Title

Factors and reasons associated with low COVID-19 vaccine uptake among highly hesitant communities in the US

Journal

American Journal of Infection Control, 50(3)

ISSN

0196-6553

Authors

Khairat, Saif
Zou, Baiming
Adler-Milstein, Julia

Publication Date

2022-03-01

DOI

10.1016/j.ajic.2021.12.013

Peer reviewed

Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

American Journal of Infection Control 50 (2022) 262–267

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

Factors and reasons associated with low COVID-19 vaccine uptake among highly hesitant communities in the US

Saif Khairat PhD, MS, MA [a,b,c,*], Baiming Zou PhD, MS, MA [c,d], Julia Adler-Milstein PhD, MS, MA [e]

[a] Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill, Chapel Hill, NC
[b] Carolina Health Informatics Program, University of North Carolina at Chapel Hill, Chapel Hill, NC
[c] School of Nursing, University of North Carolina at Chapel Hill, Chapel Hill, NC
[d] Department of Biostatistics, Gilling's School of Global Health, University of North Carolina at Chapel Hill, Chapel Hill, NC
[e] Center for Clinical Informatics and Improvement Research, University of California – San Francisco, San Francisco, CA

Key Words:
Education
Vaccination
Health Services Research
Public Health

A B S T R A C T

Background: The inability to achieve high COVID-19 vaccination rates can continue to have serious harm to our communities. Vaccine hesitancy is a major barrier towards high vaccination rates. We evaluated the relationship between COVID-19 vaccine uptake and vaccine hesitancy, and then examined whether community factors were associated with COVID-19 vaccine uptake and hesitancy.

Methods: We constructed and evaluated a cross-sectional, county-level dataset that included the levels of vaccination uptake and vaccine hesitancy, and population characteristics based on those included in the CDC's Social Vulnerability Index.

Results: Across 3142 US counties, vaccine hesitancy was significantly and negatively correlated with vaccine uptake rates (r = -0.06, *P* value <.01). The 2 predictors associated with a low vaccination level within highly hesitant communities were: no high school education (OR:0.70, *P* value <.001), and concern on vaccine availability and distribution (CVAC) (OR:0.00, *P* value <.001). The most common reason driving vaccine hesitancy was lack of trust in COVID-19 vaccines (55%), followed by concerns around side effects of the vaccine (48%), and lack of trust in government (46%).

Conclusions: COVID-19 vaccine hesitancy is a public health threat. Our findings suggest that low education levels are a major contributor to vaccine hesitancy and ultimately vaccination levels. Since education levels are not easily modifiable, our results suggest that policymakers would be best served by closing knowledge gaps to overcome negative perceptions of the vaccine through tailored interventions.

As of May 30, 2021 approximately only 50% of the total US adult population received full vaccination against the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) after the resulting novel coronavirus disease 2019 (COVID-19) contributed to nearly 600,000 deaths in the US and millions of lives globally.[1-3] It is critical to achieve high rates of full COVID-19 vaccination among US adults to build herd immunity, and thereby reduce case and death rates.[4,5] In addition, high vaccination rates can have economic benefits including cost savings due to lower COVID-19 Emergency Department (ED) visits [6] and improved work productivity due to reduced illness and recovery periods as well as social benefits such as health equity from free vaccines to the public and improved life expectancy among vaccinated people.[7]

Predating the COVID-19 pandemic, research on factors impeding high levels of vaccination among adults indicates that lack of access to vaccines, undervaluation of immunization, lack of reminders, and inability to pay for the vaccine were associated with low vaccination uptake among adults.[8,9] It is unclear whether

* Address correspondence to Saif Khairat, PhD, MPH, MSc, School of Nursing and Carolina Health Informatics Program, University of North Carolina at Chapel Hill, 438 Carrington Hall, Chapel Hill, NC 27514.
E-mail address: Saif@unc.edu (S. Khairat).

Conflicts of interest: None to report.

Author contributions: All authors had access to the data and a role in writing the manuscript.

