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Estimates of COVID-19 vaccine uptake in major occupational groups and detailed occupational categories in the United States, April–May 2021

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Abstract

Background: While other studies have reported estimates of COVID-19 vaccine uptake by broad occupational group, little is known about vaccine uptake by detailed occupational category.

Methods: Data on COVID-19 vaccination were provided by US adults ages ≥18 years old who responded to the Facebook/Delphi Group COVID-19 Trends and Impact Survey (Delphi US CTIS) in April–May 2021, reported working for pay in the past 4 weeks, and answered questions about their COVID-19 vaccine status. Percentages of occupational groups reporting having had at least one COVID-19 vaccination were weighted to resemble the US general population and calculated for 23 major occupational groups and 120 detailed occupational categories in 15 major groups.

Results: COVID-19 vaccine uptake for all 828,401 working adult respondents was 73.6%. Uptake varied considerably across the 23 major occupational groups, from 45.7% for Construction and Extraction to 87.9% for Education, Training, and Library. Percentage vaccinated was also very low for Installation, Maintenance, and Repair at 52.1% and Farming, Fishing, and Forestry at 53.9%. Among the 120 detailed occupational categories, the highest percentage vaccinated was 93.9% for Postsecondary Teacher and the three lowest values were 39.1% for Any Extraction Worker in Oil, Gas, Mining, or Quarrying; 40.1% for Vehicle or Mobile Equipment Mechanic, Installer, or Repairer; and 42.0% for Any Construction Trades Worker.

Conclusion: Low vaccination percentages were seen in many US occupations by the end of May 2021, early in the period of widespread availability of vaccines for adults. These findings could help inform the deployment of occupation-specific vaccine-promotion activities during future viral epidemics and pandemics.

KEYWORDS
COVID-19, occupations, survey, vaccination, workers

1 | INTRODUCTION

Public health officials and researchers recognized early in the COVID-19 pandemic that workplaces can contribute to increased risk of exposure to the virus and provide opportunities for prevention.[1] The National Institute for Occupational Safety and Health (NIOSH) published a COVID-19 research agenda in March 2021 with pandemic-related occupational health research goals.[2] Priority Goal 8.3 in the research agenda states the need to "track workers' acceptance of COVID-19 vaccination." A few reports and publications have provided some insight into how COVID-19 vaccine uptake has varied by occupation in the United States. For example, researchers used data collected from April 28 to May 10, 2021, by the US Census Bureau's Household Pulse Survey (HPS) to investigate the extent of vaccination for COVID-19 by sociodemographic characteristics including type of recent occupation.[3] The researchers assigned workers to five broad occupational groups based on definitions outlined in recommendations for the allocation of COVID-19 vaccines.[4] For the group of workers not in essential occupations, 72.2% had received at least one dose of a COVID-19 vaccine. The comparable percentages were higher for essential workers in healthcare (80.6%) and education (82.5%), but not for other frontline workers (64.3%) and non-frontline essential workers (64.7%). The online COVIDVaxView platform that is maintained by the Centers for Disease Control and Prevention (CDC) provides data on vaccination uptake from the National Immunization Survey-Adult COVID Module (NIS-ACM), including by the same broad occupational groups as used in the HPS.[5] NIS-ACM data from a similar period as the HPS results (April 22 to May 29, 2021) revealed percentages vaccinated by occupational groups that were less than HPS estimates for comparable groups but followed the same pattern. The NIS-ACM estimate that 62.3% of nonessential workers had received at least one dose of a COVID-19 vaccine was in the middle of estimates for the four essential worker groups. Two of the groups had higher values for vaccination—71.9% essential healthcare and 76.5% school and childcare—and two had lower values—48.8% other frontline workers and 45.9% other essential workers.[5]

Another source of data about vaccine uptake by occupation in the United States is the Facebook/Delphi Group COVID-19 Trends and Impact Survey (Delphi US CTIS). This survey was developed by the Delphi Group at Carnegie Mellon University (CMU) and has been offered daily to Facebook users since April 2020.[6] With changes to the survey that added questions about the occupation in September 2020 and vaccine status in December 2020, it is possible to examine the frequency of vaccination by more specific occupational categories than with the HPS and NIS-ACM. A study by King et al.[7] based on Delphi US CTIS data collected from April 20 to May 19, 2021, examined vaccine uptake and hesitancy status by occupations for US Facebook users ages 18–64 years old. Each employed survey respondent was asked to indicate the type of occupation in which they worked, choosing from categories based on the US Bureau of Labor Statistics 2018 Standard Occupational Classification (SOC) system.[8] The options include 23 major occupational categories at the first level, followed by detailed occupational categories for 15 major groups. Cumulative vaccine uptake was 75.2% for all working respondents, and percentages were highest for the major groups Computer and Mathematical (89.0%), Life, Physical, and Social Science (89.1%), and Education, Training, and Library (88.7%), and lowest for Construction and Extraction (46.6%), Installation, Maintenance, and Repair (52.1%), and Farming, Fishing, and Forestry (53.0%). Many of the major groups with low vaccination percentages included occupations identified by the US Department of Homeland Security as being essential to critical infrastructure.[9,10] King et al.[7] presented a table with vaccination and vaccine hesitancy results for detailed occupational categories in three major groups (i.e., Education, Training, and Library; Healthcare Practitioners and Technicians; and Healthcare Support) and their related comments focused on hesitancy rather than vaccination.

Delphi US CTIS data makes it possible to go beyond existing published reports to provide a more detailed account of COVID-19 vaccine uptake by occupation in the United States. The objective of this study was to describe the frequency of vaccination by detailed occupational categories within selected major occupational groups to better understand which workers could benefit from efforts to improve vaccine acceptance.

