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A longitudinal study of vaccine hesitancy attitudes and social influence as predictors of COVID-19 vaccine uptake in the US

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ABSTRACT

Background: In many countries with high levels of COVID-19 vaccine access, uptake remains a major issue. We examined prospective predictors of COVID-19 vaccine uptake in a United States longitudinal study.

Methods: An online longitudinal study on COVID-19 and well-being assessed vaccine hesitancy attitudes, social norms, and uptake among 444 respondents who had completed both survey waves in March and June 2021.

Results: The mean sample age was 41, with 55% female, 71% white, 13% Black, and 6% Latinx. In March 2021, 14% had received at least one COVID-19 vaccine dose. By June 2021, 64% reported receiving at least one dose. In prospectively assessing predictors of vaccine uptake, we found strong correlations among five different vaccine hesitancy questions. In multivariable logistic regression models, family and friends discouraging vaccination (adjusted odds ratios [aOR] = .26, 95% CI = .07, .98), not knowing whom to believe about vaccine safety (aOR = .51, 95% CI = .27, .95), and concerns that shortcuts were taken with vaccine development (aOR = .43, 95% CI = .23, .81) were all independent predictors of lower vaccine uptake. Political conservatism, gender, education, and income were also independent predictors of reduced uptake. Vaccine hesitancy items were also modeled as a scale, and the scale was found to be strongly predictive of vaccine uptake.

Conclusions: The findings highlight the importance of social norm interventions and suggest general and specific vaccine hesitancy attitudes, especially trust, should be considered in developing vaccine uptake programs.

Introduction

Widespread vaccination uptake is critical to mitigating the COVID-19 pandemic. COVID-19 vaccine hesitancy is a concern as SARS-CoV-2 variants continue to emerge, yet a substantial proportion of the United States (US) population remains unvaccinated.[1] After initial high demand for COVID-19 vaccines in the US, demand precipitously fell after a peak in mid-April 2021, and later increases in vaccination rates have been associated with spikes in infection rates due to the Delta variant.[2,3] Vaccine coverage rates are a function of both access and demand. The latter is a much more significant issue in the US,[4] and this slackening demand is problematic for eradicating the pandemic and ensuring booster vaccine uptake.

Previous studies have assessed attitudes toward COVID-19 vaccines.[5–9] These studies have mainly assessed intentions to become vaccinated. Many studies have examined the perceived risks and benefits of vaccination, perceived susceptibility of acquiring COVID-19, the severity of becoming infected with COVID-19, and demographic factors influencing risk perception;[10] yet there is currently scant literature on correlates of actual vaccine uptake.[11] Moreover, studies that do exist are primarily cross-sectional.[12]

Vaccine hesitancy is not unique to the COVID-19 vaccine, and previous research has found numerous factors influence it.[13,14] One key attribute of vaccine hesitancy is trust.[13,15–17] Multiple factors may have led to hesitancy to accept high-quality scientific information about the safety and efficacy of COVID-19 vaccines, including changing guidelines on COVID-19 prevention measures, the rapid development of the vaccines, and misinformation about the technology used in vaccine development. Moreover, COVID-19 vaccine hesitancy has likely been bolstered by the focus of both the media and the US Food and Drug Administration (FDA) on a small number of severe side effects.

Another potential driver of vaccine hesitancy is motivated reasoning, which describes the tendency to search for and/or focus on information that supports a predetermined perspective or chosen action and discounts or ignores information that contradicts it.[18] Research on motivated reasoning suggests that people will spend less time reviewing and processing information that contradicts their beliefs than information that supports them.[19] In the case of the COVID-19 vaccine, some people may have previously decided not to be vaccinated and

then search for and endorse reasons for not being vaccinated while ignoring information supporting vaccination. Motivated reasoning may therefore lead to correlation between vaccine hesitancy attitudes.

One frequent approach to addressing vaccine hesitancy has been to provide factual information from a trusted source on the safety and efficacy of the vaccine.[20] This approach is based on the premise that information from a trusted source is more likely to be accepted as factual,[21] which may, in turn, promote a cost-benefit analysis that leads to health-promoting behaviors.[22,23] Two major concerns with this model are uncertainty as to if vaccine hesitancy attitudes predict vaccine uptake and whether individuals are making decisions about vaccination based on the perceived risk and benefits of the COVID-19 vaccines.