Ethics approval and consent to participate: This study was deemed exempt by the UNC institutional review board as it did not involve interaction with study participants and did not collect identifiable data.

https://doi.org/10.1016/j.ajic.2021.12.013

these factors are persisting in their relevance to COVID-19 vaccination levels and particularly if they explain COVID-19 vaccine hesitancy, the delay in acceptance or refusal of vaccine despite vaccine availability.[10,11]

The reported factors that historically hindered vaccination uptake may not apply to the COVID-19 vaccine uptake for several reasons. The COVID-19 vaccine was available at no cost starting December 14, 2020 to alleviate financial burden. The vaccine was systematically distributed by prioritizing health care workers, long-term care residents, and high-risk individuals, and then the general public to increase access to the vaccine.[12] In addition, COVID-19 vaccine information related to its importance and information regarding distribution sites were communicated and emphasized through an array of communication mediums channels.[13,14] While all these factors should promote uptake by addressing barriers identified in prior work, it is also possible that there are countervailing forces. Given the accelerated timeline for development and approval from the U.S. Food and Drug Administration,[15] the level of uncertainty around the technology used to develop the vaccine and its long-term outcomes affected the uptake among the public.[16] Therefore, the level of hesitancy and its contribution to vaccine uptake is of greater concern during the COVID-19 pandemic.

To design tailored and effective public health campaigns, policymakers need to know the characteristics of the communities and individuals at risk of low vaccination rates, and the role that vaccine hesitancy may be playing, specifically in the context of the current pandemic.[17,18] Therefore, in this study, we evaluated the relationship between COVID-19 vaccine uptake and COVID-19 vaccine hesitancy, and then examined whether 3 types of community factors are associated with COVID-19 vaccine uptake and hesitancy: (1) factors related to access to vaccines, (2) factors related to level of knowledge, and (3) factors related to attitudes. These 3 categories and the specific predictors within them were derived from the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI) that identifies communities that are most likely to need support during a crisis.[19] The analysis of SVI factors has also been used in prior COVID-related work.[20] Additionally, we separately examined highly hesitant communities, characterizing the variability in vaccination levels within them and then assessing the predictors associated with higher hesitancy levels. These findings are specifically useful to understand what may be needed to overcome vaccine hesitancy given the particular concerns about the COVID-19 vaccine.

METHODS

We constructed a cross-sectional, county-level dataset that included the level of vaccination uptake, the level of vaccine hesitancy, and population characteristics based on those included in the CDC's SVI, organized into 3 groups: access, knowledge, and attitudes. Vaccination uptake was defined as the percent of individuals who are fully vaccinated by receiving the full dose of the COVID-19 vaccine. Vaccination hesitancy was defined as individuals who reported that even if the COVID-19 vaccine was available to them, they will definitely not receive the vaccine.

Access is the timely use of health care services to achieve optimum health outcomes;[21] *knowledge* is the information and skills acquired through experience or formal education[22]; *attitudes* is the psychological tendency that expresses a favorable or unfavorable opinion towards a particular concept.[23]

All data was obtained from the CDC COVID-19 Data Tracker as of May 9, 2021[24]; and the US Census Bureau Health Pulse Survey (HPS).[25] The data sets used were publicly available and de-identified.

Study Measures

For county-level outcomes, we measured the level of vaccination uptake ("vaccination rate") as the percent of adults (over 18 years of age) who were fully vaccinated in each US county as of May 9, 2021. Vaccination hesitancy rates were measured as the percent of adults who reported in the US Census Bureau Health Pulse Survey (HPS) as of May 9, 2021 that they will definitely not receive the vaccine in each US county (based on the scale of 1. "definitely get a vaccine"; 2. "probably get a vaccine"; 3. "unsure"; 4. "probably not get a vaccine"; and 5. "definitely not get a vaccine").[25] HPS surveys were distributed by email and mobile telephones to sample household using US Census Contact Frame. If no cellphone number is available, email was used.[25]

During a pandemic, social factors such as the percentage of individuals living poverty or lack of access to transportation can contribute to ways in which communities respond to calls for action such as obtaining vaccinations.[26] The CDC's social vulnerability index (SVI) estimates the vulnerability of communities based on 15 variables. For our analysis, we used 9 of these variables (Supplemental Methods). We then added a new single variable "COVID-19 Vaccine Coverage Index (CVAC)" that is a comprehensive index capturing the level of concern around the availability and distribution of COVID-19 vaccines for each US county.[27] CVAC, developed by Surgo Ventures and made available by the CDC,[28] is measured from 0 (lowest level of concern) to 1 (highest level of concern). The access challenges used to calculate the CVAC, for example the available infrastructure for vaccine uptake per capita, and vaccination provider workforce per capita, are not measured by any of the existing SVI access variables.[27] Additional details on the SVI and CVAC data and methodologies can be found elsewhere.[19,27]

