Received: 4 May 2022 | Revised: 26 July 2022 | Accepted: 14 September 2022

DOI: 10.1002/ajim.23430

RESEARCH ARTICLE

AMERICAN JOURNAL OF INDUSTRIAL MEDICINE WILEY

COVID-19 in the workplace: Self-reported source of exposure and availability of personal protective equipment by industry and occupation in Michigan

Zoey Laskaris PhD, MPH[1] | Jana L. Hirschtick PhD, MPH[1] | Yanmei Xie PhD, MA[1] | Patricia McKane DVM, MPH[2] | Nancy L. Fleischer PhD, MPH[1]

[1]Department of Epidemiology, University of Michigan School of Public Health, Ann Arbor, Michigan, USA

[2]Michigan Department of Health and Human Services, Lifecourse Epidemiology and Genomics Division, Lansing, Michigan, USA

Correspondence
Zoey Laskaris, PhD, MPH, University of Michigan School of Public Health, 1415 Washington Heights, Ann Arbor, MI 48109, USA.
Email: laskaris@umich.edu

Funding information
Michigan Department of Health and Human Services; Michigan Public Health Institute; Rogel Cancer Center; Michigan Institute for Data Science, University of Michigan; University of Michigan School of Public Health Department of Epidemiology; Center for Disease Control and Prevention, U.S. Department of Health and Human Services, Grant/Award Number: 6NU50CK000510-02-04

Abstract

Objectives: Fragmented industry and occupation surveillance data throughout the COVID-19 pandemic has left public health practitioners and organizations with an insufficient understanding of high-risk worker groups and the role of work in SARS-CoV-2 transmission.

Methods: We drew sequential probability samples of noninstitutionalized adults (18+) in the Michigan Disease Surveillance System with COVID-19 onset before November 16, 2020 (N = 237,468). Among the 6000 selected, 1839 completed a survey between June 23, 2020, and April 23, 2021. We compared in-person work status, source of self-reported SARS-CoV-2 exposure, and availability of adequate personal protective equipment (PPE) by industry and occupation using weighted descriptive statistics and Rao-Scott χ^2 tests. We identified industries with a disproportionate share of COVID-19 infections by comparing our sample with the total share of employment by industry in Michigan using 2020 data from the US Bureau of Labor Statistics.

Results: Employed respondents (n = 1244) were predominantly female (53.1%), aged 44 and under (54.4%), and non-Hispanic White (64.0%). 30.4% of all employed respondents reported work as the source of their SARS-CoV-2 exposure and 78.8% were in-person workers. Work-related exposure was prevalent in Nursing and Residential Care Facilities (65.2%); Justice, Public Order, and Safety Activities (63.3%); and Food Manufacturing (57.5%). By occupation, work-related exposure was highest among Protective Services (57.9%), Healthcare Support (56.5%), and Healthcare Practitioners (51.9%). Food Manufacturing; Nursing and Residential Care; and Justice, Public Order, and Safety Activities were most likely to report having adequate PPE "never" or "rarely" (36.4%, 27.9%, and 26.7%, respectively).

Conclusions: Workplaces were a key source of self-reported SARS-CoV-2 exposure among employed Michigan residents during the first year of the pandemic. To prevent transmission, there is an urgent need in public health surveillance for the collection of

industry and occupation data of people infected with COVID-19, as well as for future airborne infectious diseases for which we have little understanding of risk factors.

KEYWORDS
COVID-19, occupational health, PPE, SARS-CoV-2 exposure, workplace

1 | INTRODUCTION

Many of the 80 million COVID-19 infections and 987,000 deaths recorded in the United States (as of April 22, 2022)[1] were caused by workplace SARS-CoV-2 exposure.[2–4] The actual number of work-related infections and deaths, and the extent to which work fueled the COVID-19 pandemic, may never be known. Fragmented industry and occupation surveillance data and incomplete record-keeping for employees infected with COVID-19 in all industries have impaired public health's ability to document work-related exposures, control hotspots, guide interventions and, ultimately, protect the lives of workers.[5,6]

Workplaces are known sources of SARS-CoV-2 transmission.[2,3,7,8] Settings with a high exposure risk are characterized as high-density, poorly ventilated spaces where people congregate for long periods of time or interact with patients and the public.[9] Even in high-risk workplaces, a combination of engineering (e.g., improved ventilation, physical barriers) and administrative (e.g., sanitation, training) controls, and personal protective equipment (PPE) are effective at reducing transmission.[10] Several COVID-19 outbreaks in food processing and manufacturing plants, prisons, and nursing homes demonstrated the devastating consequences of implementing inadequate COVID-19 safety protocols in high-risk work settings.[3,7,8,11]

Ongoing research has helped identify industries and occupations with an elevated risk of SARS-CoV-2 exposure and workers more susceptible to worse COVID-19-related outcomes (e.g., death). In an analysis of death records in California, Chen et al.[12] compared mortality rates among working-aged adults to pre-pandemic periods and found that relative excess mortality was highest in food/agriculture (39% increase), transportation/logistics (31% increase), and manufacturing (24% increase) occupational sectors. Similarly, Hawkins et al.[13] analyzed COVID-19 death records occurring between March 1 and July 31, 2020, in Massachusetts and found that 11 occupational groups, notably healthcare support, transportation and material moving, and food preparation and serving, had significantly higher mortality rates than workers overall. Because non-Hispanic (NH) Black and Hispanic populations are, in comparison to White populations, more likely to work in these high-risk occupations, research suggests that workplace exposure contributed to the disproportionate risk of COVID-19 infection and mortality experienced among people of color in the United States[6,14–18]

Enforcement by the US Occupational Safety and Health Administration (OSHA) is critical to ensure that adequate worker protections have been implemented and bad actors are penalized. Yet, more than 2 years after the start of the COVID-19 pandemic, workers continue to work under less-than-safe and stressful conditions, and without legal protections against COVID-19.[19–22] After two efforts by OSHA to establish COVID-19 Emergency Temporary Standards (ETS) for healthcare[23] and non-healthcare workers[24] were challenged and largely derailed in a US Supreme Court hearing,[25,26] experts suggested that a "risk-based" COVID-19 rule (rather than a blanket vaccine or testing standard for all private employers with more than 100 employees) is the way for OSHA to proceed.[27] Such a rule would employ protections curated for the level of risk a worker faces. Generating industry and occupation surveillance data for past and current COVID-19 infections can support and strengthen this effort.

The Michigan COVID-19 Recovery Surveillance Study (MI CReSS) presents a unique opportunity to inform our understanding of high-risk workers by industry and occupation. We collected industry and occupation surveillance data through interviews from a representative sample of Michiganders who tested positive for COVID-19 in the first year of the pandemic (before November 16, 2020). The main objectives of this descriptive analysis were to (1) identify industry subsectors that experienced a disproportionate share of Michigan residents infected with COVID-19 during the first year of the pandemic; (2) describe "in-person" worker status; (3) present self-reported source of exposure; and (4) describe the availability of adequate PPE by industry subsector and major occupation group.

