next figure is slightly different from that which comprises our main analyses.

Figure A5: Zip code representation in sample and Vermont population

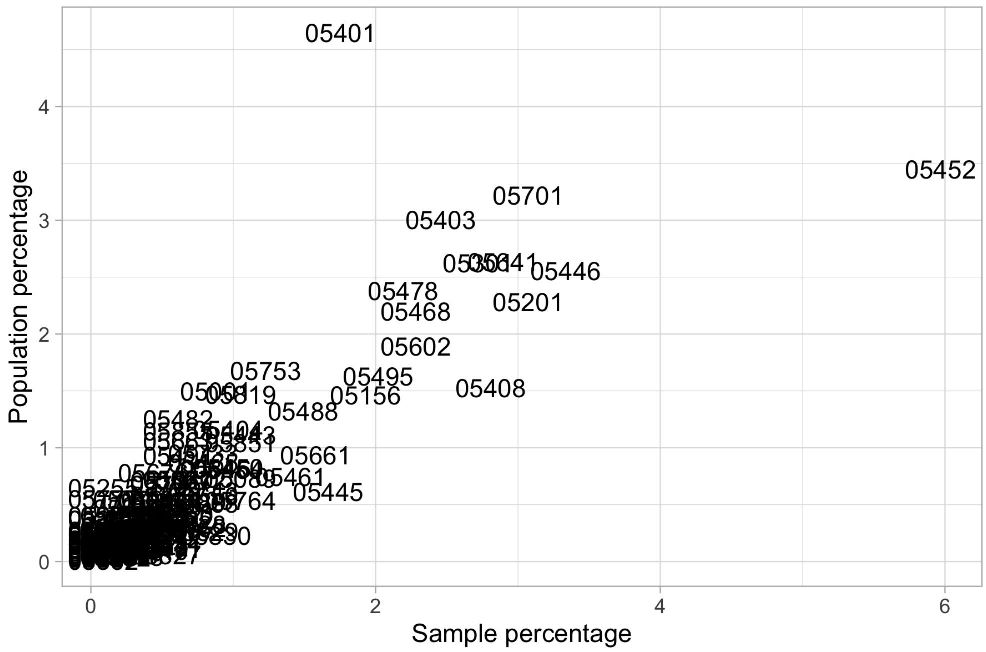


Figure A5 shows the representation of each zip code in Vermont in our sample and in the Vermont population, plotting the percentage of individuals in our sample (x-axis) and in the Vermont population (y-axis) who reside in each zip code area in the state. Zip codes that are not represented in our sample (9.6% of all Vermont zip codes) are omitted. Zip codes closer to the right of the figure are over-represented in our sample relative to the population, and those closer to the top of the figure are under-represented in our sample relative to the population. As the figure shows, representation is similar for all zip codes except 05401, which is Burlington (where there are more individuals in the population that in our sample), and 05452, which is Essex Junction (where there are more individuals in our sample than in the population).

Self-reported vaccine behavior

Table A2: Accuracy of self-reports of past vaccine behavior

	Vaccines up to date (binary) (1)	Share of vaccinations (2)
Self-reported non-compliance	-0.095^{***}	-0.041^{***}
	(0.012)	(0.007)
Age 30+	-0.103^{***}	-0.039^{**}
	(0.035)	(0.015)
Some college	-0.023	-0.019
	(0.038)	(0.019)
White	0.227^{*}	0.038
	(0.083)	(0.030)
Income > \$75K	0.051	0.026
	(0.028)	(0.016)
Two children	0.004	-0.007
	(0.028)	(0.012)
Constant	0.739^{***}	0.977^{***}
	(0.093)	(0.034)
Number of children	1,070	1,070
Clustered by household	Yes	Yes

Note: ${}^{*}p < 0.05$; ${}^{**}p < 0.01$; ${}^{***}p < 0.005$. OLS regression models with standard errors shown in parentheses.

Table A2 estimates the accuracy of self-reported past vaccine behavior using the PACV1 and PACV2 questions. These questions ask parents whether they have ever delayed giving their child a shot or not given their child a shot for reasons other than illness or injury. After merging the general parent study survey data with the behavioral data from the Vermont Immunization Registry, we estimated a similar model to Opel et al. (2013) using the PACV1 and PACV2 measures as a composite independent variable, which is the sum of the scored values for the PACV1 and PACV2 items on the Wave 1 survey. The dependent variables are the binary and continuous measures for child-level proportion up to date on all vaccines before treatment (in contrast to the dependent variables in our main analyses, which are the proportion up to date post-treatment). We use robust standard errors and cluster at the household level.