We organized our 10 county characteristic variables into our 3 thematic groups. Under access, we included (1) COVID-19 Vaccine Coverage Index (CVAC), (2) percent of households with no access to a vehicle, (3) percent of individuals with a disability, and 4) percent of individuals who are unemployed. Under knowledge, we included (1) percent of individuals with less than high school education, and (2) percent of individuals who speak English less than well. Finally, under attitudes, we included (1) percent of individuals who self-identify as a minority, defined as all individuals except non-Hispanic White, (2) percent of individuals living under poverty, and (3) percent of individuals over 65 years of age, and (4) percent of single parent households with children under 18 years. We ran descriptive analysis on the 10 county characteristics (Appendix 1).

Data Analysis

To examine potential collinearity between predictors within the same group, measured as correlation >0.8, we ran 2-tailed Pearson correlation tests and found no potential collinearity within any of the groups (Appendix 2).

To address our first research question about the relationship between vaccine uptake and vaccine hesitancy, we ran a 2-tailed Pearson Correlation test to assess the relationship between COVID-19 vaccination uptake and vaccine hesitancy and created a scatterplot diagram (Appendix 3). To address our second research question about the relationship of county characteristics with vaccination hesitancy and with vaccination rate, we employed 2 multivariate linear regression models with vaccination hesitancy and with vaccination rate as the dependent variables, and the 10 county characteristics as independent variables. In each of the regression models, we used the odds ratio to examine the constant effect of a county characteristic as a predictor on the likelihood of vaccine hesitancy or on vaccination uptake.

To address our third research question about predictors of higher vaccination rate among hesitant communities, we defined highly hesitant communities as the counties within the 75th quartile of vaccine hesitancy rates across all US counties (n = 326). We constructed a dichotomous dependent variable that assigned each of those highly hesitant counties as either highly vaccinated, that is, within lower quartile (n = 124); or low vaccination, that is, within upper quartile (n = 202), of the vaccination rates across all US counties. We then ran a binary logistic regression model including the same set of 10 county characteristics as predictors. Statistical significance was determined at the *P* value <.05. All statistical analyses were conducted by using the open-source statistical software package R (version 4.0.4).

To complement and extend our county-level analyses, we sought to understand the characteristics of highly hesitant unvaccinated people and the reasoning behind their vaccine hesitancy. This required building a dataset at the individual level using the Household Pule Survey (HPS) responses, which was distributed to 1,040,864 US adults over 18 years between April 28 and May 10, 2021 (response rate: 7.5%).[25,29] The HPS is designed to produce national-level estimates based on the US Census Bureau sampling design.[25]

To examine the characteristics of highly hesitant individuals who have not yet received the vaccine, we analyzed the responses to the HPS survey question "Once a vaccine to prevent COVID-19 is available to you, would you get a vaccine?" We then ran descriptive statistics for age, sex, race, education, presence of children under 18 years, and employment for: (1) the total population; (2) the total unvaccinated population; (3) the total unvaccinated and highly hesitant population; and (4) the percentage of the unvaccinated population that is highly hesitant (ie, group 3/group 2).

To understand the reasons behind vaccine hesitancy among the unvaccinated population who are highly hesitant, we used the HPS survey question "the reasons for not receiving or planning to receive the vaccine."[25] The HPS survey question provided 19 possible answers for individuals to check all the responses that applied. The cumulative totals therefore do not sum to 100%.

RESULTS

Across 3142 US counties, the average (SD) rate of US adults who received full COVID-19 vaccination was 34.7% (12.3%), and the average (SD) rate of US adults who reported strong hesitancy to receiving COVID-19 vaccination was 8% (2.83%), as of May 9, 2021. (Appendix 4) Vaccine hesitancy was significantly and negatively correlated with vaccine uptake rates (r = -0.06, *P* value <.01).

Predictors of COVID-19 Vaccine Uptake

Among access factors, COVID-19 vaccination uptake was positively associated with individuals with no access to a vehicle (b = 0.429, *P* < .001), and unemployment rates (b = 0.456, *P* < .001); and negatively associated with COVID-19 Vaccine Coverage Index (CVAC) (b = -7.517, *P* < .001), Table 1. Among knowledge factors, vaccination hesitancy was positively associated with individuals speaking English less than well (b = 1.099, *P* < .001), and negatively associated with individuals with no high school education (b = -0.847, *P* < .001). Among attitude factors, hesitancy was positively associated individuals over 65 years (b = 0.327, *P* < .001), and single parent households with children under 18 (b = 0.493, *P* value <.001).