Research findings suggest that attitudes are often weakly associated with behaviors. The association between attitudes and behaviors depends on the topics, the specificity of the behaviors, salience, and barriers to engaging in the behavior.[24] For non-habitual behaviors, with lower levels of barriers, attitudes and intentions are more likely to predict actual behaviors; whereas, for other types of behaviors, attitudes and intentions are frequently weak predictors of behaviors.[25] It is essential to assess if attitudes predict vaccine uptake to develop appropriate interventions regarding vaccines. If vaccine attitudes are only weakly associated with vaccine uptake, it is unlikely that public health campaigns to change attitudes will significantly impact uptake.

Some of the documented factors associated with COVID-19 vaccine uptake in the US are age, political party affiliation, evangelicalism, gender, race/ethnicity, and geographic location.[26,27] There has also been a range of studies on COVID-19 and prior vaccines on the psychosocial factors associated with vaccine hesitancy.[28–31] For the COVID-19 vaccines, there may be unique factors that impact the uptake of these specific vaccinations. These include the rapid development of COVID-19 vaccinations with large parallel clinical trials, adjuvants leading to strong short-term side effects, political polarization, and the development of the vaccine within the midst of a pandemic. Additionally, there may be concerns about the vaccine's effectiveness and side effects due to the vaccine's novelty.

There is also often a strong social component of health behaviors that may occur through social norms, modeling, and persuasion. Several studies, primarily on Human Papillomavirus vaccinations, suggest that social norms and perceptions of support from family and friends influence vaccine uptake.[32–37] In the current study, it was expected that respondents would be influenced not only by their attitudes but also by vaccine attitudes and behaviors among members of their social networks. Research on social comparison processes suggests that network members and similar others may have a greater influence during ambiguous and potentially stressful events, as compared to those that are customary and lower stress.[38,39] Since the COVID-19 vaccine is new and for some stressful, individuals may look to others for guidance about it.

Our study addresses several gaps in the COVID-19 vaccine uptake literature. We examined whether vaccine attitudes predicted actual vaccine uptake and, if so, what vaccine hesitancy attitudes predicted future vaccine uptake. We were also interested in examining whether people who reported that they were concerned about one attribute of COVID-19 vaccines were also more likely to endorse other concerns even if the concerns were conceptually independent. We hypothesized that if respondents were disinclined to obtain a COVID-19 vaccine, they would be more likely to endorse a range of reasons to support this decision.

Theoretical framework

The vaccine attitudes questions for the current study utilized a risk perception framework and were based on prior qualitative assessments of reasons for COVID-19 vaccine hesitancy.[40] The risk perception framework posits that perceived personal risks and benefits of vaccination strongly influence vaccine attitudes and behaviors.[41] The previous qualitative assessments identified both factors that overlap with prior research on vaccine concerns (e.g., concern about vaccine side effects) and concerns that are more salient to the COVID-19 vaccines in particular (e.g., short cuts due to quickly developing the vaccines).[42–48] We also assessed participants' perceptions of the vaccine's effectiveness, which aforementioned previous research has identified as an important determinant of vaccine intentions. As new SARS-CoV-2 variants have continued to emerge during the study period, we also included perceived future effectiveness against novel strains of the virus.

Methods

Recruitment and sampling

The present study examined predictors of self-reported vaccine uptake from an online longitudinal study of COVID-19 initiated in March 2020.[49,50] This study aimed to examine individual, social, and societal-level fluctuations related to COVID-19 amid the rapidly changing landscape of the pandemic. Study periods occurred every few months and aimed to capture changes in COVID-19 related information, behaviors, and health status. In the current analysis, data collected in early March 2021 were used to predict vaccine uptake in mid-June 2021. Participants were eligible for the current analysis if they completed both study waves and were unvaccinated in March 2021. Study participants were recruited through Amazon's Mechanical Turk (MTurk). Health researchers frequently use this platform as it allows for a diverse sample to be collected rapidly.[51] Research has indicated that MTurk provides better-quality data in less time than other convenience samples.[52] Study populations recruited through MTurk are not nationally representative but have been documented to perform better than other samples on several key dimensions, and studies using MTurk have demonstrated good reliability.[53] The study protocols followed MTurk's best practices, including ensuring confidentiality, using unique completion codes, integrating attention checks throughout the survey, repeating study-specific qualification questions, and removing ineligible participants.[54,55] Moreover, previous research suggests that despite COVID-19, the demographic characteristics of MTurk appear to be stable during the pandemic.[56] Eligibility

