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Cluster analysis of adults unvaccinated for COVID-19 based on behavioral and social factors, National Immunization Survey-Adult COVID Module, United States

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ABSTRACT

By the end of 2021, approximately 15% of U.S. adults remained unvaccinated against COVID-19, and vaccination initiation rates had stagnated. We used unsupervised machine learning (K-means clustering) to identify clusters of unvaccinated respondents based on Behavioral and Social Drivers (BeSD) of COVID-19 vaccination and compared these clusters to vaccinated participants to better understand social/behavioral factors of non-vaccination. The National Immunization Survey Adult COVID Module collects data on U.S. adults from September 26–December 31, 2021 ($n = 187,756$). Among all participants, 51.6% were male, with a mean age of 61 years, and the majority were non-Hispanic White (62.2%), followed by Hispanic (17.2%), Black (11.9%), and others (8.7%). K-means clustering procedure was used to classify unvaccinated participants into three clusters based on 9 survey BeSD items, including items assessing COVID-19 risk perception, social norms, vaccine confidence, and practical issues. Among unvaccinated adults ($N = 23,397$), 3 clusters were identified: the “Reachable” (23%), “Less reachable” (27%), and the “Least reachable” (50%). The least reachable cluster reported the lowest concern about COVID-19, mask-wearing behavior, perceived vaccine confidence, and were more likely to be male, non-Hispanic White, with no health conditions, from rural counties, have previously had COVID-19, and have not received a COVID-19 vaccine recommendation from a healthcare provider. This study identified, described, and compared the characteristics of the three unvaccinated subgroups. Public health practitioners, healthcare providers and community leaders can use these characteristics to better tailor messaging for each sub-population. Our findings may also help inform decisionmakers exploring possible policy interventions.

1. Introduction

Receiving a COVID-19 vaccination is important both to prevent COVID-19-related morbidity and mortality and to slow the spread of SARS-CoV-2, the virus that causes COVID-19. Though COVID-19 vaccination is recommended for adults, by the end of 2021, approximately 15% of U.S. adults remained unvaccinated against COVID-19, and vaccination initiation rates had stagnated (Centers for Disease Control and Prevention, 2022c, 2022d). The Behavioral and Social

Drivers (BeSD) of Vaccination framework was built on the Increasing Vaccine Model, which identified thinking and feeling, social processes, and practical issues as the behavioral and social drivers of COVID-19 vaccination (Brewer, 2021; Brewer et al., 2017). The National Immunization Survey Adult COVID Module (NIS-ACM) was initiated in April 2021 in response to the COVID-19 pandemic, to assess COVID-19 vaccine coverage in adults over 18 years, and to provide nationally representative estimates of the BeSD of COVID-19 vaccination (Centers for Disease Control and Prevention, 2022b).

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Recent COVID-19 research identified many population characteristics associated with low vaccination coverage or higher vaccine hesitancy, including younger age, racial/ethnic minority groups, less education, unemployment, no health insurance, living in rural or socially vulnerable areas, and no health condition that may put them at higher risk for COVID-19 (Khairat et al., 2022; Lu et al., 2022; Saelee et al., 2022). However, it's important to recognize that the unvaccinated population may have different underlying reasons for vaccine hesitancy, and these differences can be assessed by BeSD framework domains/items. Further examination, identification, and characterization of subgroups with similar BeSD assessment scores could provide better understanding of shared root causes underlying disparate unvaccinated population. The present study used cluster analysis, an unsupervised machine learning, to identify three clusters of unvaccinated survey respondents based on the BeSD domains: vaccine confidence (e.g., perceived importance and safety of COVID-19 vaccine), risk perception (concern about getting COVID-19), social norms (e.g., vaccination status of friends and families) and practical issues (e.g., availability and accessibility of vaccine). Cluster analysis is an inductive exploratory technique that uncovers structures without existing hypothesis (Wu, 2012). The clusters identified could provide additional information on the characteristics of this unvaccinated population. The objectives of this study were to compare these identified unvaccinated clusters to vaccinated participants to better understand reasons for non-vaccination and to describe the demographic and other characteristics of these clusters.

2. Methods

2.1. Participants and survey description

The NIS-ACM is a nationally representative survey of non-institutionalized U.S. adults aged ≥18 years that uses a random-digit-dialed sample of cellular telephone numbers (Wolter et al., 2017). Data collected during September 26 through December 31, 2021, were used for these analyses. Response rates were calculated for three approximate monthly analytic periods: September 26–October 30, October 31–November 27, and November 28–December 31. Response rates for these three periods ranged from 20.9% to 23.4%, and the total sample size was 187,756. However, 911 participants with incomplete data on COVID-19 vaccine status or BeSD items were excluded, leaving an analytic sample of 186,845. The survey collected detailed demographic information from the participants, including gender, age, race/ethnicity, education, household income and county of residence. Receipt of ≥1 dose of COVID-19 vaccine was assessed with the question “Have you received at least one dose of a COVID-19 vaccine?” Those responding “no” were asked “How likely are you to get a COVID-19 vaccine? Would you say you would definitely get a vaccine, probably get a vaccine, probably not get a vaccine, definitely not get a vaccine, or are not sure?” Data were weighted to represent the noninstitutionalized U.S. adult population aged ≥18 years and calibrated within states by age and sex for each monthly analytic period to COVID-19 vaccine administration data reported to CDC by state and jurisdictional health departments as of mid-month (Centers for Disease Control and Prevention, 2022a).