Predictors of COVID-19 Vaccine Hesitancy

Among access factors, COVID-19 vaccination hesitancy was positively associated with individuals with no access to vehicle (b = 0.041, *P* < .01), and disability (b = 0.110, *P* value <.001); and negatively associated with unemployment (b = -0.077, *P* value <.01) (Table 1). Among knowledge factors, vaccination hesitancy was positively associated with individuals with no high school education (b = 0.055, *P* < .001), and negatively associated with individuals speaking English less than well (b = -0.285, *P* < .001). Among attitude factors, hesitancy was positively associated with individuals living in poverty (b = 0.049, *P* < .001), and single parents with children under 18 years (b = 0.024, *P* < .001); and negatively associated with minority groups (b = -0.046, p = 0.001), and individuals over 65 years (b = -0.143, *P* < .001).

Vaccination Disparities Within Highly Hesitant Communities

Five factors were statistically significant predictors of high vaccination rates among highly hesitant communities: access factors (CVAC, no access to a vehicle), knowledge (individuals no high school education, individuals speaking English less than well), and attitudes (minority).

The 3 predictors associated with a high vaccination level within highly hesitant communities were: minorities (OR:1.109, *P* value <.001), speaking English less than well (OR:1.712, *P* value = .003), no access to a vehicle (OR:1.703, *P* value <.001), over 65 years (OR:1.037, *P* value <.05). The 2 predictors associated with a low vaccination level within highly hesitant communities were: CVAC (OR:0.000, *P* value <.001), and no high school education (OR:0.70, *P* value <.001), Table 2.

Table 1
County characteristics associated with COVID-19 vaccination rates and vaccine hesitancy: multivariate linear regression results

	County vaccination level (%)			County vaccine hesitancy level (%)		
Characteristics	Coefficient	Standard error	*P* value	Coefficient	Standard error	*P* value
Access						
CVAC	-7.517	1.197	<.001	0.002	0.275	.994
Individuals with no access to vehicle	0.429	0.054	<.001	0.041	0.012	.001
Noninstitutionalized with disability	-0.077	0.077	.318	0.11	0.018	<.001
Unemployment	0.456	0.108	<.001	-0.077	0.025	.002
Knowledge						
No high school diploma	-0.847	0.058	<.001	0.055	0.013	<.001
Individuals who speak English "less than well"	1.099	0.12	<.001	-0.285	0.028	<.001
Attitudes						
Above 65 y	0.327	0.059	<.001	-0.143	0.014	<.001
Minority	-0.006	0.018	.731	-0.046	0.004	<.001
Single parent households with children under 18	0.493	0.106	<.001	0.024	0.024	.32
Below Poverty	-0.009	0.054	.866	0.049	0.012	<.001

Table 2
County characteristics associated with COVID-19 vaccination rates in counties with high hesitancy: multivariate logistic regression results

County characteristics	Odds ratio (Exp(B))	*P* value	95% CI	
			Lower	Upper
Access				
Vaccine uptake Concern (CVAC)	0.000	<.001	0.000	0.002
No access to a vehicle	1.703	<.001	1.369	2.117
Unemployment	1.044	.660	0.862	1.265
Noninstitutionalized citizens with disability	1.109	.128	0.971	1.268
Knowledge				
No high school education	0.700	<.001	0.610	0.803
Speak English less than well	1.712	.033	1.045	2.805
Attitudes				
Over 65 y	1.061	.298	0.949	1.185
Minorities except non-Hispanic white	1.109	<.001	1.058	1.163
Single parent households with children under 18	0.892	.253	0.732	1.086
Below poverty	1.003	.957	0.896	1.123

NOTE. DV= 0 (High hesitancy – Low rates).
DV = 1 (High hesitancy – High rates).