included being age 18 or older, living in the US, being able to speak and read English, having heard of the coronavirus or COVID-19, and providing written informed consent. Additionally, eligible participants had to pass attention and validity checks embedded in the survey to enhance reliability.[57] Based on recommendations by Rouse et al., checks to mitigate inattentive and random responding were embedded; the survey included questions with exceedingly low probabilities, such as deep-sea diving in Alaska and having appendages removed; and survey responses were examined for sufficient duration of time for completion and completeness of the data.[55] Participants were compensated $4.25 for the fifth and sixth rounds of data, equivalent to approximately $12 per hour. The study protocols were approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB00012047).

At baseline, 809 people were eligible for the study, and they were asked to participate in each subsequent survey wave. Additional participants were recruited in the fifth wave to replenish the sample. Due to MTurk's tendency to under-sample minority, lower-income, and less educated respondents, the latter wave over-sampled on these domains. The current analysis examines study respondents who participated in both the fifth (March 4th −15th, 2021) and sixth (June 14th −23rd, 2021) wave data. In total, 514 people participated in both study waves.

In the US, due to the initial limited supply and prioritizing key groups for vaccination, most adults could not obtain the COVID-19 vaccine before April 2021. These restrictions were lifted on a state-by-state basis by April 19th, 2021.[58] The current analyses assess vaccine uptake at wave 6, which was administered in mid-June 2021. At this time, based on Centers for Disease Control and Prevention (CDC) estimates, over 305 million vaccine doses had been administered, and approximately 53% of the US population had received at least one dose of vaccine, with 43% of the total US population fully vaccinated.[3]

Measures

The primary outcome was the response to the question, "How many doses of the coronavirus vaccine have you received?" Vaccine hesitancy was assessed using responses to "I am concerned that a coronavirus vaccine will not be effective," "I am worried about having bad side effects if I received the vaccine," "I am concerned that shortcuts have been taken with vaccine development because of political pressures," "Most coronavirus vaccines will not protect people from new coronavirus strains," and "It is hard to know whom to believe about the safety of the coronavirus vaccines." The response categories were "Strongly agree," "Agree," "Neither agree nor disagree," "Disagree," and "Strongly disagree." These vaccine hesitancy items were based on qualitative assessments of reasons for vaccine hesitancy based on waves three, four, and five. The vaccine hesitancy items were analyzed both independently and as an ordinal scale. The Cronbach's alpha for the vaccine hesitancy scale was .87, and the mean inter-item correlation was .57. For ease of interpretation, the scale scores were converted to z-scores.

The injunctive social norm was assessed with the following statement: "My family/friends will discourage me from getting the vaccine." The response categories for self-reported race/ethnicity included "White," "Black," "Asian," "Hispanic," "Mixed," or "Other." Due to the small sample size, "Mixed," and "Other" were collapsed. Political ideology was assessed with the question, "Where would you place yourself on a scale running from "Very liberal" to "Very conservative"?" The responses were ordinal, "Very liberal," "Liberal," "Slightly liberal," "Moderate," "Slightly conservative," "Conservative," and "Very conservative." Family income was assessed and dichotomized, based on the median, as less than $60,000 or more than $60,000. Educational attainment was dichotomized as a bachelor's degree and higher versus an associate's degree or less. Sex was assessed as biological sex at birth.

Statistical analysis

Of the 514 participants who completed both waves five and six, a total of 83 were excluded for two reasons. First, at the time of the wave five survey, March 2021, a small proportion (13.6%, N = 70) of respondents had been vaccinated. As vaccinations were not open to all adults in the represented states, it was infeasible to disaggregate vaccine eligibility policies and structural and individual-level factors that may have led to vaccination, hence these 70 were excluded. An additional 13 respondents from wave six were excluded due to missing data, primarily on political ideology (n = 11), resulting in a final sample size of 431 respondents for the inferential statistical analyses.