2 | MATERIALS AND METHODS

The Delphi Group at CMU collaborated with Facebook to initiate the Delphi US CTIS, offered daily to a random sample of US Facebook users 18 years and older since April 2020. The Delphi US CTIS is a repeated cross-sectional survey in which Facebook users might be sent repeated invitations over time based on random sampling, but never sooner than 30 days after the last invitation. The current investigation used data collected from adult Facebook users in the United States every day for 2 consecutive months, April and May 2021. This time period provided sufficient numbers of respondents in most of the smaller detailed occupational categories. The 2-month data collection period means the data might have included multiple entries from the same individual. All data were deidentified by Facebook/CMU before sharing with our research group, so it was impossible to identify repeat participants.

The study to conduct the survey was approved by the CMU Institutional Review Board (IRB ID: STUDY2020_00000162). All participants gave informed consent before taking part in the survey. The current research project was approved by the West Virginia University (WVU) Institutional Review Board (IRB ID: 2008080589 Study of COVID-19 Symptoms and Occupation in the United States). Data were stored on WVU servers, and all data analyses were performed at WVU.

The Delphi US CTIS includes many sociodemographic questions and answers choices based on national surveys, including education categories from the US Census Bureau's American Community Survey (ACS),[11] and race and ethnicity questions from the 2020 Census.[12] The survey inquires about symptoms, test results indicating

COVID-19 infection, vaccination, intention to get vaccinated if not already, and other factors related to the pandemic. Questions were added in September 2020 to ask respondents 18 years and older if they did any work for pay in the past 4 weeks. Those answering "yes" were asked to select the occupation that best fits the main type of work they were doing in the past 4 weeks. The choices for occupations at the first of two levels are based on 23 major occupational groups in the US Bureau of Labor Statistics 2018 SOC system and at the second level on detailed occupational categories within 15 major occupational groups.[8] The detailed occupational categories were based on individual 2018 SOC minor and broad occupational groups and detailed occupations and combinations of these groupings. A series of questions about vaccination for COVID-19 were adapted from two CDC-initiated household panel surveys and added to the Delphi US CTIS in December 2020.[13] The first vaccination question was: Have you had a COVID-19 vaccination? A "yes" answer was followed by a question about having received, or planning to receive, all required doses. Respondents who answered "yes" to the initial question were classified as vaccinated for this study, which means some who met this criterion were not fully vaccinated when they completed the survey. Those who answered "no" or "don't know" to the initial question were then asked whether they would choose to get vaccinated if the vaccine were offered that same day.

Delphi US CTIS respondents were included in this study if they were 18 years or older, reported working for pay in the past 4 weeks, and had answered the first question about vaccination. All estimates of percentage vaccinated were weighted. Facebook provides survey weights to address sampling design and nonresponse by Facebook users. Subsequently, the weights are stratified by gender, age, and geographical distribution to represent the US general population.[14] The 95% confidence interval (95% CI) for each percentage vaccinated was calculated using a maximum likelihood-based CI interval.[15] Percentages and 95% CIs are not reported for occupational categories with fewer than 10 vaccinated respondents. When comparing the major occupational groups with the lowest and highest percentage vaccinated, p values were based on the Satterthwaite approximation to the F distribution and with denominator degrees of freedom as recommended by Thomas and Rao.[16] Data were managed, summarized, and analyzed using Excel (version 8; Microsoft) and R (versions 3.6.0+, packages survey and GDAtools).[17]

3 | RESULTS

A total of 828,401 working Facebook users 18 years or older completed the Delphi US CTIS in April–May 2021 and answered the COVID-19 vaccination question. Respondents were about equally divided by traditional gender groups (47.2% female, 48.4% male), over half were 18–44 years old (53.2%), the two most common race/ethnicity categories were Non-Hispanic White only (68.2%) and Hispanic (14.9%), and 82.5% had some education beyond high school

(Table 1). Almost half (47.2%) of respondents reported at least one pre-existing condition, and high blood pressure (22.5%) and obesity (20.9%) were the most common. The percentage vaccinated was 73.6% for the entire sample, was higher for women than men (78.3% vs. 71.6%, respectively), and increased with increasing age (from 68.8% for 18–44 years to 83.7% for ≥65) and more education (from 54.8% with less than a high school diploma to 84.0% with a graduate or professional degree; Table 1). The percentage by race/ethnicity was highest at 89.3% for Non-Hispanic Asian only and lowest at 55.9% for Non-Hispanic other/multiple races. By pre-existing conditions, percentage vaccinated was greater than the overall 73.6% for cancer (75.0%), high blood pressure (77.3%), Type 2 diabetes (78.7%), and obesity (79.7%), and lower for other conditions and no conditions.

The percentage vaccinated varied considerably among the 23 major occupational groups (Table 2, Figure 1), with a difference of 42.2 percentage points between the minimum of 45.7% and maximum of 87.9% (1.92 times the minimum). Empirical observation of these results suggested the major groups were arrayed in four tiers by the level of vaccine uptake, with each tier separated by approximately 6 to 7 percentage points. Progressing from lowest to highest, Tier 1 includes only the major group Construction and Extraction at 45.7%, Tier 2 includes Installation, Maintenance, and Repair at 52.1% and Farming, Fishing, and Forestry at 53.9%, and Tier 3 includes 8 major groups with values from 60.6% for Transportation and Material Moving to 71.1% for Personal Care and Service. Tier 4 is above the 73.6% vaccinated for all respondents, has 12 major occupational groups with percentages from 78.2% for Architecture and Engineering to 87.9% for Education, Training, and Library, and includes both healthcare major groups.

There were follow-up questions on detailed occupational categories for 15 specific major occupational groups, with 4–12 categories (median 7) per group and a total of 120 (Table 3, Supporting Information: Table S1). The 605,620 respondents in these 15 groups had 74.1% vaccinated (95% CI: 73.9, 74.2), a little greater than the 72.4% (95% CI: 72.2, 72.7) for the 222,781 respondents in the other 8 groups. The difference between the lowest and highest percentages vaccinated for all 120 detailed occupational categories was 54.8, with a minimum of 39.1% for Any Extraction Worker in Oil, Gas, Mining, or Quarrying (major group Construction and Extraction), and a maximum of 93.9% (or 2.4 times the minimum) for Postsecondary Teacher (major group Education, Training, and Library).