2 | METHODS

2.1 | Sample

In collaboration with the Michigan Department of Health and Human Services (MDHHS), we drew sequential probability samples of people infected with COVID-19 before November 16, 2020, from the Michigan Disease Surveillance System (MDSS). The sampling frame included noninstitutionalized adults (18+) with a positive polymerase chain reaction (PCR) test. Adults who were not alive at the time of the study, or with missing telephone, zip code, or county information, were excluded from the sample. Samples were drawn based on the timing of illness from 13 geographic strata in the state of Michigan. Based on availability, the COVID-19 onset date was derived from the date of symptom onset, collection date of the positive COVID-19 test, or date of referral to the MDHHS. After drawing a base sample from each geographic stratum, the remaining sample was drawn proportionally for each stratum based on overall case counts.

Between June 16, 2020, and March 8, 2021, we drew five sequential samples based on the COVID-19 onset date and selected 6000 cases from the 237,468 eligible adults in the database with COVID-19 between January 1, 2020, and November 15, 2020. A

recruitment letter was sent to each of the potential respondents requesting their participation to complete an online or telephone questionnaire. Two to three reminder letters were sent and at least five phone calls were made to encourage surveillance study enrollment. Telephone interviews were conducted in English, Spanish, or Arabic by trained interviewers using a standardized script.

Among the 6000 selected, 1839 participants completed a telephone or online interview between June 23, 2020, and April 23, 2021, resulting in a response rate (American Association for Public Opinion Research Response Rate #6) of 31.8%.[28] Among the total respondents, 1248 were employed for wages or self-employed immediately before their COVID-19 illness. The total sample for this study ($N = 1244$) was restricted to employed respondents with a self-reported industry ($n = 1161$) and/or occupation ($n = 1212$). This secondary analysis of MI CReSS data was deemed exempt by the University of Michigan Institutional Review Board.

2.2 | Measures

2.2.1 | Industry and occupation

Respondents who indicated they were employed before their COVID-19 symptom onset reported their industry (or job setting for healthcare workers) and job title in an open-ended text box. The self-reported industry was classified into 2017 North American Industry Classification System (NAICS) industry subsectors.[29] Self-reported occupation was coded into the 2018 Standard Occupation Classification (SOC) major occupation groups.[30] Industry subsector and major occupation group were chosen over more detailed levels of classification to avoid small cell sizes. Industry and occupation coding was performed through the National Institute of Occupational Safety and Health (NIOSH) Industry and Occupation Computerized Coding System (NIOCCS).[31] NIOCCS generates a match probability for each of the automated industry and occupation designations. All industry and occupation designations with a match probability of less than 0.9 were manually checked, and approximately 5% of the reviewed designations were recoded.

2.2.2 | In-person worker status and statewide shutdown period

"In-person" workers included all respondents who indicated that their "physical presence was required at work" before the start of their COVID-19 illness. Respondents classified as "not in-person" comprised employees able to perform their jobs remotely and those who were temporarily laid off due to statewide restrictions on all nonessential businesses and activities. It is possible that some "not in-person" respondents worked in-person some or all of the time even though their physical presence was not "required" at work. The governor of Michigan issued the "Stay Home, Stay Safe" executive order on March 23, 2020, suspending all activities "not necessary to sustain or protect life."[32,33] In Michigan, critical infrastructure sectors and workers were identified using the US Cybersecurity and Infrastructure Security Agency (CISA) "Guidance on the Essential Critical Infrastructure Workforce" (Version 1, March 19, 2020).[34] The "shutdown" period lasted with few modifications until June 1, 2020. By June 1, 2020, most restrictions on nonessential businesses, including noncritical construction, transportation equipment manufacturing, retail, and restaurants, had been lifted.[35]

2.2.3 | Self-reported source of exposure

Respondents were asked if they knew the source of their coronavirus infection (yes/no) and, if so, how were they exposed. We classified the source of into three categories: "work-related," "unknown exposure source," and "not work-related" (e.g., household member, social gathering, travel, etc.).

2.2.4 | Availability of adequate PPE

Thinking about the time directly before their illness, respondents were asked "how often did you have adequate equipment to protect yourself from contracting COVID-19 at work?" Responses were recorded on a 5-point Likert scale ranging from "Never" to "Always." To avoid small cell sizes, the 5-point Likert scale was collapsed into three categories: "Never-Rarely," "Sometimes," and "Often-Always."

2.2.5 | Additional variables

Sociodemographic characteristics were collected for age (18–34, 35–44, 45–54, 55–64, 65+), sex at birth (male, female), race/ethnicity (NH White, NH Black, Hispanic, another NH race/ethnicity), education (high school or less, some college, college degree or more), and income (<$25,000, $25–49,999, $50–74,999, $75,000+).

2.3 | Statistical analysis

All analyses accounted for the complex sampling design using strata and individual sample weights calibrated to be representative of the population size within the geographic stratum, overall, and by sex and age. We generated weighted descriptive statistics and evaluated missing data for all key variables. Income was imputed for the 11.4% of respondents with missing income data using hot deck imputation under the missing at random assumption.[36] Industries and occupations with fewer than 30 respondents were collapsed into an "other" category to avoid small cell sizes.

The total share of employment by industry subsector in Michigan during 2020 was calculated using data reported by the Quarterly Census of Employment and Wages (QCEW) series from the US

TABLE 1 Descriptive statistics of employed respondents ($N = 1244$) (Michigan COVID-19 Recovery Surveillance Survey)

	Unweighted *N*	Weighted % (95% CI)
Sex		
Male	517	46.9 (43.8, 50.0)
Female	727	53.1 (50.0, 56.2)
Age		
18–34	357	32.7 (29.9, 35.7)
35–44	259	21.7 (19.3, 24.4)
45–54	297	23.0 (20.5, 25.6)
55–64	257	17.8 (15.6, 20.1)
65+	74	4.8 (3.7, 6.2)
Race-ethnicity		
Non-Hispanic White	818	64.0 (61.1, 66.8)
Non-Hispanic Black	150	11.2 (9.6, 13.1)
Hispanic	118	11.6 (9.7, 13.9)
Another NH race/ethnicity	132	11.0 (9.2, 13.0)
Missing	26	2.1 (1.4, 3.2)
Income		
$0–24,999	194	16.1 (14.0, 18.5)
$25k–49,999	282	22.8 (20.3, 25.5)
$50k–74,999	220	17.7 (15.5, 20.2)
$75,000+	548	43.3 (40.3, 46.3)
Education		
High school or less	284	24.1 (21.5, 26.8)
Some college	430	33.0 (30.3, 36.0)
College	522	42.4 (39.4, 45.4)
Missing	8	0.5 (0.2, 1.2)
In-person worker status		
In-person	972	78.8 (76.3, 81.2)
Not in-person	264	20.6 (18.3, 23.1)
Missing	8	0.6 (0.3, 1.2)
Self-reported source of exposure		
Work	390	30.4 (27.7, 33.3)
Other	390	32.6 (29.8, 35.6)
Unknown	434	34.2 (31.4, 37.1)
Missing	30	2.8 (1.9, 4.0)
Adequate PPE availability[a]		
Never-rarely	176	18.4 (15.8, 21.2)
Sometimes	120	12 (9.9, 14.4)
Often-always	669	68.9 (65.6, 72.0)
Missing	7	0.8 (0.4, 1.7)
Sample wave		
On or before April 15, 2020	462	35.7 (32.9, 38.6)
4/16/20–5/31/20	176	14.5 (12.4, 16.8)
6/1/20–7/31/20	218	17.6 (15.4, 20.1)
8/1/20–9/30/20	175	13.7 (11.8, 16.0)
10/1/20–11/15/20	213	18.5 (16.2, 21.0)
Survey mode		
Telephone	568	46.0 (43.0, 49.1)
Online	676	54.0 (50.9, 57.0)

Abbreviations: NH, non-Hispanic; PPE, personal protective equipment.
[a]PPE availability was only measured among in-person employees ($n = 972$).