Table 3
Characteristics of US population who has not yet received COVID-19 vaccine, and who is hesitant to take the vaccine as of May 10, 2021

Select characteristics	(1) Total adult population (n)	(2) Total adult population that is unvaccinated, n(% of total population)	(3) Adult population that is unvaccinated and answered, "will definitely not get a vaccine," n (% of total population)	(4) % of Adult population that is unvaccinated who answered "will definitely not get a vaccine" (%: (3)/(2))
Total	250,265,449	63,111,500 (25%)	17,999,786 (7%)	29%
Age				
18-24	23,445,638	8,994,762 (14%)	1,884,902 (10%)	21%
25-39	65,230,956	23,621,802 (37%)	6,982,254 (39%)	30%
40-54[†]	63,471,403	17,733,259 (28%)	4,908,380 (27%)	28%
55-64[‡]	42,533,760	7,373,303 (12%)	2,103,443 (12%)	29%
65 and above	55,583,692	5,388,374 (9%)	2,120,807 (12%)	39%
Sex[*]				
Male	121,078,275	31,067,884 (49%)	8,895,733 (49%)	29%
Female	129,187,174	32,043,616 (51%)	9,104,053 (51%)	28%
Hispanic origin and Race				
Hispanic or Latino (may be of any race)	43,041,957	12,848,382 (20%)	2,864,458 (16%)	22%
White alone, not Hispanic	155,928,642	36,385,081 (58%)	11,992,067 (67%)	33%
Black alone, not Hispanic	28,569,240	9,502,882 (15%)	1,972,067 (11%)	21%
Asian alone, not Hispanic	13,703,920	1,312,324 (2%)	118,336 (1%)	9%
Two or more races + Other races, not Hispanic	9,021,690	3,062,831 (5%)	1,052,858 (6%)	34%
Education				
Less than high school	20,156,177	8,377,280 (13%)	2,360,715 (13%)	28%
High school or GED	77,288,442	25,852,939 (41%)	7,544,014 (42%)	29%
Some college/associate's degree	75,567,240	19,544,682 (31%)	5,669,672 (31%)	29%
Bachelor's degree or higher	77,253,590	9,336,599 (15%)	2,425,385 (13%)	26%
Presence of children under 18 y old				
Children in household	96,993,159	34,227,924 (54%)	9,830,783 (55%)	29%
No children	153,272,290	28,883,576 (46%)	8,169,004 (45%)	28%
Respondent currently employed				
Yes	146,518,424	37,654,182 (60%)	11,367,000 (63%)	30%
No	101,655,976	25,127,586 (40%)	6,549,950 (36%)	26%

[*]Fully Vaccinated individuals, sex was unknown for 1%.
[†]Age category is 40-49.
[‡]Age category is 50-64.

Individual Characteristics and Perceptions Associated with Vaccine Hesitancy

Of 250 million US adults' estimated responses, 63.1 (25%) million had not received the COVID-19 vaccine by May 10, 2021. Of the 63.1 million unvaccinated individuals, 17.9 million (7% of total population and 29% of unvaccinated population) reported strong hesitancy towards the vaccine.

Among the total population, we found that the largest subgroups of highly hesitant unvaccinated individuals were those who identify as racial minority (67%), individuals with high school education or less (55%), individuals over the age of 65 years (39%), and individuals have children in the household under the age of 18 (29%), and unemployment (26%), Table 3.

Among highly hesitant unvaccinated individuals, 5 of the top 10 reported reasons behind vaccine hesitancy were characterized as attitudes, 3 as knowledge, and 2 as attitudes/knowledge. The most common reason driving vaccine hesitancy was lack of trust in COVID-19 vaccines (55%), followed by concerns around side effects of the vaccine (48%), and lack of trust in government (46%), Figure 1. No vaccine hesitancy reason was related to vaccine access.