We sorted the 120 detailed categories in ascending order of vaccination percentage independent of major groups and divided them into quartiles (Supporting Information: Table S2). The first quartile includes 31 detailed categories from nine different major occupational groups, with values from 39.1% to 62.5%, a 23.4 percentage point difference. The fourth quartile has 30 categories from seven different major groups, with values from 80.7% to 93.9%, a 13.2 percentage point difference. Taken together, these two extreme quartiles include detailed occupational categories from all 15 major groups and have the major group Personal Care and Service in common.

TABLE 1 Distribution of participants and frequency of COVID-19 vaccination by sociodemographic characteristics and pre-existing medical conditions[a]

Characteristics	Categories	Distribution		Vaccinated		
		N	Weighted %[a]	n	Weighted % of N[a]	95% CI
Total	NA	828,401	100	639,058	73.6	73.5, 73.7
Gender	Female	497,013	47.2	399,027	78.3	78.2, 78.5
	Male	304,712	48.4	227,243	71.6	71.4, 71.8
	Other	25,213	4.2	11,722	44.3	43.5, 45.1
	Missing	1463	0.2	1066	66.8	63.4, 70.0
Age, years	18–44	352,480	53.2	254,785	68.8	68.6, 69.1
	45–64	382,646	38.6	304,423	78.1	78.0, 78.3
	65 and older	92,348	8.1	79,401	83.7	83.3, 84.0
	Missing	927	0.1	449	44.1	40.3, 48.0
Race/ethnicity	Hispanic	96,277	14.9	71,592	71.2	70.8, 71.5
	Non-Hispanic Asian only	22,647	3.5	20,249	89.3	88.8, 89.8
	Non-Hispanic Black only	45,961	5.7	35,368	73.7	73.2, 74.2
	Non-Hispanic White only	607,205	68.2	478,000	75.3	75.1, 75.4
	Non-Hispanic Other/Multiple Races	47,618	6.5	28,596	55.9	55.4, 56.5
	Missing	8693	1.1	5253	56.5	55.2, 57.8
Education[b]	Less than high school	15,356	2.5	8971	54.8	53.7, 55.8
	High school graduate or equivalent	104,197	14.7	66,675	59.0	58.6, 59.4
	Some college	186,471	23.9	133,212	68.6	68.3, 68.8
	Two-year degree	93,722	10.9	68,459	69.9	69.5, 70.2
	Four-year degree	234,183	27.3	194,012	81.6	81.4, 81.8
	Graduate or professional degree	192,359	20.4	166,574	84.0	83.8, 84.3
	Missing	2113	0.3	1155	49.8	47.2, 52.4
Pre-existing conditions	Cancer	31,759	3.1	25,529	75.0	74.3, 75.7
	Heart disease	44,326	4.8	32,880	69.4	68.9, 70.0
	High blood pressure	213,942	22.5	171,679	77.3	77.1, 77.5
	Asthma	111,513	13.0	86,193	73.1	72.8, 73.5
	Chronic lung disease	25,435	2.7	17,346	62.3	61.5, 63.1
	Kidney disease	14,012	1.6	9732	62.2	61.1, 63.4
	Type 1 diabetes	9956	1.4	6636	60.1	58.8, 61.4
	Type 2 diabetes	73,303	7.6	59,705	78.7	78.3, 79.1
	Weakened or compromised immune system	39,037	4.4	27,084	65.0	64.3, 65.6
	Obesity	199,236	20.9	164,114	79.7	79.5, 79.9
	None indicated	320,263	42.1	233,249	69.1	68.9, 69.3
	Missing	72,960	10.7	58,101	76.5	76.1, 76.9

[a]Percentages for the distribution of participants and the frequency of COVID-19 vaccination are weighted to resemble eligible Facebook users and the general US adult population. Percentages vaccinated and 95% confidence intervals are not reported for categories with fewer than 10 vaccinated respondents.

[b]Highest degree or level of school completed.

TABLE 2 Frequency of COVID-19 vaccination by major occupational groups, with weighted percentages divided into four tiers[a]

| Tier[b] | 2018 SOC major occupational groups | | N | Vaccinated | | |
	Codes	Titles		n	Weighted %[a]	95% CI
1	47-0000	Construction and extraction[c]	14,006	7165	45.7	44.7, 46.7
2	49-0000	Installation, maintenance, and repair[c]	20,500	11,648	52.1	51.2, 52.9
	45-0000	Farming, fishing, and forestry	5595	3301	53.9	52.2, 55.5
3	53-0000	Transportation and material moving[c]	30,849	19,616	60.6	60.0, 61.3
	33-0000	Protective service[c]	9629	6434	63.1	61.9, 64.3
	51-0000	Production[c]	19,428	12,860	63.6	62.8, 64.5
	37-0000	Building and grounds cleaning and maintenance[c]	16,896	11,465	64.5	63.6, 65.5
	55-0000	Military	3598	2559	65.9	63.7, 68.1
	35-0000	Food preparation and serving related[c]	45,436	31,368	67.8	67.2, 68.4
	41-0000	Sales and related[c]	66,420	47,837	69.1	68.7, 69.6
	39-0000	Personal care and service[c]	17,447	12,721	71.1	70.2, 71.9
4	17-0000	Architecture and engineering	10,567	8465	78.2	77.1, 79.2
	11-0000	Management	31,555	26,001	80.2	79.6, 80.8
	13-0000	Business and financial operations	24,687	20,124	80.3	79.6, 80.9
	31-0000	Healthcare support[c]	45,361	37,319	80.9	80.4, 81.3
	43-0000	Office and administrative support[c]	106,409	87,145	81.2	80.9, 81.5
	21-0000	Community and social service[c]	36,692	31,095	82.5	81.9, 83.0
	27-0000	Arts, design, entertainment, sports, and media[c]	27,022	22,772	83.1	82.6, 83.7
	29-0000	Healthcare practitioners and technicians[c]	66,403	56,354	83.2	82.9, 83.6
	15-0000	Computer and mathematical	29,193	24,887	85.0	84.5, 85.5
	19-0000	Life, physical, and social science	7439	6509	85.9	84.8, 87.0
	23-0000	Legal	11,531	10,147	86.0	85.1, 86.9
	25-0000	Education, training, and library[c]	83,122	74,111	87.9	87.6, 88.2
		Answered "other occupational group"	80,447	54,788	63.6	63.2, 64.1
		Did not answer occupation questions	18,169	12,367	63.5	62.6, 64.5
		Overall	828,401	639,058	73.6	73.5, 73.7

[a]Percentages for the frequency of COVID-19 vaccination are weighted to resemble eligible Facebook users and the general US adult population.