Bureau of Labor Statistics (BLS).[37] We calculated the numerator (i.e., the number of active employees for each industry subsector) by taking the 12-month average of monthly employee counts (from private and federal, state, and local government establishments) for each industry subsector. The denominator (i.e., the total number of active employees in Michigan during 2020) was calculated by summing the average counts for all industry subsectors. Data from <1% of the total number of establishments in Michigan were not disclosed and, therefore, not included in this analysis. Pearson χ^2 tests were used to compare the weighted proportion of sample respondents in each industry subsector with the corresponding proportion for the state of Michigan. Design-adjusted, Rao-Scott χ^2 tests were used to compare differences in in-person work status, source of exposure, and PPE availability by industry subsector and major occupation group. For descriptive purposes only, we tabulated differences in in-person status, source of exposure, and PPE availability stratified by time (pre- and post-Michigan's statewide shutdown). Statistical significance was set with an alpha level of 0.05. Data were analyzed using Stata version 16 and figures were made using RStudio version 4.1.2.

3 | RESULTS

Weighted descriptive statistics of the analytic sample are presented in Table 1 ($N = 1244$). The sample included 53.1% female respondents and was predominantly aged 44 and under (54.4%), and NH White (64.0%). Approximately three-quarters of the sample (78.8%) were in-person workers. Work was the reported source of SARS-CoV-2 exposure in 30.4% of all cases. Among in-person workers ($n = 972$), 18.4% reported having adequate PPE "never or rarely."

The proportion of in-person workers varied significantly by industry subsector ($p < 0.001$) and occupation group ($p < 0.001$) (Figure 1A,B). The share of in-person respondents was highest in

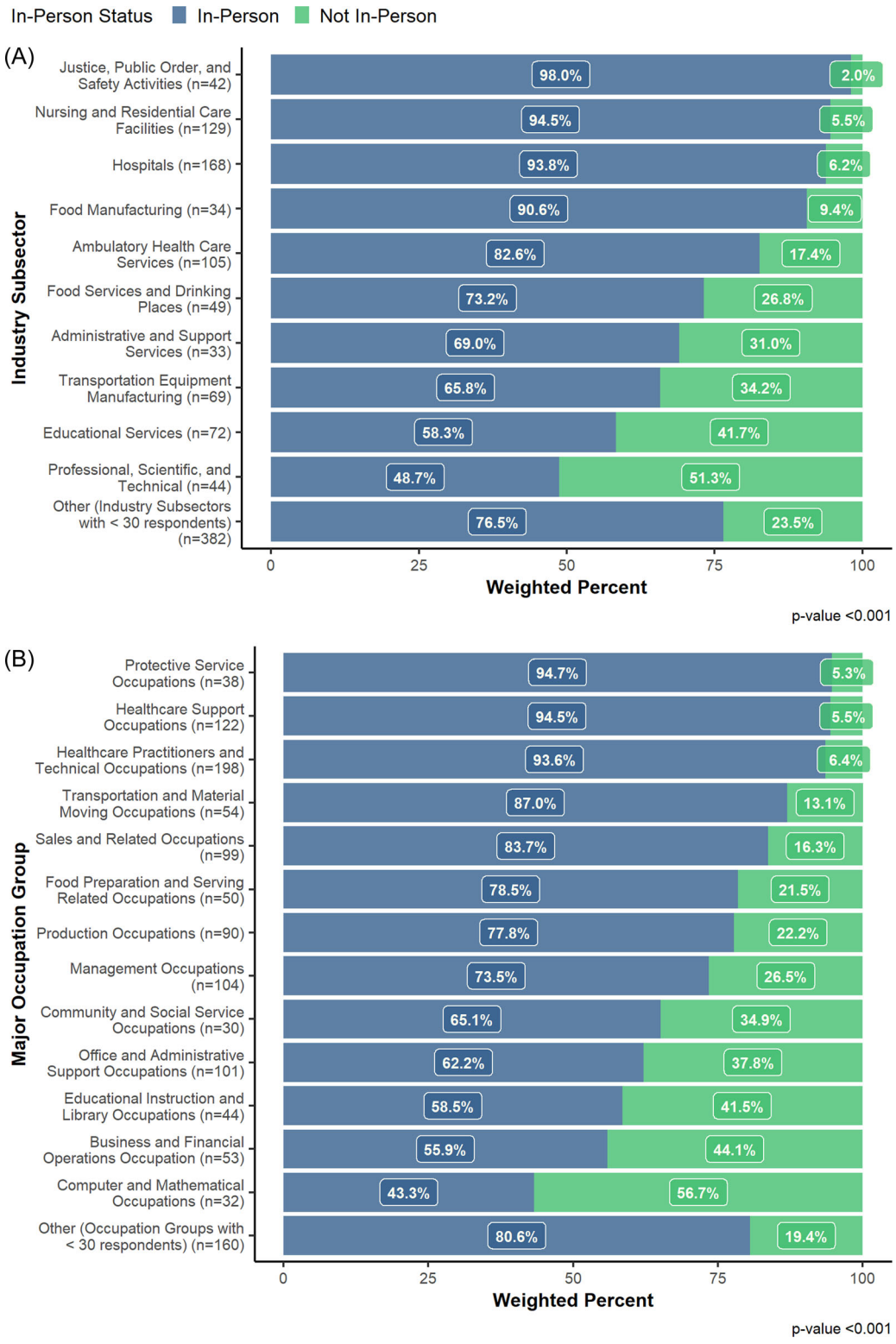

FIGURE 1 In-person work status by (A) industry subsector ($n = 1127$) and (B) major occupation group ($n = 1175$) (Michigan COVID-19 Recovery Surveillance Survey). *P*-values are derived from design-adjusted Rao-Scott χ^2, which tested whether the share of in-person employees was the same (null hypothesis) or different across any of the industry or occupation categories. [Color figure can be viewed at wileyonlinelibrary.com]