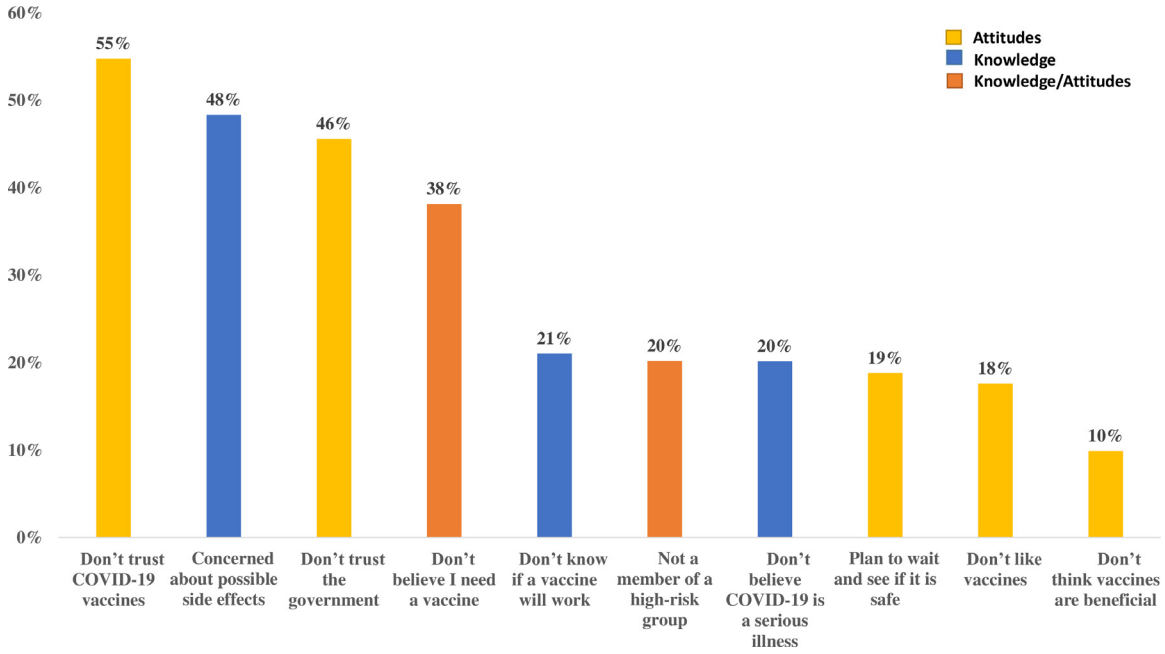

Fig 1. . Top 10 reasons for not receiving or planning to receive vaccine among unvaccinated highly hesitant US Adults as of May 10, 2021.

DISCUSSION

In this cross-sectional study of US communities, we sought to provide new insights into COVID-19 vaccination levels and vaccine hesitancy. Overall, we found an inverse relationship between COVID-19 vaccine uptake and vaccine hesitancy, as would be expected. When we then assessed predictors of vaccination level and of hesitancy level, we found that access factors, knowledge factors, and attitude factors all mattered, but in complex ways. For example, lower levels of vehicle access were associated with both higher vaccination levels and with higher hesitancy. When we further investigated predictors of high vaccination levels within highly hesitant communities, we again found that predictors in all 3 groups were significant. High vaccination levels were present in communities with less vehicle access, more poor English speakers, and more minorities, suggesting that many traditional vaccination barriers were effectively addressed in the COVID-19 vaccination rollout. However, low vaccination levels were found in communities with a less educated population and with more concern about vaccine uptake capacity, suggesting that education and infrastructure are ongoing challenges. Since we suspect that many of the dimensions of capacity (as captured by the CVAC) have been addressed in recent months, determining a strategy for decreasing hesitancy among less well-educated citizens appears to be the top challenge.

Here, our findings suggest that levels of education may be related to gaps in knowledge about the vaccine among unvaccinated individuals. At the individual-level, more than half of the unvaccinated US adults who reported strong hesitancy towards the vaccine had a high school education or less. Additionally, 5 of the top 10 reasons for not receiving the COVID-19 vaccine were related to lack of knowledge around potential side effects, benefits of the vaccine, vaccine effectiveness, and risks to remaining unvaccinated. This conclusion is consistent with prior research showing that individuals with higher education levels have higher levels of knowledge of the COVID-19 vaccine,[30] and that lack of knowledge around the COVID-19 vaccine are associated with lower levels of intent to vaccinate in the US and in the UK.[31,32]

A nuanced assessment of our findings reveals that, while education appears to be a key barrier, there are other demographic considerations in play. Specifically, among highly hesitant communities, counties with high proportion of individuals over 65 years and high proportion of individuals associated with racial minority groups had high vaccination rates. Nonetheless, among unvaccinated populations, more than two thirds of highly hesitant populations belonged to racial minority groups, and over a third of the highly hesitant populations were over 65 years of age. This suggests that although over 65 and minority groups contributed to increased vaccination rates, there remains a significant majority of unvaccinated populations who are still strongly hesitant to take the vaccine fall in these 2 groups. It is plausible that these are the subset of the over 65 and minority demographic groups with lower education levels and that they may be easier to persuade with targeted interventions that address knowledge gaps.