The results suggest that self-reported non-compliance in the survey is associated with non-compliance in the behavioral data from the Vermont Immunization Registry. A one-unit increase in self-reported non-compliance (where the maximum score is four and the minimum score is zero) is associated with a 9.5-percentage point decrease in likelihood of being up to date on all vaccines and a decrease of 0.04 (on a 0–1 scale) in vaccine share (the number of vaccines a child has divided by the total number the child should have at a given age).

Robustness checks

Table A3: Probit models for vaccine up to date status (binary)

	General parent study (1)	Non-compliance study (2)
Standard	0.069	
	(0.147)	
Norms	0.035	−0.052
	(0.146)	(0.139)
Myths	0.040	−0.191
	(0.147)	(0.138)
Controls	✓	✗
Clustered by household	No	Yes
Number of children	1,070	618

$^{*}p < 0.05$. Probit models with standard errors shown in parentheses. Estimates are relative to the control group, which was exposed to no information. Control variable is proportion up to date on all vaccines at the child level. For each outcome, higher values indicate higher vaccine compliance.

Table A3 reports regression results for the binary up-to-date status outcome variable in the general parent study (left column) and the non-compliance study (right column) using probit. We find no significant effects, suggesting that our results reported in the main text are robust to model specification.

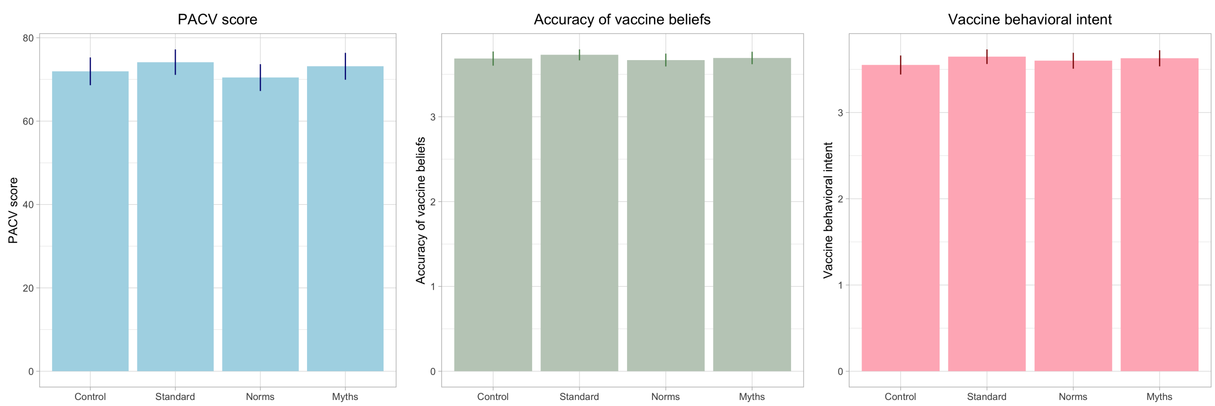
Table A4: General parent study message effects on survey outcomes (larger sample)

	Vaccine attitudes (1)	Vaccine beliefs (2)	Vaccine intent (3)
Standard	0.848	0.021	0.059
	(1.167)	(0.040)	(0.042)
Norms	−0.874	−0.006	0.066
	(1.195)	(0.044)	(0.044)
Myths	0.562	−0.004	0.060
	(1.149)	(0.042)	(0.045)
Norms − standard	−1.722	−0.027	0.007
	(1.163)	(0.041)	(0.041)
Myths − standard	−0.285	−0.025	0.001
	(1.142)	(0.041)	(0.041)
Norms − myths	−1.437	−0.003	0.006
	(1.170)	(0.042)	(0.042)
Controls	✓	✓	✓
Clustered by household	No	No	No
Number of parents	940	940	940

$^{*}p < 0.05$. OLS regression models with standard errors shown in parentheses. Estimates are relative to the control group, which was exposed to no information. Control variable is Wave 1 PACV score. For each outcome, higher values indicate more positive vaccine attitudes (lower hesitancy), more accurate beliefs about vaccines, and higher intent to vaccinate.

Table A4 and Figure A6 report regression results for the effect of messaging on vaccine attitudes, beliefs, and intent using all parents with complete survey outcome data ($N = 940$). The sample used for this analysis is larger than that which we report in the main text. In the main text, we include only parents with complete survey outcome data *and* child immunization data. These null results suggest that the results we report in the main text are not attributable to sample exclusions due to missing registry data. Notably, the difference between the social norms experimental condition and the myths and facts condition on vaccine attitudes (sixth row) that we report in the main text is no longer significant.