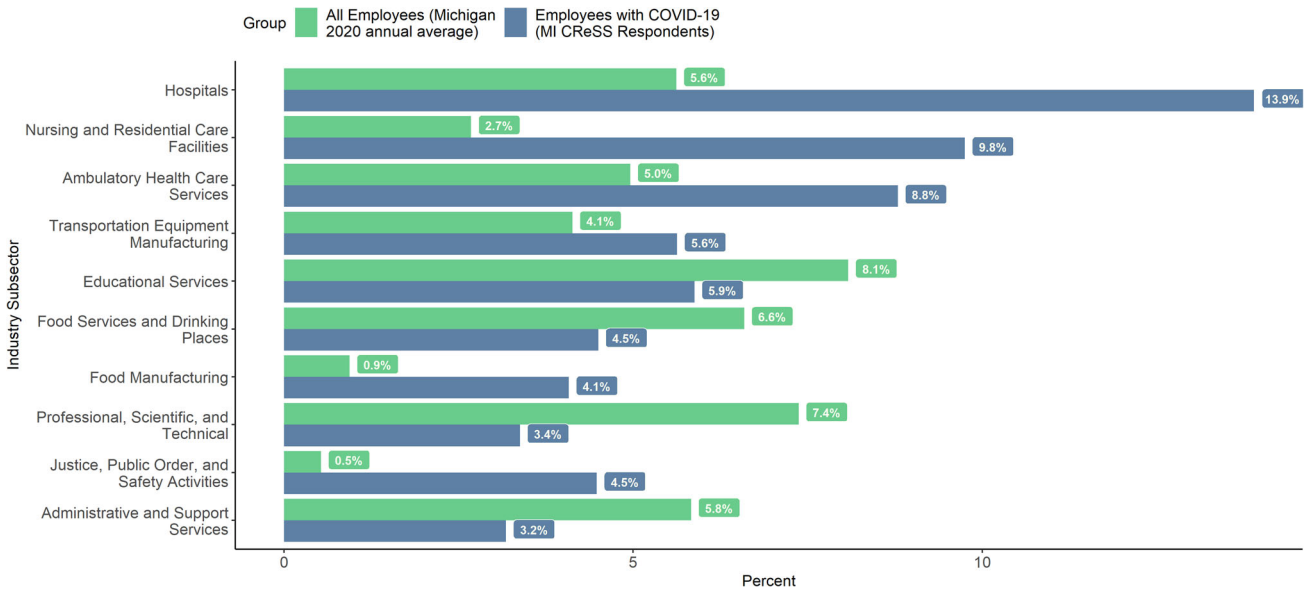

FIGURE 2 Proportion of employed Michigan COVID-19 Recovery Surveillance Survey (MI CReSS) respondents with COVID-19 by industry subsector ($n = 1161$) compared to the proportion of all active employees in Michigan during 2020 by industry subsector. Michigan COVID-19 Recovery Surveillance Survey. *P*-values for Pearson's χ^2 tests, which tested whether the proportion of sample respondents in each industry subsector (counts were enumerated using sampling weights) was the same as the corresponding proportion for the state of Michigan, were all <0.001. Percentages for the MI CReSS sample are weighted. The figure only shows industry subsectors with ≥30 MI CReSS respondents, therefore, the percentages do not add up to 100%. Data used to calculate the average share of employment by industry subsector in Michigan come from the US Bureau of Labor Statistics' Quarterly Census of Employment and Wages series for the year 2020. [Color figure can be viewed at wileyonlinelibrary.com]

critical infrastructure industry subsectors, including Justice, Public Order, and Safety Activities (98.0%); Nursing and Residential Care Facilities (94.5%); Hospitals (93.8%); and Food Manufacturing (90.6%). In-person work status was lowest among respondents in the Professional, Scientific, and Technical Services (48.7%) industry subsector and for the Computer and Mathematical Occupations occupation group (43.3%). As expected, the share of in-person workers increased in nonessential industry subsectors (i.e., Food Services and Drinking places) and those with a remote option (i.e., Educational Services) after the "Stay Home, Stay Safe" executive order was rescinded (June 1, 2020) (Supporting Information: Table I).

Several industry subsectors contained a disproportionate share of MI CReSS participants infected with COVID-19 before November 16, 2020, compared to their share of Michigan's total employed individuals in 2020 (Figure 2). In descending order of proportion of employed MI CReSS respondents, the difference in the proportion of MI CReSS respondents in an industry subsector compared to the proportion of total employed individuals in Michigan was 8.3 percentage points in Hospitals; 7.1 percentage points in Nursing and Residential Care Facilities; 4.0 percentage points in Justice, Public Order, and Safety; 3.8 percentage points in Ambulatory Healthcare; and 3.1 percentage points in Food Manufacturing and Transportation Equipment Manufacturing (*p*-values were <0.001 for all two-way comparisons) (Figure 3).

Source of self-reported SARS-CoV-2 exposure varied by industry subsector ($p < 0.001$) and major occupation group ($p < 0.001$) (Figure 3A,B). Work-related exposure was most prevalent among critical infrastructure industry subsectors, including Nursing and Residential Care Facilities (65.2%); Justice, Public Order, and Safety Activities (63.3%); Food Manufacturing (57.5%); and Hospitals (55.6%) (Figure 3A). After the "Stay Home, Stay Safe" executive order was rescinded (June 1, 2020), the share of work-related exposure decreased among workers in Hospitals (during shutdown: 65.6% [95% CI: 56.4%–73.9%], postshutdown: 27.4% [15.6%–43.6%]) and in Nursing and Residential Care Facilities (during shutdown: 72.3% [61.2%–81.2%], postshutdown: 48.2% [31.1%-65.8%]) (Supporting Information: Table II).

Over 50% of respondents with Protective Services (57.9%), Healthcare Support (56.5%), and Healthcare Practitioners and Technical (51.9%) occupations cited work as the source of their exposure (Figure 3B). An unknown source of exposure was most common among respondents in Educational Instruction (51.4%), while nonwork-related exposure was most common among Computer and Mathematical occupations (57.5%) (Figure 3B).

Among in-person employees, availability of adequate PPE varied by industry subsector ($p = 0.051$) and occupation groups ($p = 0.047$) (Figure 4A,B). The same three industry subsectors with the highest work-related exposure—Food Manufacturing; Nursing and Residential Care; and Justice, Public Order, and Safety Activities—were most likely to report having adequate PPE "never" or "rarely" (36.4%,