[b]The 23 major occupational groups are divided into four tiers by level of vaccine uptake, with each tier separated by approximately 6–7 percentage points.

[c]Data available for detailed occupational categories within 15 major occupational groups.

Results for detailed occupational categories in the first quartile are presented in Table 4. The 10 lowest percentages were less than 54% and included detailed categories from five major groups: Construction and Extraction; Installation, Maintenance, and Repair; Personal Care and Service; Production; and Building and Grounds Cleaning and Maintenance (Table 4). The five lowest values were <50% and from three major groups: 39.1% for Any Extraction Worker in Oil, Gas, Mining, or Quarrying, and 42.0% for Any Construction Trades Worker (major group Construction and Extraction); 40.1% for Vehicle or Mobile Equipment Mechanic, Installer, or Repairer, and 46.7% for Heating, Air Conditioning, and Refrigeration Mechanic or Installer (Installation, Maintenance, and Repair); and 44.4% for Miscellaneous Entertainment Attendant (Personal Care and Service).

The following five higher values were from four major groups: 50.0% for Woodworker (major group Production); 50.8% for Pest Control Worker (Building and Grounds Cleaning and Maintenance); 53.1% for First-line Supervisor of Construction Trades or Extraction Workers, and 53.6% for Any Other Construction Worker, Including Inspector and Highway Worker (Construction and Extraction); and 53.5% for Line Installer or Repairer for Electrical or Telecommunications (Installation, Maintenance, and Repair). The major group Farming, Fishing, and Forestry did not have results by detailed categories but had a vaccine percentage of 53.9%, in the same range as the 10 detailed categories with the lowest values.

Both major healthcare groups had high vaccine uptake (Supporting Information: Table S1). Healthcare Support had 80.9% vaccinated
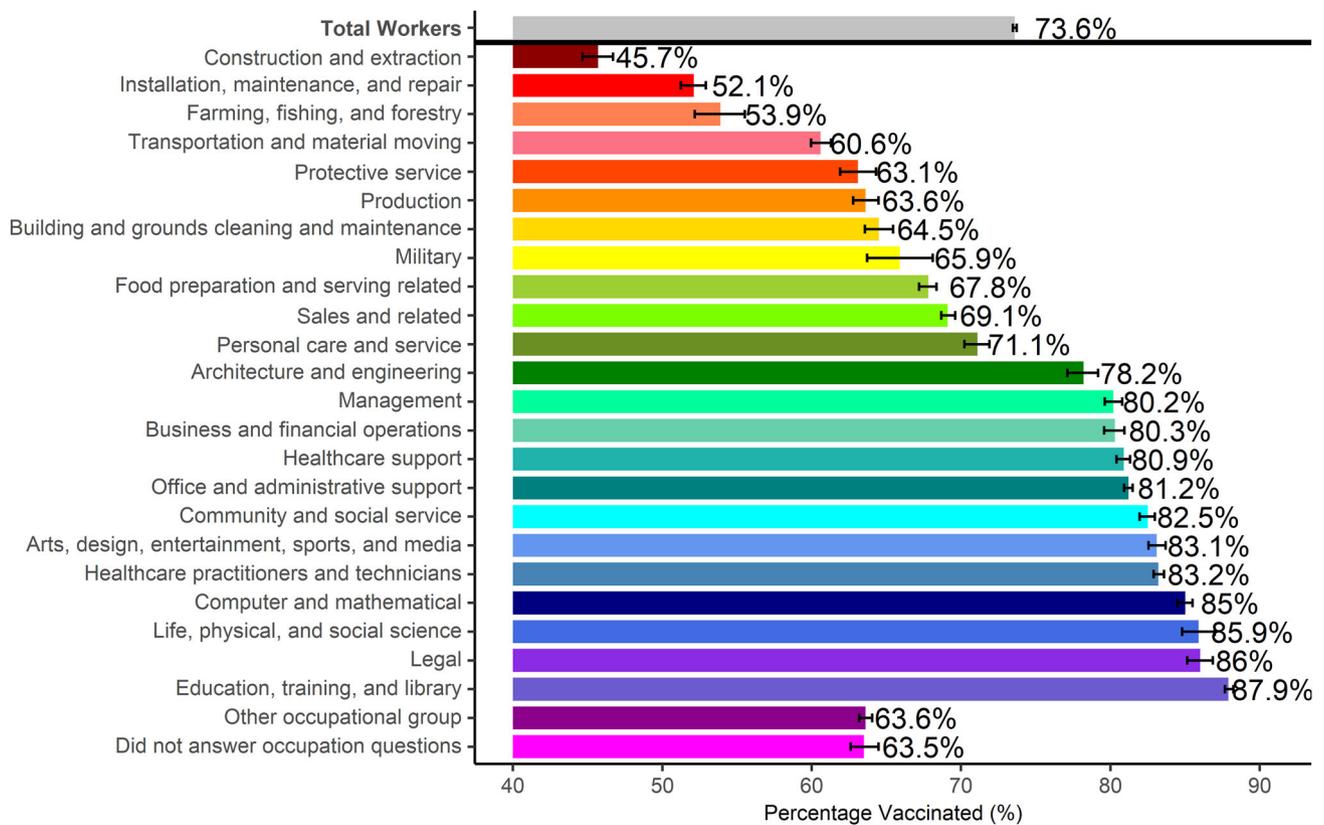
FIGURE 1 Percentage vaccinated for COVID-19 and 95% confidence interval for major occupational groups.