We first used descriptive statistics to examine the sample and then assessed the correlation among the vaccine hesitancy items using a Spearman's rank correlation. For the primary analyses, respondents who reported receiving one or two doses of any COVID-19 vaccine were compared to those who had not received a dose. Bivariate and multivariable logistic regression models assessed the relationship between measures of vaccine hesitancy and social influence at wave five with COVID-19 vaccine uptake at wave six. The second multivariate model included the scale of vaccine hesitancy, rather than the five individual items on vaccine hesitancy, due to the high correlations among the five vaccine hesitancy items. The final multivariate models adjusted for sociodemographic and other covariates with a p-value <.20.[59,60]

Results

Demographic characteristics are summarized in Table 1. Of the 444 individuals in the study at both waves five and six, 161 individuals did not receive a vaccine, and 29 received the single-dose Johnson and Johnson vaccine. Among those that had only received a single dose, 13 received their first Pfizer dose, 12 received their first Moderna dose, and one did not know. Among those that received two vaccine doses, 138 received Pfizer, 89 received Moderna, and one did not know which vaccine they received. Other demographic variables such as age, sex, income, and race were relatively evenly distributed between those that had and had not received any vaccine doses, although those that had not received any vaccine doses had fewer years of education completed.

Table 1. Sociodemographic characteristics of the study population.

Characteristic	Received at least one dose (N = 283)	No doses received, June 2021 (N = 161)	Total (N = 444)
Mean Age (sd)	41.65 (11.12)	40.56 (10.69)	41.25 (10.97)
Male Sex, n (%)	125 (44.17)	75 (46.58)	200 (45.05)
Race, n (%)			
White	200 (70.7)	114 (70.81)	314 (70.72)
Black	34 (12.01)	26 (16.15)	60 (13.51)
Hispanic	14 (4.95)	11 (6.83)	25 (5.63)
Asian	23 (8.13)	6 (3.73)	29 (6.53)
Other	12 (4.24)	4 (2.48)	16 (3.60)
Education, n (%)			
High school or less	24 (8.48)	36 (22.36)	60 (13.51)
Some college	73 (25.80)	52 (32.30)	125 (28.15)
Bachelor's degree	131 (46.29)	57 (35.40)	188 (42.34)
Graduate egree	55 (19.43)	16 (9.94)	71 (15.99)
Income, n (%)			
Less than $35,000	66 (23.40)	48 (29.81)	114 (25.73)
$35,000 - $60,000	77 (27.30)	55 (34.16)	132 (29.80)
$60,000 - $90,000	69 (24.47)	28 (17.39)	97 (21.90)
Over $90,000	70 (24.82)	30 (18.63)	100 (22.57)

The Spearman's rank-order correlation coefficients included in Table 2 (N = 444) show moderate to high correlations among the vaccine hesitancy items. Concern about possible side effects was highly correlated with worry about shortcuts taken during vaccine development (r = .70) and worry about whom to trust for vaccine information correlated with concern about shortcuts taken during development (r = .71).

Only individuals who had complete responses (N = 431) for all the survey items were included in the logistic models (Table 3). Odds ratios from logistic bivariate and multivariate for each question used to assess vaccine-related concern are summarized in Table 3. Bivariate logistic regression models indicated no significant difference in the odds of getting

Table 2. Spearman's rank-order correlation matrix.

Variable	1	2	3	4	5
1. Concerned that the vaccine will not be effective.					
2. Worried about having bad side effects from the vaccine.	0.63				
3. Concern that shortcuts have been taken with vaccine development.	0.62	0.70			
4. Belief that vaccines will not protect people from new coronavirus strains.	0.51	0.41	0.48		
5. My family/friends will discourage me from getting the vaccine.	0.31	0.33	0.39	0.40	
6. It's hard to know who to believe about vaccine safety.	0.56	0.66	0.71	0.45	0.38

All the correlations were statistically significant, p<0.01

a vaccine between individuals based on sex, race, or age. Those who reported being more liberal were significantly more likely to be vaccinated in the unadjusted and fully adjusted models, as were those that made more than $60,000 in the last year. In the unadjusted model, all the vaccine worry questions were related to a decreased odds of receiving a COVID-19 vaccine dose. In the fully adjusted model, only worry about shortcuts taken during vaccine development and whom to trust about the vaccine showed a significant association with reduced odds of receiving a vaccine after adjusting for all other factors.