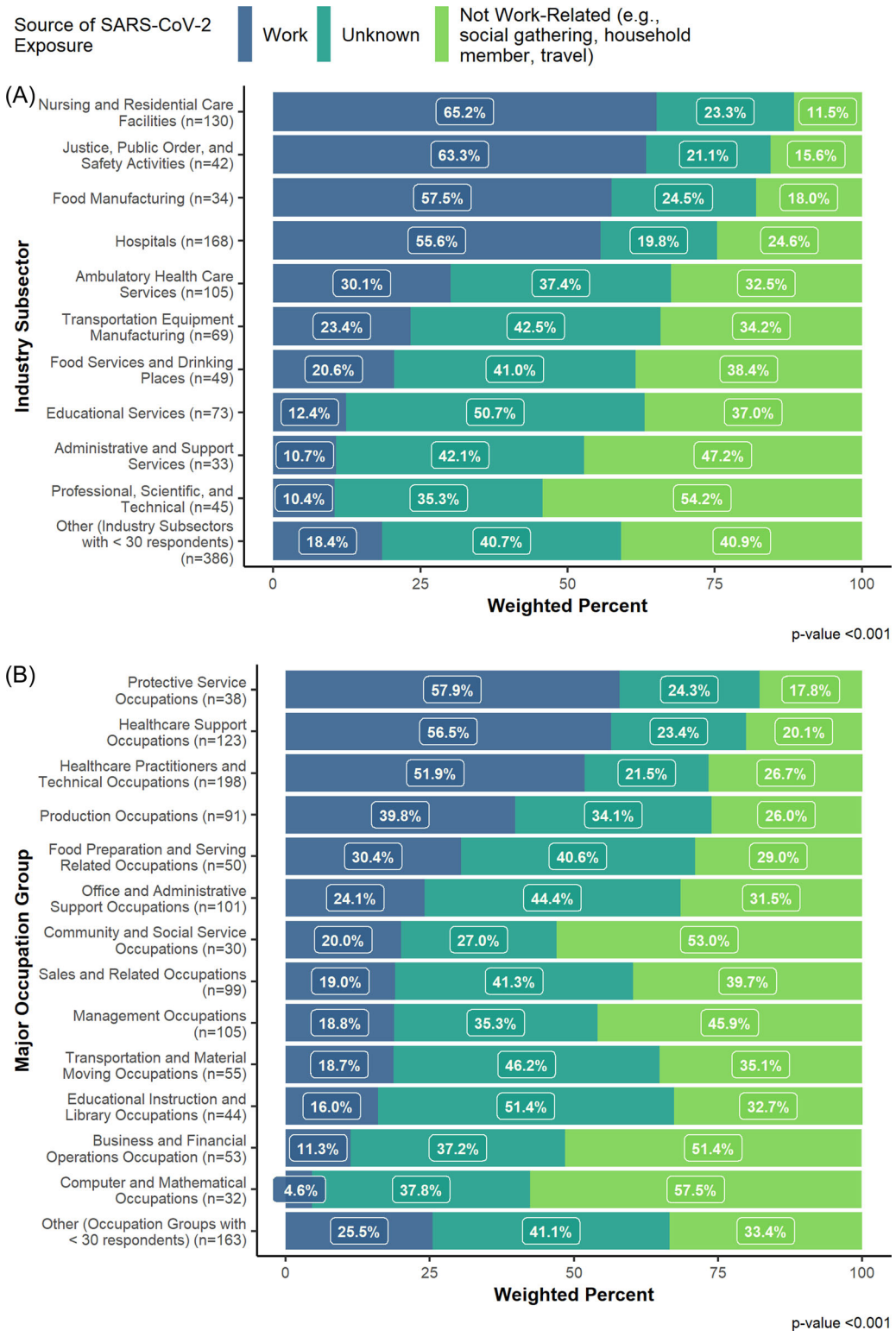

FIGURE 3 Self-reported source of SARS-CoV-2 exposure by (A) industry subsector ($n = 1134$) and (B) major occupation group ($n = 1182$) (Michigan COVID-19 Recovery Surveillance Survey). *P*-values are derived from design-adjusted Rao-Scott χ^2, which tested whether the distribution of self-reported exposure is the same (null hypothesis) or different across any of the industry or occupation categories. [Color figure can be viewed at wileyonlinelibrary.com]

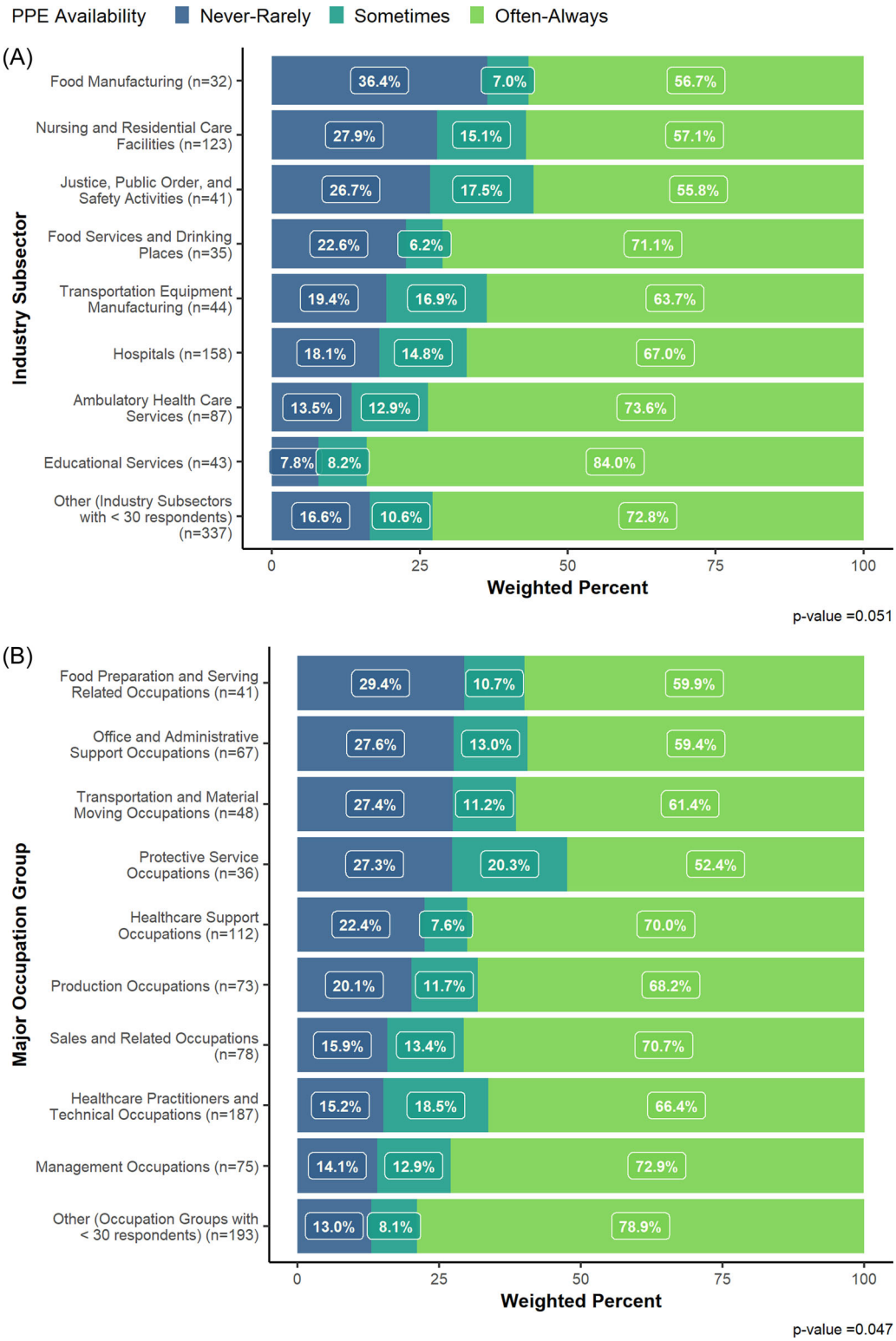

FIGURE 4 Availability of adequate personal protective equipment (PPE) by (A) industry subsector ($n = 900$) and (B) major occupation group ($n = 938$) among in-person respondents (Michigan COVID-19 Recovery Surveillance Survey). *p*-values are derived from design-adjusted Rao-Scott χ^2, which tested whether the distribution of self-reported exposure is the same (null hypothesis) or different across any of the industry or occupation categories. [Color figure can be viewed at wileyonlinelibrary.com]