2.2. Statistical analysis

K-means clustering was used to classify unweighted, unvaccinated participants into three clusters based on nine survey items related to behavioral and social drivers of COVID-19 vaccination, including four items assessing vaccine confidence (perceived importance, safety, information-seeking behavior, regret about not having a COVID-19 vaccine), two items assessing risk perception (concern about getting COVID-19, mask-wearing behavior), one item assessing social norms (e.g., vaccination status of friends and families) and two items assessing

practical issues (e.g., availability, accessibility), as presented in Table 1. The K-means model is an unsupervised machine learning algorithm that uses Euclidean distances and clusters observations with a standard iterative algorithm for minimizing the sum of squared distances from the cluster means (Wu, 2012). Once clusters were identified, weighted means of all nine BeSD items on behavioral and social drivers were compared among the four groups using a one-way ANOVA test. Statistical significance was set at $\alpha = 0.05$. Because the large sample size of the study yielded small p -values ($p < 0.01$) for all one-way ANOVA tests, even those with relatively small differences among groups, the effect sizes (F-values) were reported in lieu of p -values when comparing the BeSD item means among groups. Descriptive analyses were performed using SUDAAN to compare demographic characteristics (e.g., sex, race/ethnicity, education, income, health conditions) between the vaccinated group (Cluster 0) and the three identified unvaccinated clusters (Cluster 1–3). Chi-square tests were performed to assess categorical demographic differences among the four groups. The 95% confidence intervals were reported for both means and percentages and were used for pairwise comparisons.

The study was reviewed by Centers for Disease Control and Prevention (CDC) and conducted consistent with applicable federal law and CDC policy.

Table 1

Nine survey items used to assess behavioral and social drivers (BeSD) of COVID-19 vaccination, National Immunization Survey-Adult COVID Module, September 26–December 31, 2021.

BeSD items	Label	Value
Item 1: How concerned are you about getting COVID-19?	Not at all concerned	1
	A little concerned	2
	Moderately concerned	3
	Very concerned	4
	Very concerned	4
Item 2: In the past 7 days, how often have you worn a mask when going into indoor public spaces like restaurants, stores, or other businesses?	Never or rarely	1
	Sometimes	2
	Often	3
	Always	4
Item 3: In the past month, how often have you tried to find information about COVID-19 vaccines?	Never	1
	Rarely	2
	Sometimes	3
	Often	4
Item 4: How much do you agree with the following statement: If I do not get a COVID-19 vaccine, I will regret it / if I had not gotten a COVID-19 vaccine, I would have regretted it.	Do not agree	1
	Somewhat agree	2
	Strongly agree	3
	Very strongly agree	4
Item 5: How safe do you think a COVID-19 vaccine is for you?	Not at all safe	1
	Somewhat safe	2
	Very safe	3
	Completely safe	4
Item 6: How important do you think getting a COVID-19 vaccine is to protect yourself against COVID-19?	Not at all important	1
	A little important	2
	Somewhat important	3
	Very important	4
Item 7: If you had to guess, about how many of your family and friends have received a COVID-19 vaccine?	None	1
	Some	2
	Many	3
	Almost all	4
Item 8: How difficult would it be for you / was it for you to get a COVID-19 vaccine?	Very difficult	1
	Somewhat difficult	2
	A little difficult	3
	Not at all difficult	4
Item 9: I can get a COVID-19 vaccine if I want to (asked only of unvaccinated respondents).	Do not agree	1
	Somewhat agree	2
	Strongly agree	3
	Very strongly agree	4

3. Results

Among all participants, 79.0% received at least one dose of COVID-19 vaccine. Based on participants' answers to the BeSD questions, K-means cluster analysis identified three distinct clusters within the unvaccinated adult population (labeled Clusters 1, 2, and 3), with 5406 (24.2%), 6242 (27.1%), and 11,749 (48.8%) participants, respectively.

Table 2 and Fig. 1 present the comparison of the weighted means of the nine survey items on BeSD factors among the four clusters, including the vaccinated group (Cluster 0) and the three unvaccinated groups. The weighted percentages for the four clusters in the population were: 79.0% (Cluster 0), 5.1% (Cluster 1), 5.7% (Cluster 2), and 10.3% (Cluster 3). The minimum score for the nine survey items was 1 and the maximum score was 4, with all items scaled in the same direction such that higher numbers indicate greater vaccine confidence, greater COVID risk perception, more favorably perceived social norms towards COVID vaccine and fewer practical issues related to vaccine accessibility. Based on the distribution of means of the BeSD items between clusters, to facilitate interpretation of results, we labeled the Cluster 0 as "Vaccinated" group, Cluster 1 as unvaccinated "Reachable" group, Cluster 2 as unvaccinated "Less reachable" group, and Cluster 3 as unvaccinated "Least reachable" group.