Figure A6: General parent study survey outcomes (larger sample)



Mean PACV outcome score (recoded; left), accuracy of vaccine beliefs (middle), and vaccine behavioral intent (right) by treatment group for the general parent study with all complete survey responses included (N = 940).

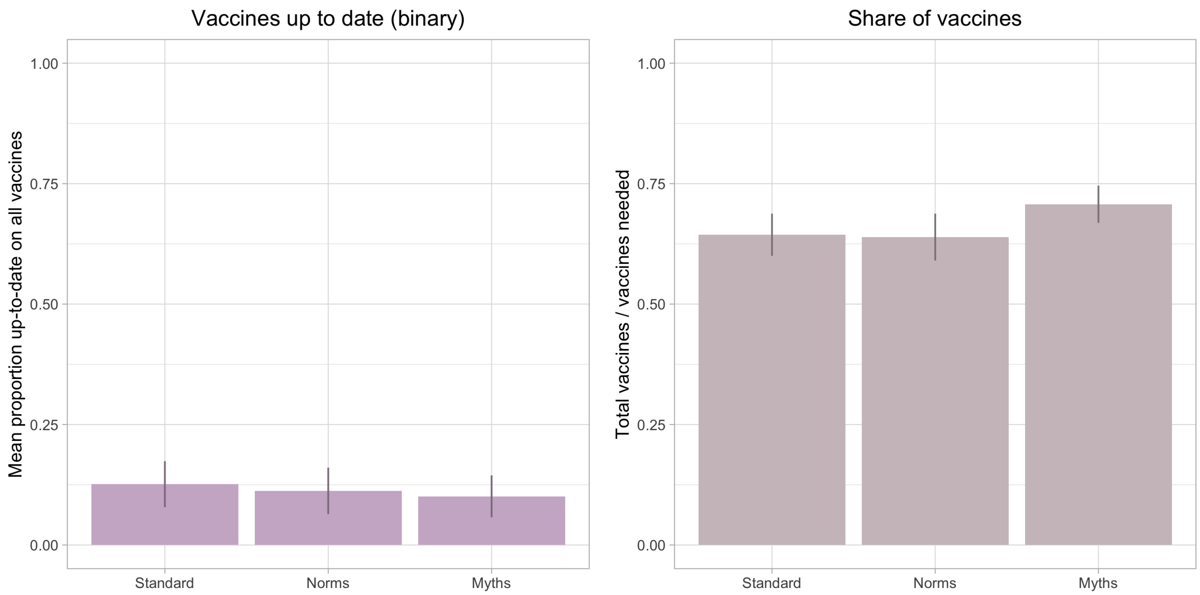
Table A5: Non-compliance study effects on vaccine behavior with 71 observations dropped

	Vaccines up to date (binary) (1)	Share of vaccinations (2)
Norms	−0.014	−0.005
	(0.034)	(0.033)
Myths	−0.025	0.063*
	(0.033)	(0.030)
Norms − myths	0.011	−0.068*
	(0.033)	(0.031)
Controls	✗	✗
Clustered by household	Yes	Yes
Number of children	547	547

*$p < 0.05$. OLS regression models with standard errors shown in parentheses. Estimates are relative to the standard message used by VDH. No control variables. For each outcome, higher values indicate higher vaccine compliance.

Table A5 reports the non-compliance study results after dropping 71 observations corresponding to children who were up to date on all of their vaccines at Time 1 in the data file supplied by VDH. The results are presented graphically in Figure A7. We observe a significant effect for the myths and facts condition, suggesting that the myths and facts condition is associated with, on average, a 6-percentage point increase in the share of vaccines a child has, relative to the standard message. We also find a significant difference between the myths and facts condition and the social norms condition for the continuous measure, suggesting that the myths and facts condition was more effective at increasing a child's share of vaccines than the social norms condition. However, we do not observe any significant effects for the binary measure. Taking this result in combination with the other results reported in the main text, we conclude that there are no consistent effects of our treatments on vaccine behavior among parents of non-compliant children.

Figure A7: Non-compliance study outcomes



Mean proportion of children who are up to date on all recommended vaccines (left) and mean number of vaccines a child has divided by the total number of vaccines recommended for his or her age group (right) by treatment group in the non-compliance study. 71 children who were up-to-date before treatment in the data file supplied by VDH are dropped.

References

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