27.9%, and 26.7%, respectively) (Figure 4A). Among in-person healthcare workers, 22.4% of Health are Support and 15.2% of Healthcare Practitioners and Technical occupations reported having adequate PPE "never" or "rarely" during the first year of the pandemic (Figure 4B). We observed improvements in reported PPE availability among all industry subsectors over time, however, 11.3% of Food Manufacturing and 9.9% of Nursing and Residential Care Facilities still reported having adequate PPE "never" or "rarely" after June 1, 2020, when national supplies were improving (Supporting Information: Table III).

4 | DISCUSSION

Using industry and occupation surveillance data collected from surveys among a representative sample of Michigan residents infected with COVID-19 before November 16, 2020, we identified industry subsectors that experienced a disproportionate share of COVID-19 infections and described patterns of work-related exposure and PPE availability by industry subsector and occupation group. The results established work as a key source of self-reported SARS-CoV-2 exposure in 30.4% of all cases among employed Michigan residents with COVID-19. Self-reported work-related exposure was highest among respondents in Nursing and Residential Care Facilities (65.2%); Justice, Public Order, and Safety Activities (63.3%); and Food Manufacturing (57.5%). Occupations with a high prevalence of work-related exposure included Protective Services (57.9%); Healthcare Support (56.5%); Healthcare Practitioners (51.9%); and Production workers (39.8%). Respondents in the three industry subsectors with the highest levels of work-related SARS-COV-2 exposure were also most likely to report limited availability of adequate PPE. These findings provide needed data on work-related SARS-CoV-2 exposure and offer insight into criteria that can be used to identify high-risk industries and worker groups. Moreover, this study demonstrated the usefulness of industry and occupation surveillance data to help target the allocation of needed supplies and detect strengths and weaknesses in existing prevention methods.

According to data provided by MDHHS, Michigan sustained numerous COVID-19 outbreaks, defined as "two or more cases with a link by place and time" in long-term care facilities, prisons, and food processing plants during the first year of the pandemic.[38–40] In concordance with these outbreak events, Nursing and Residential Care Facilities; Justice, Public Order, and Safety Activities; and Food Manufacturing industry subsectors were most likely to report work-related exposure and the least likely to report having adequate PPE "often" or "always" in comparison to the other subsectors. Despite numerous COVID-19 clusters in K-12 schools throughout Michigan,[40] the share of COVID-19 cases in Educational Services within the study sample was 2.2 percentage points less than their share of Michigan's total employed individuals. This may be attributed to the fact that the study period covered summer months during which many employees in Educational Services have off and were less likely to have been exposed at school. At the same time, teachers, like employees with a high level of public interface, may also have a harder time isolating their exposure source; 51.4% of respondents in Educational Instruction and Library occupations reported not knowing their source of exposure and only 16% described it as being work-related.

A key contribution of this study is a population-based estimate of self-reported work-related COVID-19 infections in the United States. Our finding that 30.4% of COVID-19 infections among employed Michigan residents before November 16, 2020, were work-related is in support of the few available, albeit international, estimates published since the start of the pandemic. Based on the review of COVID-19 workers' compensation claims in Italy submitted before May 15, 2020, covering approximately 85% of the national workforce, Marinaccio et al.[41] estimated that 30.0% of working-age people infected with COVID-19 had work-related exposures. Similarly, in the Netherlands, reports of occupational COVID-19 (between March and September 2020) accounted for 33.0% of all reported occupational diseases.[42] And in Canada, using a combination of partial public health surveillance data on industry and occupation and workers' compensation claims from workers who tested positive for COVID-19 (accepted claims only), an estimated 20% of all cases among working-aged adults between March and August 2020 were considered work-related.[43] While workers' compensation claims may be subject to some bias related to the financial needs of a worker or the claim adjudication process, they provide powerful insight into the long-term impacts of the COVID-19 pandemic on occupational health.

Our results mostly support existing methods of classifying occupational risk of SARS-CoV-2 exposure based on work characteristics.[9,14] For example, respondents in jobs with direct patient contact (e.g., Healthcare Support and Healthcare Practitioners) and jobs with close proximity to others (e.g., Production workers) were more likely to report work-related exposure than respondents in sectors less likely to have these features (e.g., Business and Financial Operations and Computer and Mathematical occupations). However, we found that respondents in occupations with a high likelihood of public interface were more likely to report not knowing their source in comparison to work-related or not work-related sources: 40.6% of Food Preparation and Serving and 41.3% of Sales and Related occupations reported not knowing the source of their SARS-CoV-2 exposure. It may be hard for a worker with frequent contact with the public and co-workers to feel confident in knowing their source of exposure. This finding may have implications for how occupational COVID-19 and related workers' compensation laws are defined.

In addition to work characteristics, job status may contribute to a worker's SARS-CoV-2 exposure risk. Existing evidence suggests that job status, defined as "the proportion of workers within each occupation with at least some college education," is a contributing factor to an employee's level of access to workplace COVID-19 risk mitigation measures, such as PPE.[16] Although we observed differences in the availability of PPE between Healthcare Support occupations, a low-status job in the healthcare industry, and Healthcare Practitioners, a high-status job, the confidence intervals were wide and the difference did not reach statistical significance. It may be, however, that there are

larger differences in COVID-19 prevention methods that are higher up on the hierarchy of controls, such as improved ventilation and social distancing, when comparing workers across job status. In the future, larger studies are needed to better understand the intersection between workplace COVID-19 prevention methods and job status on work-related SARS-CoV-2 exposure. This is especially important given our knowledge that workers in low-status jobs may be more susceptible to worse COVID-19-related outcomes due to higher rates of comorbidities and less access to medical insurance.[6,44,45]

This study has limitations. The MI CReSS study only collects data among PCR-confirmed COVID-19 positive individuals, limiting our ability to calculate the risk of COVID-19 infection among all employed individuals by industry and occupation. However, using data from the BLS to calculate the total number of employees by industry subsector during the same timeframe as the study, we were able to describe industries that experienced a disproportionate number of Michigan residents infected with COVID-19. Additionally, the use of a self-reported source of exposure is subject to bias. Respondents in high-risk settings, such as healthcare workers, may be more likely to report work as the source of their exposure even if they are unsure. Respondents were not given guidance on the type of PPE necessary to "adequately" protect them from SARS-CoV-2 exposure at work given differences in appropriate levels of PPE for specific occupations and at different times throughout the pandemic. Therefore, interpretations of what constitutes adequate PPE may have differed among respondents within the same occupation depending on their level of PPE awareness and the period of the pandemic during which they were infected. Given the sample size of employed MI CReSS respondents, we were unable to make comparisons across more specific industry and occupation classifications, such as industry groups and minor occupation groups. Lastly, the data source for the sampling frame, MDSS, only includes individuals who tested positive for COVID-19 and likely does not reflect all individuals who contracted COVID-19 during the relevant period, given the limited access to COVID-19 testing for qualifying individuals at the start of the pandemic. Testing limitations were more severe among NH Black and Hispanic low-income populations,[46] which may have resulted in an under-representation of occupations more commonly held by individuals of lower socioeconomic status in our sample. Moreover, we were unable to account for race/ethnicity when constructing the sample weights because of its high level of missingness in the testing data reported to the MDHHS. Nevertheless, due to our population-based sampling and weighting by age and sex within geographic strata, our sample is representative of noninstitutionalized adults with a positive PCR test for COVID-19 in Michigan who survived, unlike clinical or convenience samples.