The vaccinated group and all unvaccinated clusters had high and relatively similar scores (smallest F-values/effect size among all BeSD items) regarding difficulty getting the vaccine (F-value = 45) and being able to get the vaccine if they wanted to (F-value = 11). The unvaccinated "Reachable" group (Cluster 1) reported the highest vaccine information seeking behavior among the four clusters (Fig. 1), and resembled the vaccinated cluster (differed by a mean of <0.50) in terms of perceived importance of the vaccine (mean = 3.73 for Cluster 0 "Vaccinated" vs mean = 3.31 for Cluster 1 "Reachable") and concern about COVID-19 (mean = 2.55 for Cluster 0 "Vaccinated" vs mean = 2.77 for Cluster 1 "Reachable"). In comparison, the unvaccinated "Less reachable" group (Cluster 2) reported lower concern (mean = 1.60), and the unvaccinated "Least reachable" group (Cluster 3) reported the lowest concern (mean = 1.29) among the four groups. The unvaccinated "Less reachable" group (Cluster 2) reported highest mask frequency (mean = 3.71), while unvaccinated Cluster 3 reported lowest mask wearing behavior (mean = 1.22) among the four groups.

Table 2

Mean scores of responses to behavioral and social drivers of COVID-19 vaccination (BeSD) items among vaccinated and unvaccinated clusters, National Immunization Survey-Adult COVID Module, September 26–December 31, 2021.

Weighted percentage	Total ¹ (N=186,845)	Vaccinated cluster 0 (N = 163,448)	Unvaccinated cluster 1: Reachable (N = 5406)	Unvaccinated cluster 2: Less reachable (N = 6242)	Unvaccinated cluster 3: Least reachable (N = 11,749)	F-value
	–	78.99 (78.55–79.42)	5.08 (4.84–5.32)	5.68 (5.43–5.94)	10.25 (9.93–10.58)	–
		Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	
Item 1: Concern about COVID-19 (risk perception)	2.38 (2.37–2.39)	2.55 (2.54–2.56)	2.77 (2.72–2.82)	1.60 (1.56–1.64)	1.29 (1.27–1.31)	1562
Item 2: Mask-wearing behavior	3.04 (3.03–3.05)	3.20 (3.19–3.21)	3.41 (3.36–3.45)	3.71 (3.69–3.73)	1.22 (1.20–1.23)	19,956
Item 3: Sought vaccine information	2.23 (2.22–2.24)	2.25 (2.24–2.26)	2.79 (2.74–2.85)	2.08 (2.02–2.13)	1.87 (1.83–1.91)	356
Item 4: Anticipated regret for not getting vaccine	2.59 (2.58–2.61)	2.93 (2.92–2.94)	2.01 (1.96–2.06)	1.11 (1.09–1.13)	1.10 (1.09–1.12)	589
Item 5: Confidence in vaccine safety	2.86 (2.85–2.87)	3.14 (3.13–3.15)	2.39 (2.34–2.43)	1.42 (1.39–1.45)	1.38 (1.36–1.41)	804
Item 6: Confidence in vaccine importance	3.34 (3.33–3.35)	3.73 (3.72–3.73)	3.31 (3.28–3.35)	1.46 (1.43–1.50)	1.33 (1.31–1.36)	4574
Item 7: Friends/family vaccinated (social norms)	3.22 (3.21–3.23)	3.47 (3.46–3.47)	2.81 (2.77–2.86)	2.23 (2.20–2.27)	2.07 (2.04–2.09)	417
Item 8: Difficulty getting vaccine	3.56 (3.56–3.57)	3.55 (3.54–3.56)	3.47 (3.43–3.52)	3.61 (3.57–3.65)	3.72 (3.69–3.74)	45
Item 9: Can get the vaccine if I want to (self-efficacy)	3.08 (3.06–3.10)	3.20 (3.15–3.25)	3.13 (3.09–3.17)	2.99 (2.94–3.03)	3.08 (3.05–3.11)	11

Footnote 1: The original sample size was 187,756. However, 911 participants with incomplete data on COVID-19 vaccine status or BeSD items were excluded, leaving an analytic sample of 186,845.

The unvaccinated "Reachable" group (Cluster 1) had lower scores than the vaccinated cluster for anticipated regret if one did not get the COVID-19 vaccine (mean = 2.93 for Cluster 0 "Vaccinated" vs mean = 2.01 for Cluster 1 "Reachable"), perceived vaccine safety (mean = 3.14 for Cluster 0 "Vaccinated" vs mean = 2.39 for Cluster 1 "Reachable"), and perceived family/friends vaccinated (mean = 3.47 for Cluster 0 "Vaccinated" vs mean = 2.81 for Cluster 1 "Reachable"). Compared with unvaccinated "Reachable" group (Cluster 1), unvaccinated "Less reachable" and "Least reachable" groups (Clusters 2 and 3) had similar lower mean values in the domains of anticipated regret if one did not get the COVID-19 vaccine (mean = 1.11 for Cluster 2 "Less reachable", mean = 1.10 for Cluster 3 "Least reachable") and perceived vaccine safety (mean = 1.42 for Cluster 2 "Less reachable", mean = 1.38 for Cluster 3 "Least reachable").

Table 3 presents data on willingness to be vaccinated across the three unvaccinated clusters. The "Reachable" group (Cluster 1) had the highest percentage of people who were willing to get vaccinated or unsure (53.0% reported probable/definite intent to get vaccinated, 28.2% were unsure, and 18.8% reported they probably/definitely would not get vaccinated). Compared with the "Reachable" group (Cluster 1), the "Less reachable" group (Cluster 2), had a lower percentage of adults who were willing to get vaccinated and a higher percentage with probable or no intent to get vaccinated (10.0% reported probable/definite intent to get vaccinated, 19.6% were unsure, 22.7% reported they probably would not get vaccinated, and 47.7% reported they definitely would not get vaccinated). The majority of the "Least reachable" group (Cluster 3), had no intent to get vaccinated (6.5% reported probable/definite intent to get vaccinated, 10.7% were unsure, 18.0% reported they probably would not get vaccinated, and 64.8% reported they definitely would not get vaccinated).