and a maximum among detailed occupational categories of 85.3% for Veterinary Assistant or Laboratory Animal Caretaker. This group also included three detailed categories with percentages less than the overall 73.6% for all respondents: Phlebotomist (67.9%), Massage Therapist (69.7%), and Dental Assistant (72.4%). The other major healthcare group was Healthcare Practitioners and Technicians, with vaccine uptake at 83.2%. The lowest value for detailed occupational categories was 71.4% for Emergency Medical Technicians and Paramedics, and the highest was 90.5% for Pharmacist. Vaccination percentages were similar for three of four nursing care categories from the two healthcare groups—74.4% for Nursing Assistant or Psychiatric Aide, 75.6% for Home Health or Personal Care Aide, and 78.0% for Licensed Practical or Vocational Nurse - and the fourth was higher at 86.8% for Registered Nurse. The category of Physician or Surgeon also had a high value at 83.5% vaccinated.

Table 5 provides a comparison of sociodemographic characteristics and selected pre-existing medical conditions between the major occupational groups with the lowest (Construction and Extraction) and highest (Education, Training, and Library) vaccine uptake (45.7% and 87.9%, respectively). Consistent with what was associated with greater vaccine uptake in Table 1, workers in Education, Training, and Library occupations were more likely to be female (68.2% vs. 6.5%), 65 years or older (8.1% vs. 5.3%), and Non-Hispanic White only (75.7% vs. 65.1%) or Non-Hispanic Asian only (3.1% vs. 1.0%), to have completed at least a 4-year degree (81.3% vs. 26.6%), and to

report at least one of the four pre-existing conditions cancer, high blood pressure, Type 2 diabetes, and obesity (37.5% vs. 29.4%) compared to workers in Construction and Extraction.

4 | DISCUSSION

To the best of our knowledge, this paper presents the most detailed account to date of COVID-19 vaccine uptake by occupation in the United States. This includes estimates of vaccination percentages for 23 major occupational groups and 120 detailed occupational categories in 15 major groups, using data reported by workers 18 years and older who responded to the invitation to complete the Delphi US CTIS during April–May 2021. As expected, the vaccination percentages by major occupational groups in the current study were nearly the same as estimates previously reported by researchers who used Delphi US CTIS data collected from April 20 to May 19, 2021 (data not shown).[7] However, the current results for 120 detailed occupational categories in 15 major groups provide another level of precision regarding the variation in vaccine uptake by occupation. For example, the lowest quartile of percentages vaccinated included detailed categories from nine different major occupational groups. Compared to vaccine results for the major groups, the results for detailed categories make it possible to identify more precisely which workers had low COVID-19 vaccine uptake by May 2021. This

TABLE 3 Distribution of weighted percentages vaccinated for COVID-19 for detailed occupational categories in 15 major occupational groups[a]

| Codes | Weighted percentages (%) vaccinated for 2018 SOC major occupational groups, arranged in ascending order[a] | | Number of detailed occupational categories[b] | Minimum, maximum, and range of weighted percentages (%) vaccinated for detailed occupational categories within major occupational groups[a] | | | | |
| | Titles | % | | Minimum % vaccinated[a] | | Maximum % vaccinated | | Range |
				Titles	%	Titles	%	
47-0000	Construction and extraction	45.7	4	Any extraction worker in oil, gas, mining, or quarrying	39.1	Any other construction worker, including inspector and highway worker	53.6	14.5
49-0000	Installation, maintenance, and repair	52.1	6	Vehicle or mobile equipment mechanic, installer, or repairer (aircraft, automotive, bus, truck, and heavy vehicles)	40.1	Electrical or electronic equipment mechanic, installer, or repairer	57.3	17.2
53-0000	Transportation and material moving	60.6	7	Motor vehicle operator	57.0	Air transportation worker (pilot, flight engineer, air traffic controller, and flight attendant)	73.9	16.9
33-0000	Protective service	63.1	8	Police or sheriff officer	55.6	Any other protective service worker	69.8	14.2
51-0000	Production	63.6	10	Woodworkers	50.0	First-line supervisor of production and operating workers	68.6	18.6
37-0000	Building and grounds cleaning and maintenance	64.5	7	Pest control worker	50.8	Janitor or building cleaner	71.5	20.7
35-0000	Food preparation and serving related	67.8	12	Fast food or counter worker	60.2	Dining room or cafeteria attendant or bartender helper	77.6	17.4
41-0000	Sales and related	69.1	7	Cashier	61.9	Real estate broker or sales agent	72.3	10.4
39-0000	Personal care and service	71.1	9	Miscellaneous entertainment attendant	44.4	Funeral service worker	80.9	36.5
31-0000	Healthcare support	80.9	11	Phlebotomist	67.9	Veterinary assistant or laboratory animal caretaker	85.3	17.4
43-0000	Office and administrative support	81.2	8	Postal service worker or mail carrier	71.4	Any other office or administrative support worker	83.7	12.3
21-0000	Community and social service	82.5	6	Probation officer or correctional treatment specialist	68.4	Social Worker	86.7	18.3
27-0000	Arts, design, entertainment, sports, and media	83.1	7	Sports and related worker (athlete, coach, scout, umpire, and referee)	75.7	Media and communication worker (announcer, analyst, reporter, editor, translator)	89.7	14.0
29-0000	Healthcare practitioners and technicians	83.2	11	Emergency medical technicians and paramedics	71.4	Pharmacist	90.5	19.1
25-0000	Education, training, and library	87.9	7	Preschool or kindergarten teacher	80.9	Postsecondary teacher	93.9	13.0

[a]Percentages vaccinated for COVID-19 are weighted to resemble eligible Facebook users and the general US adult population.

[b]The number of detailed occupational categories by major groups includes neither (a) the "Missing" category in each major group for respondents who did not indicate a more detailed occupation; nor (b) any category with fewer than 10 vaccinated respondents.