5 | CONCLUSION

Fragmented industry and occupation surveillance throughout the COVID-19 pandemic, and incomplete record-keeping of workplace infections and deaths, have left the public health community with an insufficient understanding of high-risk worker groups and the role of work in SARS-CoV-2 transmission. Using industry and occupation surveillance data from surveys from a representative sample of Michigan residents with PCR-confirmed COVID-19 before November 16, 2020, we found a substantial share of infections to be work-related (according to self-report) and identified high-risk jobs and job settings. The results of this study support the need for workers' compensation laws for COVID-19 in Michigan and across the United States and the implementation of a risk-based COVID-19 standard to protect workers in all industries. The results demonstrated how state-level systems for industry and occupation surveillance can help: detect patterns of workplace exposure, identify strengths and weaknesses in workplace mitigation measures, target health and safety inspections and the distribution of PPE, and examine the impacts of policy changes (e.g., reopening of nonessential services) on viral transmission. Multidisciplinary collaborations between public health departments, epidemiologists, and occupational health and safety officials, for example, can maximize the usefulness of these data. We recommend the inclusion of open-entry industry and occupation fields in all public health surveillance of people infected with COVID-19 or future airborne infectious diseases, for which we have little understanding of risk factors and preventing transmission is critical.

ACKNOWLEDGMENTS

We would like to acknowledge the respondents who took time to share with us their personal and often difficult experiences with COVID-19 for the purpose of this study, and the team of interviewers who documented their stories. The Michigan COVID-19 Recovery Surveillance Study has received funding from the Michigan Department of Health and Human Services, the Michigan Public Health Institute, the University of Michigan Institute for Data Science, the University of Michigan Rogel Cancer Center, and the University of Michigan Epidemiology Department. This manuscript is supported by the Centers for Disease Control and Prevention, US Department of Health and Human Services (HHS) through grant number 6NU50CK000510-02-04. The contents are those of the authors and do not necessarily represent the official views of, nor an endorsement by, CDC/HHS, or the US Government.

CONFLICTS OF INTEREST

The authors declare that there are 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

Zoey Laskaris, Nancy L. Fleischer, and Jana L. Hirschtick conceptualized and designed the study. Zoey Laskaris wrote the original manuscript, prepared the data, and performed the analysis. Yanmei Xie, Nancy L. Fleischer, Jana L. Hirschtick, and Patricia McKane provided feedback on the methods and writing, and approved of the final version. All authors agree to be accountable for all aspects of the work.

ETHICS APPROVAL AND INFORMED CONSENT

This secondary analysis of MI CReSS data was deemed exempt by the University of Michigan Institutional Review Board.

ORCID

Zoey Laskaris http://orcid.org/0000-0002-2836-2017
Patricia McKane http://orcid.org/0000-0003-2382-8663
Nancy L. Fleischer http://orcid.org/0000-0002-4371-9133