Detailed demographic characteristics of the three unvaccinated clusters and vaccinated participants are shown in Table 4. Chi-square tests for all demographic characteristics yielded small p-values ($p < 0.01$) due to large sample size, thus p-values were not included in the Table 4. Compared with the unvaccinated groups, participants in the vaccinated group were more likely to have >12 years of education (34.4%), to report a health condition associated with high risk of COVID-19 (32.7%), to be insured (92.3%), to have a household income above \$75,000 (46.9%), to live in metropolitan statistical area (MSA)

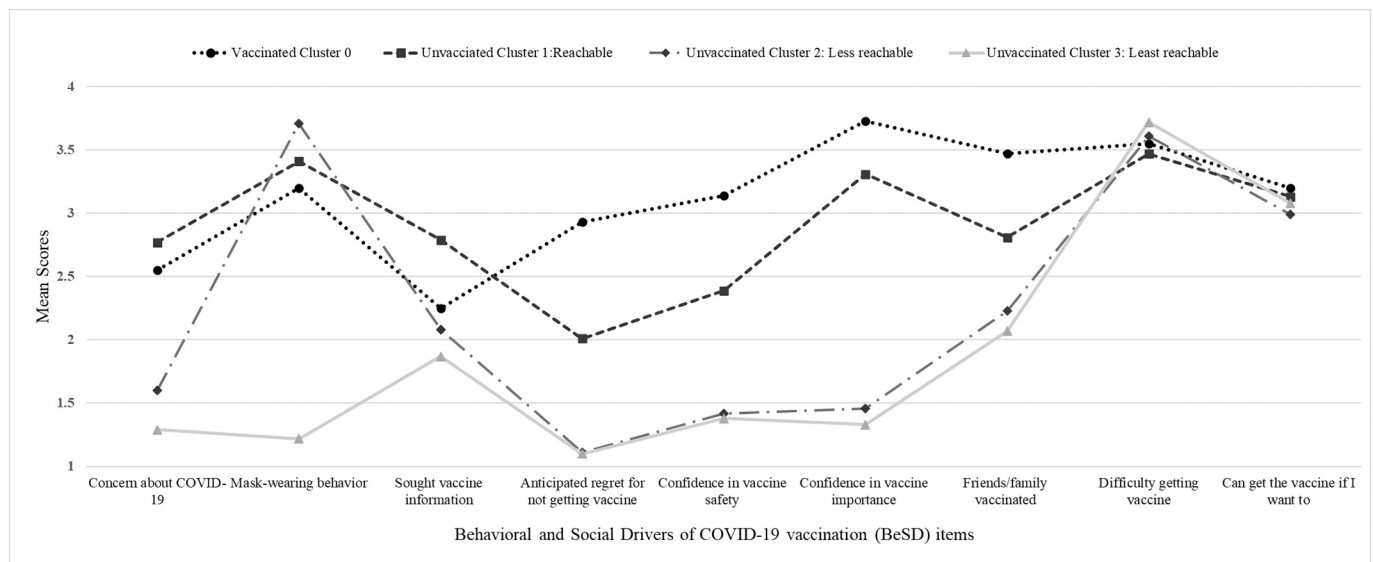


Fig. 1. Comparison of mean scores of responses to behavioral and social drivers of COVID-19 vaccination (BeSD) items among vaccinated and unvaccinated clusters, National Immunization Survey-Adult COVID Module, September 26–December 31, 2021.

Table 3

Reported intention to receive COVID-19 vaccine among the unvaccinated clusters, National Immunization Survey-Adult COVID Module, September 26–December 31, 2021.

	Sample size (N)	Total (N = 23,397) Weighted percent (95% CI)	Cluster 1: Reachable (n = 5406) Weighted percent (95% CI)	Cluster 2: Less reachable (n = 6242) Weighted percent (95% CI)	Cluster 3: Least reachable (n = 11,749) Weighted percent (95% CI)
Definitely plan to get vaccinated	1817	8.1 (7.5–8.8)	24.9 (22.9–27.1)	3.1 (2.4–4.0)	2.5 (2.1–3.1)
Probably will get vaccinated	2303	10.6 (9.9–11.4)	28.1 (25.9–30.4)	6.9 (5.8–8.2)	4.0 (3.4–4.8)
Unsure	3940	17.3 (16.4–18.3)	28.2 (26.1–30.5)	19.6 (17.9–21.6)	10.7 (9.6–11.8)
Probably will not get vaccinated	3987	17.7 (16.8–18.7)	11.7 (10.0–13.5)	22.7 (20.7–24.8)	18.0 (16.7–19.3)
Definitely will not get vaccinated	11,131	46.2 (45.0–47.5)	7.1 (5.9–8.6)	47.7 (45.3–50.0)	64.8 (63.1–66.4)

Abbreviations: CI = confidence interval.

principal and MSA non-principal areas (88.0%), to have received a vaccine other than COVID-19 in the past two years (64.5%), to report previously had COVID-19 (19%), to have received a COVID-19 vaccine recommendation from a HCP (46.9%), and to have a COVID-19 vaccine requirement at work or school (32.9%).