Table 3. Multivariable logistic models: Sociodemographic and vaccine hesitancy predictors of COVID-19 vaccine uptake. (N = 431).

Variable	OR	95% CI	aOR	95% CI
Vaccine hesitancy items^				
Concerned the vaccine won't be effective.	0.38	(.24, .57)*	1.17	(.64, 2.15)
Concerned about having bad side effects.	0.19	(.12, .32)*	0.52	(.27, 1.03)
Belief that COVID-19 vaccines won't protect people from new strains.	0.32	(.20, .49)*	0.71	(.40, 1.27)
Concerned that shortcuts have been taken with vaccine development.	0.17	(0.10, 0.27)*	0.43	(0.23, 0.81)*
Not knowing who to believe about vaccine safety.	0.20	(0.13, 0.32)*	0.51	(0.27, 0.95)*
Social norms				
My family/friends discourage me from getting the vaccine.^	0.09	(.02, .29)*	0.26	(.07, .98)*
Demographics				
Where would you place yourself on a scale running from "very liberal (7)" to "very conservative (1)"	1.41	(1.26, 1.59)*	1.27	(1.11, 1.47)*
Age in years (continuous)	1.01	(.99, 1.03)	1.01	(.99, 1.04)
Sex (0 = male, 1 = female)	1.10	(.81, 2.84)	1.47	(.86, 2.48)
Race				
White	Ref.		Ref.	
Black	0.71	(.41, 1.23)	1.14	(.56, 2.27)
Hispanic	0.71	(.31, 1.60)	0.85	(.31, 2.36)
Asian	2.29	(.91, 5.74)	2.31	(.79, 6.72)
Other	1.74	(.55, 5.48)	1.41	(.36, 5.54)
Highest level of education completed. (0 = Less then bachelor's degree, 1 = Bachelor's degree or more)	2.31	(1.56, 3.43)*	1.76	(1.08, 2.86)*
Annual income. (0 = less than $60,000, 1 = more than $60,000)	1.72	(1.16, 2.57)*	1.74	(1.06, 2.86)*

^- Responses of strongly disagree, disagree, neither agree or disagree, disagree, strongly disagree
*: p ≤ 0.05

In Table 4, a second logistic regression model was created using a scale of the five vaccine hesitancy items, which were combined and then converted to a z-score. High scores on the combined scale of vaccine hesitancy were associated with a significant and marked reduction in odds of getting a vaccine.

Discussion

Our study showed that vaccine hesitancy attitudes in March 2021 predicted actual vaccine uptake three months later. Even after over a hundred million US residents had been vaccinated, with only a handful of reported severe side effects, our study supports that prior vaccine hesitancy attitudes predict uptake of the COVID-19 vaccine. Although vaccine hesitancy attitudes predicting future behaviors may seem self-evident, studies do not always find this association, especially for behaviors that require substantial effort, resources, and access. Our study also reported specific and general vaccine hesitancy attitudes that strongly predict vaccine uptake (Table 3). The adjusted models attenuated all the odds ratios for the specific vaccine hesitancy items, which is not surprising due to the strong correlations among the five items. The high correlations among the vaccine hesitancy survey items suggest motivated reasoning. It is plausible that individuals who have developed a negative perception of the COVID-19 vaccines will seek out information to support this view. Consequently, addressing one concern may

Table 4. Unadjusted and adjusted odds ratios from bivariate and multivariate logistic regression models of predictors of COVID-19 vaccine uptake. (N = 431).