Finally, our results related to reasons for hesitancy among the unvaccinated reveal the specific knowledge gaps that need to be addressed. Respondents reported that their concerns about vaccine side effects and its overall efficacy were among the top reasons for their hesitancy. These findings align with previous findings that populations with less favorable attitudes toward a COVID-19 vaccination also perceived the virus to be less threatening.[33] Other work has shown the mechanisms underlying these knowledge gaps, which are misinformation from social networks, inaccurate posts on social media, and unreliable media sources to inform their perceptions of the vaccine.[17] To combat misinformation, novel ways to disseminate accurate and reliable vaccine information are needed, similar to previous efforts among adolescents.[34] To the extent that policymakers and community leaders should identify communication strategies that are specifically effective for over 65 years and minority groups, which will then inform targeted awareness campaigns in order to help neutralize misconceptions and persuade towards vaccinations.[18] Effective strategies likely need to focus on nonstandard scientific responses such as communicating the percent of individuals who received the vaccine within their community or to promote a path back to normalcy through herd immunity, which can provide more reassurance and helps reinstate trust.[35]

LIMITATIONS

This study had several limitations. First, no vaccination rates were reported from counties within the state of Texas, such that our results are not fully nationally-representative. Second, the response rate to the HP survey was relatively low. However, we incorporated the statistical weights calculated by the US Census Bureau used to produce estimates for the total persons aged 18 or older in the US. Third, data on county-level characteristics were from 2018 as compared to data on vaccination and hesitancy rates which were from 2021. However, the characteristics we included do not change substantially over time, as reflected by the fact that the American Community Survey (ACS) is updated by the US Census Bureau every 10 years.

CONCLUSION

COVID-19 vaccine hesitancy is a public health threat. Our study suggests that low education levels are a major contributor to vaccine hesitancy and ultimately vaccination levels. Specifically, low vaccination levels were found in communities with a less educated population and with more concern about vaccine uptake capacity, suggesting that education is an ongoing challenge. Our findings suggest that policy makers and community leaders should tailor vaccine information and efforts to those with limited education and specifically address knowledge concerns that are prevalent and likely more modifiable. The rapidly evolving nature of the COVID-19 pandemic, including novel variants of the virus, pose a clear urgency to vaccinate highly hesitant groups to improve public health in the US.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.ajic.2021.12.013.