TABLE 4 First quartile of weighted percentages vaccinated for COVID-19 among the 120 detailed occupational categories[a],[b]

| Major occupational group | | Detailed occupational category | Weighted percentage (%) vaccinated[a] | |
Code	Title	Title	%	95% CI
39-0000	Construction and extraction	Any extraction worker in oil, gas, mining, or quarrying	39.1	36.6, 41.6
49-0000	Installation, maintenance, and repair	Vehicle or mobile equipment mechanic, installer, or repairer (aircraft, automotive, bus, truck, heavy vehicles)	40.1	37.8, 42.4
49-0000	Construction and extraction	Any construction trades worker (carpenter, electrician, plumber, roofer, helper)	42.0	40.6, 43.5
49-0000	Personal care and service	Miscellaneous entertainment attendant	44.4	32.7, 56.6
51-0000	Installation, maintenance, and repair	Heating, air conditioning, and refrigeration mechanic or installer	46.7	43.7, 49.6
33-0000	Production	Woodworker	50.0	41.9, 58.1
47-0000	Building and grounds cleaning and maintenance	Pest control worker	50.8	35.1, 66.4
51-0000	Construction and extraction	First-line supervisor of construction trades or extraction workers	53.1	51.1, 55.2
33-0000	Installation, maintenance, and repair	Line installer or repairer (electrical or telecommunications)	53.5	49.5, 57.5
37-0000	Construction and extraction	Any other construction worker, including inspector and highway worker	53.6	50.5, 56.6
39-0000	Installation, maintenance, and repair	First-line supervisor of mechanics, installers, or repairers	54.1	51.6, 56.6
37-0000	Installation, maintenance, and repair	Any other installation, maintenance, or repair worker	54.4	53.2, 55.7
51-0000	Production	Metal or plastic worker (machinist, welder, soldering)	54.7	51.7, 57.6
35-0000	Protective service	Police or sheriff officer	55.6	52.5, 58.7
53-0000	Personal care and service	Gambling service worker	56.6	30.2, 80.5
49-0000	Building and grounds cleaning and maintenance	First-line supervisor of landscaping, lawn service, or grounds keeping workers	57.0	53.1, 60.8
53-0000	Transportation and material moving	Motor vehicle operator	57.0	55.9, 58.0
53-0000	Installation, maintenance, and repair	Electrical or electronic equipment mechanic, installer, or repairer	57.3	55.5, 59.2
35-0000	Transportation and material moving	Any material moving worker	58.7	56.9, 60.6
35-0000	Protective service	Lifeguard, ski patrol, or other recreational protective service worker	59.8	39.5, 78.0
37-0000	Production	Any assembler or fabricator	60.0	57.8, 62.1
47-0000	Building and grounds cleaning and maintenance	Grounds maintenance worker	60.1	57.7, 62.4
35-0000	Protective service	Bailiff, correctional officer, or jailer	60.1	54.9, 65.2
49-0000	Food preparation and serving related	Fast food or counter worker	60.2	58.3, 62.0
47-0000	Food preparation and serving related	Dishwasher	61.5	56.2, 66.6
45-0000	Food preparation and serving related	Waiter or waitress	61.8	59.9, 63.7

TABLE 4 (Continued)

Major occupational group Code	Title	Detailed occupational category Title	Weighted percentage (%) vaccinated[a] %	95% CI
33-0000	Production	Plant and system operator (power, water, wastewater, chemical)	61.9	57.9, 65.8
41-0000	Sales and related	Cashier	61.9	60.2, 63.6
33-0000	Transportation and material moving	Rail transportation worker (including railway, subway, and streetcar operator)	62.3	58.2, 66.2
49-0000	Food preparation and serving related	Cook	62.5	60.0, 65.0
51-0000	Protective service	Security guard or gaming surveillance officer	62.5	59.9, 64.9

[a]Percentages for COVID-19 vaccination are weighted to resemble eligible Facebook users and the general US adult population.

[b]The 31 detailed occupational categories in this table have the lowest percentages of vaccinated among the 120 categories presented in Supporting Information: Table S2. The major group Farming, Fishing, and Forestry did not have results by detailed occupational categories and had a vaccine percentage of 53.9% which is in the range of this first quartile of detailed occupational categories.

occupation-specific information may be useful in subsequent viral epidemics or pandemics regarding which occupations are likely to need additional efforts to encourage vaccine acceptance during the first months the vaccines are widely available for adults.

The Cybersecurity & Infrastructure Security Agency in the US Department of Homeland Security identified workers in several industries as essential to critical infrastructure.[9,10] These workers are primarily in 14 of the 23 major occupational groups included in the current investigation. Four of the 14 had relatively high vaccine uptake, including Education, Training, and Library at 87.9%, the two healthcare groups of Healthcare Practitioners and Technicians at 83.3% and Healthcare Support at 80.9%, and Community and Social Service at 82.5%. These results are consistent with vaccine plans in many states that prioritized healthcare workers and teachers for vaccination early in the COVID-19 vaccination program (https://coronavirus.jhu.edu/vaccines/vaccine-state-plans). The remaining 10 major groups had vaccination percentages less than the overall 73.6%, accounting for all but one group (i.e., Military) in Tiers 1 through 3. This suggests that many essential critical infrastructure workers did not have the protective benefits of COVID-19 vaccines by the end of May 2021.

Similar mixed results for essential workers were reported by the US Census Bureau's HPS conducted from April 28 to May 10, 2021, and the CDC NIS-ACM conducted from April 22 to May 29, 2021.[3,5] This similarity is evident even though these two other studies categorized working participants in five broad essential worker groups that do not directly align with the major SOC groups used in the current study. Results from the HPS included high percentages vaccinated of 82.5% for education and 80.6% for healthcare, but lower percentages of 64.3% for other frontline workers and 64.7% for non-frontline essential workers.[3] From the NIS-ACM, the worker group school and childcare had the highest percentage vaccinated at 76.5% and essential healthcare was the second-highest at 71.9%, but values were much lower at 48.8% for other frontline workers and 45.9% for other essential workers.[5]

While current results were encouraging overall for the two major healthcare groups, they included several detailed occupational categories with relatively low percentages of vaccinated. A survey of healthcare workers conducted in November and December 2020 indicated that intention to receive a COVID-19 vaccine was higher with increasing education level and lower for Black and Hispanic/Latino respondents.[18] These factors may have also contributed to current findings.