The unvaccinated “Reachable” group (Cluster 1) reported the highest percentage of respondents who were non-Hispanic Black (22.7%) and Hispanic (23.7%), and who lived below the poverty level (30.1%). Compared with the other two unvaccinated clusters, the unvaccinated “Reachable” group (Cluster 1) reported higher percentage of health conditions (23.9%) and disability (13.3%), as well as a higher proportion who had received a non-COVID-19 vaccine in the past 2 years (29.8%). By contrast, respondents of the unvaccinated “Least reachable” group (Cluster 3) had the highest average age among the three unvaccinated clusters (mean = 55.1), and were more likely to be male (60.8%), non-Hispanic White (78.3%), employed as essential workers (37.2%), have previously had COVID-19 (43.1%), report no health conditions (86.3%), from non-MSAs (25.3%), have not received any other vaccines in the past two years (82.3%), and not have received a recommendation for COVID-19 vaccine from a healthcare provider (73.1%). Unvaccinated “Reachable” group (Cluster 1) was more likely than the other two unvaccinated clusters to have received a provider recommendation for COVID-19 vaccination (42.0% compared with 31.0% and 26.9% for clusters 2 and 3, respectively).

4. Discussion

Identifying different subgroups within the unvaccinated population and understanding the characteristics and social and behavioral factors of COVID-19 vaccine can help to differentiate those who may be more responsive to messaging about COVID-19 vaccines. In the present study, we examined the social and behavioral drivers of COVID-19 vaccination and provided machine-learning generated (i.e., predicted by the data rather than explicitly specified by a programmer) clusters based on behavioral and social factors of the sub-populations who are not vaccinated. Public health practitioners, health care providers, and jurisdictions can use these findings to tailor messaging, and the findings also may be useful to decisionmakers exploring policy options to increase vaccine uptake. We found that the clusters formed using the behavioral and social drivers of vaccine uptake also clearly separated unvaccinated persons by levels of intent to get vaccinated, providing support for the usefulness of the BeSD framework (Wolter et al., 2017).

The four clusters had very similar scores on the marker of COVID-19 vaccine accessibility, all having high agreement with the statement “I can get the vaccine if I want to” and low perceived difficulty getting the COVID-19 vaccine. This suggests that practical issues obtaining access to the COVID-19 vaccine were not perceived as a major barrier for COVID-19 primary series vaccination among most adults in the United States during September to December 2021.

Table 4

Demographic and other characteristics of vaccinated and unvaccinated clusters, National Immunization Survey-Adult COVID Module, September 26–December 31, 2021.