Variable	OR	95% CI	aOR	95% CI
Vaccine Hesitancy Scale				
Vaccine Hesitancy Scale (z-Score)	0.30	(.23, .39)*	0.34	(.25, .46)*
Social norms				
My family/friends discouraged me from getting the vaccine.	0.08	(.02, .29)*	0.37	(.09, 1.41)
Demographics				
Where would you place yourself on a scale running from "very liberal (7)" to "very conservative (1)"	1.41	(1.26, 1.59)*	1.24	(1.07, 1.43)*
Age in years	1.01	(.99, 1.03)	1.02	(.99, 1.04)
Sex (0 = male, 1 = female)	1.10	(.75, 1.63)	1.78	(1.05, 2.99)*
Race				
White	Ref.		Ref.	
Black	0.71	(.41, 1.23)	0.98	(.49, 1.99)
Hispanic	0.71	(.31, 1.60)	0.79	(.29, 2.17)
Asian	2.29	(.91, 5.74)	2.19	(.73, 6.57)
Other	1.74	(.55, 5.48)	1.46	(.36, 5.94)
Highest level of education completed. (0 = Less then bachelor's degree, 1 = bachelor's degree or more)	2.31	(1.56, 3.43)*	1.65	(1.01, 2.72)*
Annual income. (0 = less than $60,000, 1 = more than $60,000)	1.73	(1.16, 2.57)*	1.74	(1.05, 2.89)*

*: $p \leq 0.05$.

simply lead to voicing other concerns. The findings from this study tend to mirror prior international studies on reasons for COVID-19 vaccine hesitancy that were conducted before COVID-19 vaccines were available.[7,61,62]

Lack of trusted sources of COVID-19 vaccination information may also help us understand why the domains of vaccine hesitancy, which may not seem to logically correlate, such as concern that the vaccine may not be effective, were highly correlated with concern about side effects. A lack of trust in the scientific and public health institutions that regulate and ensure vaccine safety may lead to more concerns about both vaccine efficacy and safety. Previous research has documented the vital role of trust in vaccine hesitancy and uptake, with a 2019 study by Quinn et al. finding that trust was a strong and independent predictor of flu vaccine uptake.[63] Additionally, a global survey of potential acceptance of a COVID-19 vaccine found that trust in government was strongly associated with vaccine acceptance.[64] One way to view trust is a gateway perception; that is, a lack of trust will lead to the rejection of other information. Therefore, although it may be tempting to try to correct misinformation, this approach is not likely to be effective if people do not trust the sources of information. Hence, it is crucial to assess the trustworthiness of information sources when developing campaigns to increase vaccine uptake.

In the current study, one of the strongest predictors of vaccine uptake was the item "It's hard to know whom to believe about vaccine safety." The confusion around the trustworthiness of information sources can be partially attributed to the politicizing of response to the COVID-19 pandemic and the demonization of the media by conservative political figures as well as the ability to disseminate misinformation on social media widely. The strategy in the US and elsewhere among some conservative groups and leaders to sow distrust of the news media and governmental organizations may lead people not to know what to believe, and this phenomenon, coupled with the downplaying of the pandemic, may also make individuals more receptive to misinformation, especially on social media, that emphasizes the negative aspects of vaccination.

One way to build trust may be to address individual concerns. Regarding specific concerns in the unadjusted models, all the odds ratios for the vaccine hesitancy items were statistically significant and ranged from .17 to .38. One pervasive concern and a strong predictor of vaccine uptake in the bivariate models was the issue of side effects. Given that the vaccines are new, there is no data on long-term side effects. Based on the finding from other vaccines and the mechanism of action for the COVID-19 vaccines, the probability of long-term side effects is low; however, the short-term side effects are high due in part to the adjuvants.[65,66] Given the cognitive bias of overestimating low probability but high salient events, it may be that individuals are overestimating the probability of severe side effects rather than making relative risk assessments, comparing the risk of mild short-term side effects to the risk of severe COVID-19. One approach to potentially address this concern is a government sponsored insurance program, which has been utilized with other vaccines, that would pay for care due to side effects. Attributing health conditions to vaccines decades from now may be difficult. However, as there are numerous ongoing studies of COVID-19 vaccinations, it will be feasible to identify any future health conditions associated with vaccination.

In addition to concern about future side effects, there was also concern about the vaccines' effectiveness on future strains of COVID-19, though this concern was not statistically significant in the multivariable analyses that adjusted for all the other vaccine hesitancy items. Evidence to date suggests that the currently approved vaccines are effective against a range of strains.[67] However, there will be more COVID-19 strains due in part to limited uptake in some geographic regions and limited access in most of the world. Regardless, the logic of not getting vaccinated because of future variants is similar to that of not using malaria prophylaxis due to concerns about drug resistance. This logic suggests that people may be searching for reasons not to get vaccinated.