Similar to data from the US Census HPS, the Delphi US CTIS likely overestimates the frequency of COVID-19 vaccination.[3] The current estimate that 73.6% of working adults had received at least one vaccination based on April–May 2021 Delphi US CTIS data is similar to the HPS estimate of 72.2% for late April/early May 2021 but greater than the estimate of 60.3% for adults 18 years or older based on the CDC NIS-ACM conducted late April through late May in 2021.[5] Vaccination trends by gender and age were the same for NIS-ACM and Delphi US CTIS, being more common for females and increases with age. Selection bias may have contributed to higher results for percentage vaccination. We used weights when estimating the percentage vaccinated to resemble the general US population. However, Facebook users who voluntarily completed the Delphi US CTIS may have represented a

TABLE 5 Distribution of respondents in the major occupational groups with the lowest and highest percentages vaccinated, by sociodemographic characteristics and selected pre-existing medical conditions

Demographic characteristics and pre-existing medical conditions		Distribution in major occupational groups				Statistical test
		Construction and Extraction		Education, Training, and Library		
Characteristics	Categories	N*	Weighted %[a]	N*	Weighted %[a]	p[b]
Total	NA	14,006	100%	83,122	100%	NA
Gender	Female	1509	6.5	64,432	68.2	<0.0001
	Male	11,724	86.9	17,012	29.1	
	Other	747	6.5	1584	2.6	
	Missing	26	0.2	94	0.1	
Age, years	18–44	6322	57.2	36,474	53.2	<0.0001
	45–64	6546	37.4	37,781	38.6	
	65 and older	1119	5.3	8798	8.1	
	Missing	19	0.2	69	0.1	
Race/ethnicity	Hispanic	2305	20.7	6948	10.6	<0.0001
	Non-Hispanic White only	9733	65.1	66,389	75.7	
	Non-Hispanic Black only	408	2.9	3933	5.0	
	Non-Hispanic Asian only	143	1.0	1686	3.1	
	Non-Hispanic other/multiple races	1221	9.1	3510	4.7	
	Missing	196	1.3	656	0.8	
Education[c]	Less than high school	584	5.3	139	0.3	<0.0001
	High school graduate or equivalent	3373	26.5	2192	3.3	
	Some college	4181	29.6	6754	9.7	
	Two-year degree	1710	11.5	4396	5.5	
	Four-year degree	2821	17.9	23,135	30.0	
	Graduate or professional degree	1279	8.7	46,447	51.3	
	Missing	58	0.5	59	0.1	
Selected pre-existing conditions[d]	No	7834	59.4	41,121	52.3	<0.0001
	Yes	4830	29.4	34,936	37.5	
	Missing	1342	11.2	7065	10.2	

Abbreviation: NA, not applicable.

[a]Percentages for the distribution of participants are weighted to resemble eligible Facebook users and the general US adult population.

[b]p Values were based on the Satterthwaite approximation to the F distribution.

[c]Highest degree or level of school completed.

[d]A "Yes" indicates respondent reported at least one of the following four conditions that had a vaccination percentage greater than the 73.6% for all 828,401 working respondents: cancer, high blood pressure, Type 2 diabetes, and obesity.

subset of the US adult working population more likely to be vaccinated. In fact, Delphi US CTIS participants were more likely to have greater than a high school education and to be female than the general US population based on results from the US Census Bureau's ACS.[6] Also, all results are based on self-reported data, and vaccine status was not confirmed by an objective source like medical or vaccination records. Instances of inaccurate vaccine status would add to random error and potentially to information bias. At least for the frequency of COVID-19, Delphi US CTIS estimates of state-specific rates were highly correlated with estimates from the US Census Bureau and CDC.[6]

A limitation of the current study is that data may have been collected two times from the same person during the 2 months of the study. The Delphi US CTIS has a repeated cross-sectional design, and Facebook may send another invitation to the same eligible person 30 days or longer after the last invitation. Unpublished data checks conducted by Facebook indicated that approximately 10% of survey respondents in May 2021 had also responded in April 2021. If the same occurred with our subset of working adults who participated during these 2 months, we underestimated the variance for percentages vaccinated and the reported CIs should be a little wider. Another limitation is that some respondents may have mistakenly assigned themselves to the wrong occupation, contributing at least to random error and potentially to information bias as well. Also, many occupations occur in multiple industries, and vaccination levels for the same occupation might vary between different employing industries. Because the Delphi US CTIS inquires only about occupation, it was impossible to investigate vaccination by different industries or industry/occupation combinations.

As presented in Table 1, the sociodemographic characteristics associated with vaccine acceptance were more common for the major occupational group Education, Training, and Library with the highest vaccination percentage than for the group Construction and Extraction with the lowest percentage (Table 5). Also, from an analysis of data from the 2017–2018 Behavioral Risk Factor Surveillance System survey, about a third (32.5%) of Construction and Extraction workers have no health insurance compared to only 3.6% of those in Education, Training, and Library.[19] These contrasts illustrate how occupations can have different sociodemographic and healthcare access profiles that might influence health-related behavior such as vaccine access and acceptance. A limitation of the current investigation was the absence of information on workplace culture and the potential for co-workers and managers to influence an individual either in favor of or against being vaccinated.

The current results are from an era of the pandemic (April–May 2021) when vaccine availability had expanded, just before the Delta variant of the virus became dominant in the United States and many months before the Omicron variant was detected. In the months following May 2021, publicity about the infectivity of the Delta variant and additional efforts by public health and medical personnel may have motivated many working adults to become vaccinated and follow recommendations for other prevention efforts such as masking and physical distancing at work. Additional analyses of Delphi US CTIS data from June 2021 onward could help describe subsequent trends in vaccine uptake, especially for occupations with low vaccination percentages by May 2021.