References

1. Centers for Disease Control and Prevention. United States COVID-19 Cases and Deaths by State Over Time. Accessed June 22, 2021, https://data.cdc.gov/Case-Surveillance/United-States-COVID-19-Cases-and-Deaths-by-State-o/9mfq-cb36.
2. Pifarré i Arolas H, Acosta E, López-Casasnovas G, et al. Years of life lost to COVID-19 in 81 countries. *Sci Rep*. 2021;11:3504.
3. Bilinski A, Emanuel EJ. COVID-19 and excess all-cause mortality in the US and 18 comparison countries. *JAMA*. 2020;324:2100–2102.
4. Aschwanden C. Five reasons why COVID herd immunity is probably impossible. *Nature*. 2021;591:520–522.
5. Khairat S, Zalla LC, Adler-Milstein J, Kistler CE. U.S. nursing home quality ratings associated with COVID-19 cases and deaths. *J Am Med Dir Assoc*. 2021;22:2021–2025.e1.
6. Christie A, Henley SJ, Mattocks L, et al. Decreases in COVID-19 cases, emergency department visits, hospital admissions, and deaths among older adults following the introduction of COVID-19 vaccine - United States, September 6, 2020-May 1, 2021. *MMWR Morb Mortal Wkly Rep*. 2021;70:858–864.
7. Rodrigues CMC, Plotkin SA. Impact of vaccines; health, economic and social perspectives. Review. *Front Microbiol*. 2020;11:1526.
8. Tan L. Adult vaccination: now is the time to realize an unfulfilled potential. *Hum Vaccin Immunother*. 2015;11:2158–2166.
9. Bach AT, Kang AY, Lewis J, Xavioer S, Portillo I, Goad JA. Addressing common barriers in adult immunizations: a review of interventions. *Expert Rev Vaccines*. 2019;18:1167–1185.
10. MacDonald NE. Vaccine hesitancy: definition, scope and determinants. *Vaccine*. 2015;33:4161–4164.
11. Sallam M. COVID-19 vaccine hesitancy worldwide: a concise systematic review of vaccine acceptance rates. *Vaccines (Basel)*. 2021;9:160.
12. Moghadas SM, Vilches TN, Zhang K, et al. The impact of vaccination on Coronavirus Disease 2019 (COVID-19) outbreaks in the United States. *Clin Infect Dis*. 2021;73:2257–2264.
13. Hyland-Wood B, Gardner J, Leask J, Ecker UKH. Toward effective government communication strategies in the era of COVID-19. *Humanit Soc Sci Commun*. 2021;8:30.
14. Leongini M. Corporate communications are key to success during a pandemic. *J AWWA*. 2021;113:83–85.
15. Heaton PM. The Covid-19 vaccine-development multiverse. *N Engl J Med*. 2020;383:1986–1988.
16. Rief W. Fear of adverse effects and COVID-19 vaccine hesitancy: recommendations of the treatment expectation expert group. *JAMA Health Forum*. 2021;2. e210804-e210804.
17. Rosenbaum L. Escaping catch-22 — overcoming covid vaccine hesitancy. *N Engl J Med*. 2021;384:1367–1371.
18. Wilson SL, Wiysonge C. Social media and vaccine hesitancy. *BMJ Global Health*. 2020;5: e004206.
19. Centers for Disease Control and Prevention. CDC SVI Documentation 2018. Accessed June 2, 2021, https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/SVI_documentation_2018.html.
20. Karaye IM, Horney JA. The impact of social vulnerability on COVID-19 in the U.S.: an analysis of spatially varying relationships. *Am J Prev Med*. 2020;59:317–325.
21. Institute of Medicine Committee on Monitoring. Access to personal health care S. In: Millman, ed. *Access to Health Care in America*. National Academies Press (US) Copyright 1993 by the National Academy of Sciences; 1993. All rights reserved.
22. Chin J, Morrow DG, Stine-Morrow EA, Conner-Garcia T, Graumlich JF, Murray MD. The process-knowledge model of health literacy: evidence from a componential analysis of two commonly used measures. *J Health Commun*. 2011;16(suppl 3):222–241.
23. Haddock G, Maio G. Attitudes: content, structure, and function. *Introduction to Social Psychology: A European Perspective*. Wiley-Blackwell: Hoboken, NJ; 2007. pp. 112–113.
24. Centers for Disease Control and Prevention. COVID data tracker. Accessed June 2, 2021, https://covid.cdc.gov/covid-data-tracker/#county-view.
25. United States Census Bureau. Week 29 household pulse survey: April 28 – May 10. Accessed June 13, 2021, https://www.census.gov/data/tables/2021/demo/hhp/hhp29.html.
26. Bonanno GA, Galea S, Bucciarelli A, Vlahov D. What predicts psychological resilience after disaster? The role of demographics, resources, and life stress. *J Consult Clin Psychol*. 2007;75:671–682.
27. Ventures S. Surgo precision for COVID. Accessed June 2, 2021, https://vaccine.precisionforcovid.org/.
28. Prevention CfDCa. Fully vaccinated adults Accessed July 6, 2021, https://data.cdc.gov/Vaccinations/Fully-Vaccinated-Adults/jm79-dz78.
29. United States Census Bureau. Household pulse survey: measuring social and economic impacts during the coronavirus pandemic. Accessed June 2, 2021, https://www.census.gov/programs-surveys/household-pulse-survey.html.
30. Gerosa T, Gui M, Hargittai E, Nguyen MH. Mis)informed during COVID-19: how education level and information sources contribute to knowledge gaps. *Int J Commun*. 2021;15:21.
31. Loomba S, de Figueiredo A, Piatek SJ, de Graaf K, Larson HJ. Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA. *Nat Hum Behav*. 2021;5:337–348.
32. Geldsetzer P. Knowledge and perceptions of COVID-19 among the general public in the United States and the United Kingdom: a cross-sectional online survey. *Ann Intern Med*. 2020;173:157–160.
33. Fridman A, Gershon R, Gneezy A. COVID-19 and vaccine hesitancy: a longitudinal study. *PLoS One*. 2021;16: e0250123.
34. Walling EB, Benzoni N, Dornfeld J, et al. Interventions to improve HPV vaccine uptake: a systematic review. *Pediatrics*. 2016;138:e20153863.
35. Miller M, Castrucci BC. Changing the COVID-19 conversation: it's about language. *JAMA Health Forum*. 2021;2. e210020-e210020.