REFERENCES

1. U.S. Center for Disease Control and Prevention. *COVID Data Tracker*. 2022. Accessed April 22, 2022. https://covid.cdc.gov/covid-data-tracker/#datatracker-home
2. Baker MG, Peckham TK, Seixas NS. Estimating the burden of United States workers exposed to infection or disease: a key factor in containing risk of COVID-19 infection. *PLoS One*. 2020;15(4):e0232452.
3. Dyal JW, Grant MP, Broadwater K, et al. COVID-19 among workers in meat and poultry processing facilities—19 states, April 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(18):557-561.
4. The Lancet. The plight of essential workers during the COVID-19 pandemic. *Lancet (London, England)*. 2020;395(10237):1587.
5. Strategic Organizing Center. *Hidden Pandemic: Amazon's Secrecy and Obstruction During the COVID-19 Crisis*. Accessed March 20, 2022. https://thesoc.org/wp-content/uploads/2021/11/Hidden-Pandemic-Amazons-Secrecy-And-Obstruction-During-The-COVID-19-Crisis.pdf2021
6. Carlsten C, Gulati M, Hines S, et al. COVID-19 as an occupational disease. *Am J Ind Med*. 2021;64(4):227-237.
7. Porter KA, Ramaswamy M, Koloski T, Castrodale L, McLaughlin J. COVID-19 among workers in the seafood processing industry: implications for prevention measures—Alaska, March–October 2020. *MMWR Morb Mortal Wkly Rep*. 2021;70(17):622-626.
8. Hagan LM, McCormick DW, Lee C, et al. Outbreak of SARS-CoV-2 B.1.617.2 (Delta) variant infections among incarcerated persons in a federal prison—Texas, July–August 2021. *MMWR Morb Mortal Wkly Rep*. 2021;70(38):1349-1354.
9. U.S. Department of Labor Occupational Safety and Health Administration. *Guidance on Preparing Workplaces for COVID-19*. 2021. Accessed February 2, 2022. https://www.osha.gov/coronavirus
10. Herstein JJ, Degarege A, Stover D, et al. Characteristics of SARS-CoV-2 transmission among meat processing workers in Nebraska, USA, and effectiveness of risk mitigation measures. *Emerg Infect Dis*. 2021;27(4):1032-1038.
11. Ouslander JG, Grabowski DC. COVID-19 in nursing homes: calming the perfect storm. *J Am Geriatr Soc*. 2020;68(10):2153-2162.
12. Chen YH, Glymour M, Riley A, et al. Excess mortality associated with the COVID-19 pandemic among Californians 18–65 years of age, by occupational sector and occupation: March through November 2020. *PLoS One*. 2021;16(6):e0252454.
13. Hawkins D, Davis L, Kriebel D. COVID-19 deaths by occupation, Massachusetts, March 1–July 31, 2020. *American Journal of Industrial Medicine*. 2021;64(4):238-244.
14. Hawkins D. Differential occupational risk for COVID-19 and other infection exposure according to race and ethnicity. *Am J Ind Med*. 2020;63(9):817-820.
15. Hawkins D. Social determinants of COVID-19 in Massachusetts: an ecological study. *J Prev Med Public Health*. 2020;53(4):220-227.
16. Goldman N, Pebley AR, Lee K, Andrasfay T, Pratt B. Racial and ethnic differentials in COVID-19-related job exposures by occupational standing in the US. *PLoS One*. 2021;16(9):e0256085.
17. Silver SR, Li J, Boal WL, Shockey TL, Groenewold MR. Prevalence of underlying medical conditions among selected essential critical infrastructure workers—behavioral risk factor surveillance system, 31 states, 2017–2018. *MMWR Morb Mortal Wkly Rep*. 2020;69(36):1244-1249.
18. Mackey K, Ayers C, Kondo K, et al. Racial and ethnic disparities in COVID-19-related infections, hospitalizations, and deaths: a systematic review. *Ann Intern Med*, 174(3):362-373. doi:10.7326/M20-6306
19. U.S. Department of Labor Occupational Safety and Health Administration. *Statement on the Status of the OSHA COVID-19 Vaccination and Testing ETS*. 2022. Accessed February 28, 2022. https://www.osha.gov/coronavirus/ets2
20. Holpuch A. CVS and Walgreens temporarily shut some stores as Omicron cases soar. *N Y Times*. January 15, 2022.
21. Smith M. Doctors and nurses are 'Living in a Constant Crisis' as COVID fills hospitals and Omicron looms. *New York Times*. December 17, 2021.
22. Chokshi N. Airlines Say Storms and Omicron Caused Flight Cancellations. *New York Times* (Online).2022.
23. US Department of Labor Occupational Health and Safety Administration. *COVID-19 Healthcare Emergency Temporary Standard. Vol 29 CFR 1910 Subpart U*. Office of the Federal Registrar. 2021. Accessed February 15, 2022. https://www.osha.gov/coronavirus/ets
24. US Department of Labor Occupational Health and Safety Administration. *COVID-19 Vaccination and Testing; Emergency Temporary Standard. Vol 29 CFR 1910 Subpart U*. Federal Register. 2021. https://www.osha.gov/coronavirus/ets2
25. Supreme Court of the United States. *National Federation of Independent Business v. Department of Labor, Occupational Safety and Health Administration, and Ohio v. Department of Labor, Occupational Safety and Health Administration. Vol Nos. 21A244 and 21A2472022*. 2022.
26. Liptak A. Supreme Court blocks Biden's virus mandate for large employers. *New York Times* (Online). 2022.
27. Michaels D, Barab J. OSHA can do more to protect Americans from Covid-19: guest essay. *New York Times* (Online). 2022.
28. American Association for Public Opinion Research. *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys*. 2016. Accessed February 1, 2022. https://www.aapor.org/AAPOR_Main/media/publications/Standard-Definitions20169theditionfinal.pdf
29. U.S. Office of Management and Budget. *North American Industry Classification System*. 2017. Accessed January 20, 2021. https://www.census.gov/naics/reference_files_tools/2017_NAICS_Manual.pdf
30. U.S. Office of Management and Budget. *Standard Occupational Classification Manual*. 2018. Accessed January 23, 2021. https://www.bls.gov/soc/2018/soc_2018_manual.pdf
31. National Institute for Occupational Safety and Health. *NIOSH Industry and Occupation Computerized Coding System (NIOCCS)*. 2021. Accessed February 1, 2022. https://csams.cdc.gov/nioccs/
32. The office of Governor Gretchen Whitmer. *Governor Whitmer Signs "Stay Home, Stay Safe" Executive Order*. 2020. Accessed February 1, 2022. https://www.michigan.gov/whitmer/0,9309,7-387-90499_90705-522626–,00.html
33. The office of Governor Gretchen Whitmer. *Governor Whitmer Extends "Stay Home, Stay Safe" Executive Order to Save Lives*. 2020. Accessed February 1, 2022. https://www.michigan.gov/whitmer/0,9309,7-387-90499_90640-525173–,00.html
34. US Department of Homeland Security—Cybersecurity and Infrastructure Security Agency. *Guidance on the Essential Critical Infrastructure Workforce: Ensuring Community and National Resilience in COVID-19 Response (Version 1.0)*. 2020. Accessed January 20, 2022. https://www.cisa.gov/sites/default/files/publications/CISA-Guidance-on-Essential-Critical-Infrastructure-Workers-1-20-508c.pdf

35. The office of Governor Gretchen Whitmer. *Governor Whitmer Rescinds Safer at Home Order, Moves Michigan to Phase Four of the MI Safe Start Plan*. 2020. Accessed February 1, 2022. https://www.michigan.gov/whitmer/0,9309,7-387-90499_90640-530627–,00.html
36. Cox BG. The weighted sequential hot deck imputation procedure. Paper presented at: proceedings of the American Statistical Association, Section on Survey Research Methods. Washington, DC: August 11, 1980.
37. U.S. Bureau of Labor Statistics. *Quarterly Census of Employment and Wages. NAICS-Based Data Files. Annual Averages by Industry*. 2020. Accessed January 4, 2022. https://www.bls.gov/cew/downloadable-data-files.htm
38. Jackson A. Michigan prison sees COVID-19 outbreak: 155 inmates, 2 staff test positive since July 27. *Detroit Free Press*. 2020.
39. Vedapudi V. COVID-19 outbreaks in prisons across state spark distrust in Michigan Department of Corrections. *Michigan Daily*. 2020.
40. Michigan Department of Health and Human Services. *Coronavirus: Outbreak Reporting*. 2022. Accessed May 29–November 19, 2020. https://www.michigan.gov/coronavirus/0,9753,7-406-98163_98173_102057—,00.html
41. Marinaccio A, Boccuni F, Rondinone BM, Brusco A, D'Amario S, Iavicoli S. Occupational factors in the COVID-19 pandemic in Italy: compensation claims applications support establishing an occupational surveillance system. *Occup Environ Med*. 2020;77(12):818-821.
42. van der Molen HF, Kezic S, Visser S, et al. Occupational COVID-19: what can be learned from notifications of occupational diseases? *Occup Environ Med*. 2020;78(6):464.
43. Mustard C. *What Research Can Do: Estimating the Role of Workplaces in COVID-19 Transmissions*. Issue 101: Institute for Work & Health; 2020.
44. Himmelstein DU, Woolhandler S. Health insurance status and risk factors for poor outcomes with COVID-19 among U.S. health care workers: a cross-sectional study. *Ann Intern Med*. 2020;173(5):410-412.
45. Waltenburg M, Rose C, Victoroff T, et al. Coronavirus disease among workers in food processing, food manufacturing, and agriculture workplaces. *Emerg Infect Dis*. 2021;27(1):243-249.
46. Lieberman-Cribbin W, Tuminello S, Flores RM, Taioli E. Disparities in COVID-19 testing and positivity in New York City. *Am J Prev Med*. 2020;59(3):326-332.

SUPPORTING INFORMATION

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

How to cite this article: Laskaris Z, Hirschtick JL, Xie Y, McKane P, Fleischer NL. COVID-19 in the workplace: self-reported source of exposure and availability of personal protective equipment by industry and occupation in Michigan. *Am J Ind Med*. 2022;1-12. doi:10.1002/ajim.23430