Our study did not examine in detail respondents' affective evaluation (e.g., like vs. dislike) of the COVID-19 vaccine. Individuals may have negative affect toward injections, fear of

a novel vaccine, and discomfort based on all the misinformation and sensationalized stories of low probability side effects. These experiences may lead to a general negative valence based on emotion rather than cognition. Consequently, simply addressing the facts and providing accurate information may not lead to a change in attitudes.

In the bivariate analyses, family and friends discouraging vaccination was strongly associated with uptake. This finding was attenuated in one of the multivariable models. This statistical attenuation is likely due to the strong correlation between this variable and the vaccine hesitancy items, indicating that family and friends are likely to hold similar vaccine attitudes and may influence each other's vaccine attitudes. Therefore, it may be beneficial for those who do get vaccinated to share this information with family, friends, and other social network members. Disseminating information about becoming vaccinated through social media and encouraging engagement in conversations with peers may highlight the social norms of becoming vaccinated for COVID-19. Moreover, the more people that share that they have been vaccinated, the more salient the norms supporting vaccines are likely to be.

In addition to vaccine hesitancy attitudes and social influence factors, we also found that higher education and income predicted vaccine uptake. These may indicate access, sources of information, norms, and health literacy. Political conservatism was also associated with a lack of vaccine uptake, which has been found in studies of COVID-19 vaccine intentions and helps validate the findings.[68]

This study is subject to several limitations. We did not include measures of structural factors that may have impeded vaccine uptake, such as time and distance to vaccination locations. These factors were not included because wait-time and distance have changed dramatically from March to June in many jurisdictions. However, structural factors, including the ability to take time off work or caregiving responsibilities, are critical to consider to improve vaccination rates. We also used self-reports of vaccine uptake, which may be subject to social desirability bias. Future studies may want to consider having participants provide a photo of their vaccination cards to verify self-reports. Moreover, we excluded the early vaccine recipients as guidelines on vaccine eligibility dictated who could receive a vaccine before mid-April 2021. The study was not a random or representative sample but contained a large proportion of racial and ethnic minority participants. However, even with a large proportion of minority respondents, the sample size was insufficient to stratify by race/ethnicity. However, we observed few differences by race in the level of endorsement of the vaccine hesitancy survey items.

Given the range of vaccine hesitancy attitudes, simple approaches to addressing information deficit are not optimal to change behaviors. Public health campaigns need to include a range of health communication approaches. These include ensuring information comes from a trusted source. Trusted sources may have key attributes such as race, ethnicity, gender, political and religious affiliations that should be considered.[69,70] Messages that address social norms, trust, and highlight vaccines for protecting family, friends, and community should all be considered. Messages can also focus on altruism in protecting vulnerable others, such as children and those who are immunocompromised, and using one's social influence or standing to encourage others to become

vaccinated, which may help individuals and communities. Moreover, in addition to ensuring easy access to vaccines it is prudent to utilize a range of behavior change approaches to increase vaccine uptake. These include nudges or reminders. Future research should examine the effectiveness of framing messages based on gains and losses to not only oneself but also family, friends, and community. In addition, future research should utilize the current scale and items from the scale in other countries to assess the generalizability of these findings and identify other psychosocial barriers to vaccine uptake.

Prior research suggests that individuals who espouse anti-vaccination beliefs are exceedingly difficult to persuade to become vaccinated and attempts to persuade them may lead to a boomerang effect.[71–73] For these individuals, policies requiring vaccination may likely be more effective than public health campaigns or social influence approaches. In the US, there is a focus on convincing the public to become vaccinated, yet most of the world does not have access to effective COVID-19 vaccines. Without effective programs for global vaccination, low vaccination rates anywhere can have a detrimental impact everywhere.

Conclusion

This longitudinal study found that vaccine hesitancy attitudes predicted COVID-19 vaccine uptake. However, the high correlation between vaccine hesitancy attitudes indicates that addressing individual vaccine hesitancy beliefs may not lead to behavior change as other hesitancy beliefs may continue to impede vaccine uptake. Study findings also identified social norms as a predictor of COVID-19 vaccine uptake which suggests that vaccination uptake interventions should focus on promoting pro-vaccination social norms.

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