	Sample size (N)	Total ^a (N = 186,845)	Vaccinated Cluster 0 (n = 163,448)	Unvaccinated Cluster 1: Reachable (n = 5406)	Unvaccinated Cluster 2: Less reachable (n = 6242)	Unvaccinated Cluster 3: Least reachable (n = 11,749)
		Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)
Age (mean)	186,484	61.0 (59.9–62.2)	63.1 (61.9–64.4)	48.2 (43.3–53.1)	53.7 (47.7–59.6)	55.1 (51.0–59.2)
Gender						
Male	88,980	48.4 (47.9–48.9)	47.1 (46.6–47.6)	46.5 (44.0–48.9)	46.2 (43.8–48.5)	60.8 (59.1–62.4)
Female	97,298	51.6 (51.1–52.1)	52.9 (52.4–53.4)	53.5 (51.1–56.0)	53.8 (51.5–56.2)	39.2 (37.6–40.9)
Age group						
18–24	16,749	12.4 (12.0–12.7)	10.5 (10.2–10.8)	22.4 (20.4–24.5)	18.5 (16.7–20.4)	18.2 (16.9–19.6)
25–39	44,585	25.9 (25.5–26.3)	22.4 (22.0–22.8)	39.3 (36.9–41.8)	40.9 (38.6–43.2)	38.1 (36.4–39.8)
40–49	28,960	16.0 (15.7–16.4)	15.4 (15.0–15.7)	16.4 (14.6–18.3)	19.9 (18.0–21.8)	18.9 (17.5–20.3)
50–64	51,871	24.3 (23.9–24.7)	26.1 (25.6–26.5)	16.5 (14.8–18.4)	15.5 (14.1–17.1)	19.7 (18.4–21.0)
65–74	29,117	12.7 (12.4–13.0)	15.1 (14.7–15.5)	3.7 (2.8–4.7)	3.5 (2.8–4.4)	3.4 (2.9–4.0)
75+	13,351	8.7 (8.4–9.0)	10.6 (10.2–10.9)	1.8 (1.4–2.4)	1.8 (1.3–2.4)	1.8 (1.3–2.3)
Race/ethnicity						
White, non-Hispanic	118,476	62.2 (61.7–62.7)	61.9 (61.4–62.4)	45.9 (43.4–48.4)	51.9 (49.5–54.3)	78.3 (76.7–79.7)
Black, non-Hispanic	21,238	11.9 (11.6–12.2)	11.7 (11.4–12.0)	22.7 (20.7–24.9)	18.8 (17.1–20.6)	4.0 (3.3–4.8)
Hispanic	24,505	17.2 (16.8–17.6)	17.5 (17.1–17.9)	23.7 (21.6–25.8)	19.2 (17.3–21.2)	10.7 (9.6–11.9)
Other	18,239	8.7 (8.4–9.0)	8.9 (8.6–9.1)	7.7 (6.5–9.1)	10.1 (8.6–11.8)	7.0 (6.2–8.0)
Education						
Less than high school (< 12 years)	45,503	39.0 (38.5–39.5)	35.9 (35.4–36.4)	53.5 (51.0–56.0)	51.5 (49.1–53.8)	48.7 (47.0–50.5)
High school (=12 years)	52,073	30.6 (30.2–31.1)	29.7 (29.2–30.2)	33.1 (30.8–35.6)	34.4 (32.2–36.7)	34.4 (32.9–36.1)
Some college	47,486	19.2 (18.8–19.5)	21.1 (20.7–21.5)	10.2 (9.0–11.7)	10.7 (9.4–12.1)	13.5 (12.4–14.7)
College graduate	37,414	11.2 (11.0–11.5)	13.3 (13.0–13.6)	3.1 (2.4–4.1)	3.4 (2.8–4.3)	3.4 (2.9–3.9)
Health conditions associated with high risk of COVID-19 ^b						
With health conditions	56,614	29.5 (29.1–29.9)	32.7 (32.2–33.2)	23.9 (21.8–26.1)	18.1 (16.3–20.0)	13.7 (12.7–14.9)
No health conditions	127,850	70.5 (70.1–70.9)	67.3 (66.8–67.8)	76.1 (73.9–78.2)	81.9 (80.0–83.7)	86.3 (85.1–87.3)
Disabilities ^c						
Disabilities	17,237	9.8 (9.5–10.1)	10.0 (9.7–10.4)	13.3 (11.8–15.0)	8.0 (6.9–9.2)	7.2 (6.3–8.2)
No disabilities	169,999	90.2 (89.9–90.5)	90.0 (89.6–90.3)	86.7 (85.0–88.2)	92.0 (90.8–93.1)	92.8 (91.8–93.7)
Health insurance						
Insurance	168,303	89.9 (89.6–90.2)	92.3 (92.0–92.6)	78.8 (76.7–80.8)	80.9 (78.9–82.8)	81.7 (80.2–83.0)
No insurance	14,179	10.1 (9.8–10.4)	7.7 (7.4–8.0)	21.2 (19.2–23.3)	19.1 (17.2–21.1)	18.3 (17.0–19.8)
Income						
Below poverty	16,765	14.1 (13.7–14.5)	12.4 (12.0–12.8)	30.1 (27.5–32.9)	23.0 (20.7–25.4)	14.2 (12.9–15.6)
Above poverty, <\$75 k	57,884	42.0 (41.4–42.5)	40.7 (40.1–41.3)	47.4 (44.5–50.3)	48.1 (45.4–50.8)	45.9 (43.9–47.8)
Above poverty, ≥\$75 k	70,600	44.0 (43.4–44.5)	46.9 (46.3–47.4)	22.5 (20.1–25.0)	28.9 (26.5–31.4)	40.0 (38.1–41.9)
Social vulnerability index (SVI) ^d						
Low SVI	57,614	28.5 (28.1–28.9)	29.1 (28.7–29.6)	23.1 (20.9–25.5)	21.2 (19.4–23.2)	30.4 (28.8–32.1)
Moderate SVI	60,610	39.3 (38.8–39.8)	39.3 (38.8–39.8)	38.8 (36.3–41.4)	41.0 (38.6–43.5)	38.3 (36.5–40.1)
High SVI	46,949	32.2 (31.8–32.7)	31.6 (31.1–32.1)	38.1 (35.6–40.6)	37.7 (35.4–40.1)	31.3 (29.7–33.0)
Urbanicity						
MSA, principal city	64,886		33.9 (33.4–34.4)	36.0 (33.7–38.4)	35.5 (33.2–37.8)	22.2 (20.9–23.7)

(continued on next page)

Table 4 (continued)