CONFLICTS OF INTEREST
The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD
John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS
Paul Henneberger, Jean Cox-Ganser, and Caroline Groth made substantial contributions to the concept and design of the study. Caroline Groth and Garret Guthrie conducted data management. Caroline Groth planned and directed the statistical analyses, and Garret Guthrie implemented most statistical analyses. Paul Henneberger, Jean Cox-Ganser, and Caroline Groth contributed to interpreting the results. Paul Henneberger drafted the manuscript, and all authors provided a critical review of the manuscript and approved the final version submitted for publication.

ETHICS APPROVAL AND INFORMED CONSENT
The study to conduct the survey was approved by the Carnegie Mellon University Institutional Review Board (IRB ID: STUDY2020_00000162). All participants gave informed consent before taking part in the survey. The current research project was approved by the West Virginia University Institutional Review Board (IRB ID: 2008080589).

DISCLAIMERS
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

REFERENCES

1. Carlsten C, Gulati M, Hines S, et al. COVID-19 as an occupational disease. *Am J Ind Med.* 2021;64(4):227-237. doi:10.1002/ajim.23222

2. NIOSH. NIOSH Disaster Science Responder Research Program COVID-19 research agenda; 2021. DHHS (NIOSH) Publication, No. 2021-113. Accessed October 8, 2021.

3. Santibanez T, Singleton J, Black C, et al. Sociodemographic Factors Associated with Receipt of COVID-19 Vaccination and Intent to Definitely Get Vaccinated, Adults aged ≥18 Years—Household Pulse Survey, United States, April 28–May 10, 2021. National Center for Immunization and Respiratory Diseases, CDC. https://www.cdc.gov/vaccines/imz-managers/coverage/adultvaxview/pubs-resources/sociodemographic-factors-covid19-vaccination.html

4. Dooling K, Marin M, Wallace M, et al. The advisory committee on immunization practices' updated interim recommendation for allocation of COVID-19 vaccine – United States, December 2020. *Morb Mortal Wkly Rep*. 2021;69(5152):1657-1660.

5. CDC. COVIDVaxView. Centers for Disease Control and Prevention (CDC). Updated September 23, 2021. Accessed September 28, 2021. https://www.cdc.gov/vaccines/imz-managers/coverage/covidvaxview/interactive.html

6. Salomon JA, Reinhart A, Bilinski A, et al. The US COVID-19 Trends and Impact Survey: Continuous real-time measurement of COVID-19 symptoms, risks, protective behaviors, testing, and vaccination. *PNAS*. 2021;118(51):e2111454118. doi:10.1073/pnas.2111454118

7. King WC, Rubinstein M, Reinhart A, Mejia R. COVID-19 vaccine hesitancy January-May 2021 among 18-64 year old US adults by employment and occupation. *Prev Med Rep*. 2021;24:101569. doi:10.1016/j.pmedr.2021.101569

8. US_BLS. Standard Occupational Classification System. United States Bureau of Labor Statistics; 2018. Accessed October 4, 2021. https://www.bls.gov/soc/2018/major_groups.htm

9. US_DHS. Advisory Memorandum on Identification of Essential Critical Infrastructure Workers During COVID-19 Response, Version 3.1. U.S. Department of Homeland Security, Cybersecurity & Infrastructure Security Agency. Updated May 19, 2020. Accessed October 13, 2021, https://www.cisa.gov/sites/default/files/publications/Version_3.1_CISA_Guidance_on_Essential_Critical_Infrastructure_Workers_0.pdf

10. US_DHS. Advisory Memorandum on Ensuring Essential Critical Infrastructure Workers' Ability to Work During the COVID-19 Response, Version 4.1. U.S. Department of Homeland Security, Cybersecurity & Infrastructure Security Agency. Updated August 10, 2021. Accessed October 11, 2021. https://www.cisa.gov/sites/default/files/publications/essential_critical_infrastructure_workforce-guidance_v4.1_508.pdf

11. US_CB. American Community Survey: Educational Attainment, Undergraduate Field of Degree. United States Census Bureau. Accessed October 6, 2021. https://www.census.gov/acs/www/about/why-we-ask-each-question/education/

12. US_CB. Sample Copy of the 2020 Census Questionnaire. United States Census Bureau. Accessed October 5, 2021. https://www2.census.gov/programs-surveys/decennial/2020/technical-documentation/questionnaires-and-instructions/questionnaires/2020-informational-questionnaire-english_DI-Q1.pdf

13. Nguyen KH, Srivastav A, Razzaghi H, et al. COVID-19 vaccination intent, perceptions, and reasons for not vaccinating among groups prioritized for early vaccination – United States, September and December 2020. *Morb Mortal Wkly Rep*. 2021;70(6):217-222. doi:10.15585/mmwr.mm7006e3

14. Barkay N, Cobb C, Eilat R, et al. Weights and Methodology Brief for the COVID-19 Symptom Survey by University of Maryland and Carnegie Mellon University, in Partnership with Facebook, Version 3. Accessed May 17, 2021. https://cmu-delphi.github.io/delphi-epidata/symptom-survey/symptom-survey-weights.pdf

15. Rao JNK, Scott AJ. On chi-squared tests for multiway contingency tables with cell proportions estimated from survey data. *Ann Stat*. 1984;12(1):46-60.

16. Thomas DR, Rao JNK. Small-sample comparisons of level and power for simple goodness-of-fit statistics under cluster sampling. *J Am Stat Assoc*. 1987;82(398):630-636. doi:10.1080/01621459.1987.10478476

17. R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://www.Rproject.org/

18. Kuter BJ, Browne S, Momplaisir FM, et al. Perspectives on the receipt of a COVID-19 vaccine: a survey of employees in two large hospitals in Philadelphia. *Vaccine*. 2021;39(12):1693-1700. doi:10.1016/j.vaccine.2021.02.029

19. Boal WL, Li J, Silver SR. Health care access among essential critical infrastructure workers, 31 States, 2017-2018. *Public Health Rep*. 2021;137:301-309. doi:10.1177/0033354921996688

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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