	Sample size (N)	Total ^a (N = 186,845)	Vaccinated Cluster 0 (n = 163,448)	Unvaccinated Cluster 1: Reachable (n = 5406)	Unvaccinated Cluster 2: Less reachable (n = 6242)	Unvaccinated Cluster 3: Least reachable (n = 11,749)
		Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)	Weighted percent (95% CI)
		32.9 (32.5–33.3)				
MSA, non-principal city	87,453	53.3 (52.9–53.8)	54.1 (53.6–54.6)	48.3 (45.8–50.7)	48.8 (46.5–51.2)	52.5 (50.8–54.2)
Non-MSA	35,417	13.8 (13.5–14.1)	12.0 (11.7–12.3)	15.7 (14.0–17.5)	15.7 (14.2–17.4)	25.3 (23.8–26.7)
Received vaccine other than COVID-19 in past 2 years						
Yes	113,303	55.4 (54.9–55.9)	64.5 (64.0–65.0)	29.8 (27.5–32.1)	19.8 (18.1–21.6)	17.7 (16.5–19.0)
No	73,286	44.6 (44.1–45.1)	35.5 (35.0–36.0)	70.2 (67.9–72.5)	80.2 (78.4–81.9)	82.3 (81.0–83.5)
Essential worker status ^c						
Essential worker	58,244	30.7 (30.3–31.2)	29.8 (29.3–30.3)	30.0 (27.8–32.4)	32.3 (30.2–34.6)	37.2 (35.6–38.9)
Not essential worker	126,075	69.3 (68.8–69.7)	70.2 (69.7–70.7)	70.0 (67.6–72.2)	67.7 (65.4–69.8)	62.8 (61.1–64.4)
Previous COVID-19 infection						
Yes	37,750	23.3 (22.9–23.8)	19.0 (18.6–19.4)	37.3 (34.9–39.8)	36.5 (34.3–38.7)	43.1 (41.4–44.8)
No	147,607	76.7 (76.2–77.1)	81.0 (80.6–81.4)	62.7 (60.2–65.1)	63.5 (61.3–65.7)	56.9 (55.2–58.6)
Received healthcare provider (HCP) recommendation for COVID-19 vaccine						
HCP recommendation	84,920	43.7 (43.2–44.2)	46.9 (46.4–47.4)	42.0 (39.5–44.6)	31.0 (29.0–33.2)	26.9 (25.4–28.4)
No HCP recommendation	100,797	56.3 (55.8–56.8)	53.1 (52.6–53.6)	58.0 (55.4–60.5)	69.0 (66.8–71.0)	73.1 (71.6–74.6)
Work or school vaccination requirement						
Requirement	48,997	27.3 (26.9–27.8)	32.9 (32.4–33.4)	12.7 (11.1–14.4)	8.1 (6.8–9.6)	6.1 (5.2–7.1)
No requirement	109,987	72.7 (72.2–73.1)	67.1 (66.6–67.6)	87.3 (85.6–88.9)	91.9 (90.4–93.2)	93.9 (92.9–94.8)

^a The original sample size was 187,756. However, 911 participants with incomplete data on COVID-19 vaccine status or BeSD items were excluded, leaving an analytic sample of 186,845.

^b Health conditions associated with high risk of COVID-19 include cancer, liver disease, overweight, pregnancy, sickle cell disease, smoking, organ or blood transplant, stroke or cerebrovascular disease, substance use disorders, chronic kidney disease, chronic lung disease, dementia or other neurological condition, diabetes, down syndrome, health conditions, HIV infection, immunocompromised state, and others.

^c Disability was defined as having serious difficulty seeing, hearing, walking, remembering, making decisions, or communicating.

^d SVI was categorized as low, moderate, or high based on county of residence using tertiles of SVI score as cut-points. <https://www.atsdr.cdc.gov/placeandhealth/svi/index.html>

^e Essential workers were defined as first responders, frontline or essential workers who work at locations or settings such as healthcare, social service, preschool or daycare, K-12 schools, death care, correctional facilities, food and beverage stores, food manufacturing facilities, agriculture, forestry, fishing or hunting, and others.

The unvaccinated “Reachable” group (Cluster 1) was similar to the vaccinated group in terms of concern about COVID-19 and believing the vaccine is important. However, they were less likely to perceive the vaccine as safe, to express regret for not getting vaccinated, and to have vaccinated friends and family, suggesting vaccination is less of a social norm for this group. This reachable group also had the highest vaccine information seeking behavior scores of all clusters, suggesting that the reachable group may be receptive to information on vaccine safety and effectiveness and shared personal experiences from friends and family who received the vaccine. Previous research has found that vaccination of friends and family or a prestigious expert scientist/president/politician could potentially lower vaccine hesitancy (Salali and Uysal, 2021). Tailored efforts can help promote vaccine confidence and increase community level COVID-19 vaccine education and information distribution (e.g., selecting vaccine ambassadors) and may help to reduce misinformation (Clay et al., 2021; Nguyen et al., 2022; Quinn et al., 2017). Providing information regarding COVID-19 vaccine safety and effectiveness through trusted channels in accessible formats using plain language offers alternatives that may be a safeguard from mis- and disinformation, especially among populations with limited health

literacy (Turhan et al., 2022). Engaging healthcare providers and community leaders to highlight the safety and effectiveness of the COVID-19 vaccine could be effective strategies in this cluster (Clay et al., 2021).

This “Reachable” cluster differs from the “Less reachable” and the vaccinated clusters not only by BeSD factors, but also socio-demographically: the “Reachable” cluster has the highest percentage of non-Hispanic Black and Hispanic participants and the highest percentage of respondents below the poverty level among the four groups and had a higher proportion of respondents living in the most socially vulnerable areas (highest social vulnerability index scores) than the vaccinated group. Our study reinforced previous research that non-Hispanic Black and Hispanic persons and persons with lower income and who live in socially vulnerable or rural areas had higher COVID-19 vaccine hesitancy (DiRago et al., 2022; Litaker et al., 2021; Momplaisir et al., 2021). Acknowledging the role of structural barriers to healthcare (e.g., transportation, wait time, co-payments) and their contribution to vaccine hesitancy, misinformation, and distrust of healthcare can help form and craft messaging around promoting vaccine confidence in this group (Bogart et al., 2021; Freed et al., 2013; Rusoja and Thomas, 2021; Yearby et al., 2022).

The vaccinated group reported the highest percentage of receipt of a recommendation for vaccination from a healthcare provider (HCP), reinforcing the association of a provider recommendation with vaccine uptake (Nguyen et al., 2021). While lower than the vaccinated, the reachable cluster was more likely to report receipt of a HCP recommendation than other unvaccinated clusters, suggesting that HCP recommendations might be effective in encouraging less reachable persons to become more amenable to COVID-19 vaccination. HCP recommendations remain one of the most effective ways to increase vaccination uptake, especially among vaccine hesitant persons (Mazor and Fisher, 2021; Rhodes et al., 2020; Wang and Liu, 2021). It is critical for HCPs to be equipped with information on vaccine efficacy and safety, including the most current guidelines, acknowledging patients' concerns about COVID-19 vaccines, practicing respectful engagement and patient empowerment, and using motivational interviewing techniques (Brewer et al., 2017; Lin et al., 2021; Opel et al., 2015; Rutten et al., 2021).

In contrast to the Cluster 1 (the "Reachable"), where just over 50% of respondents expressed a definite or probable intent to get vaccinated, Clusters 2 (the "Less reachable") and 3 (the "Least reachable") had very low proportions of respondents who intended to receive a COVID-19 vaccine. While the "Less reachable" and "Least reachable" groups had similar BeSD scores on most domains, they differed for mask-wearing behavior, with the "Less reachable" group having the highest score of all clusters and the "Least reachable" group reporting very low mask frequency. This suggests that the "Less reachable" cluster, although reporting low concern about COVID-19, still adhered to other COVID-19 mitigation policies. Although school or work requirements for COVID-19 vaccination were reported by only a small proportion of Cluster 2, vaccination policies, mandates, and requirements at different population levels (e.g., state, local, organizational) have been shown to be very effective in increasing vaccination coverage (Cataldi et al., 2020; Gostin, 2021).

The "Least reachable" group (Cluster 3) expressed the lowest intent to be vaccinated: 65% reported that they definitely would not get a COVID-19 vaccine. This group had the highest percentage of persons who were White males, from non-MSA areas, have previously had COVID-19, and reported they did not receive non-COVID vaccines. The average age of the "Least reachable" group was the highest of the three unvaccinated clusters. These findings align with previous research and ongoing Kaiser Family Foundation survey findings, which have shown that respondents who are White, living in rural areas, and identify as Republican were consistently the most likely to report that they definitely will not get a COVID-19 vaccine (Alcendor, 2021; Kaiser Family Foundation, 2022). The "Least reachable" group also comprises the largest percentage of the population who remained unvaccinated, suggesting that after eight months of the U.S. COVID-19 vaccination program (until the study period), the majority of people willing to be vaccinated had done so.

Previous literature supports that individuals who do not believe COVID-19 exists were found less likely to install contact-tracing apps, undertake health protective behaviors, get tested and vaccinated against COVID-19, and were more likely to report not supporting mask use, social distancing, or COVID-19 vaccines (Juanchich et al., 2021; Taylor and Asmundson, 2021; Zajenkowska et al., 2021). Previous research has found limited effect of health messaging in this population (Lin et al., 2021). Using messages and narratives that align with individuals' core values may shift certain views on preventive behaviors (e.g., DeMora et al. found that health protective behavioral information embedded within religious or patriotic messages may encourage mask use among White evangelical Christians), and alternative strategies and techniques for health communication (e.g., using narratives or stories that highlight personal choice, and using reactance to strengthen the message, such as "You have a right to get vaccinated to stay safe. Don't let anyone take away your right") may be effective for increasing vaccination intent among the "Least reachable" group (DeMora et al., 2021; Taylor and Asmundson, 2021).

The findings in this study are subject to several limitations. First, response rates were low (approximately 20%), but are consistent with other National Immunization Surveys and other surveys using RDD (Centers for Disease Control and Prevention, 2022b; Pew Research Center, 2017). Adjustments and weighting methods were used to reduce bias and errors (e.g., noncoverage, nonresponse, measurement, sampling) in estimators of vaccine coverage. However, errors in estimates might remain after weighting for household nonresponse and incomplete sample frame (households with only landline or no telephone service were excluded). Second, vaccination receipt was self-reported and subject to recall and misclassification bias. However, survey weights were calibrated to COVID-19 vaccine administration data to mitigate possible bias from incomplete sample frame, nonresponse, and misclassification of vaccination status. Third, we assumed that the relationship between behavioral and social drivers and vaccine uptake remained constant over the three-month data collection period. Clusters of unvaccinated persons may change over time and might vary if stratified by geographic area or sociodemographic characteristics.

5. Conclusions

In the present study, we presented the differences in social and behavioral factors of vaccination among adults unvaccinated for COVID-19 and provided a comprehensive profile of the sub-populations who may be willing but are not yet vaccinated, as well as those who are least reachable. Public health practitioners, healthcare providers and community leaders can use these characteristics to better tailor messaging for each sub-population. Our findings may also help inform decision-makers exploring possible policy interventions.

Disclosure

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CRedit authorship contribution statement

Lu Meng: Conceptualization, Methodology, Software, Writing – original draft. **Nina B. Masters:** Conceptualization, Writing – original draft. **Peng-Jun Lu:** Validation, Writing – review & editing. **James A. Singleton:** Supervision, Conceptualization, Methodology, Writing – review & editing. **Jennifer L. Kriss:** Writing – review & editing. **Tianyi Zhou:** Validation, Visualization. **Debra Weiss:** Writing – review & editing. **Carla L. Black:** Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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