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Occupation and COVID-19: Lessons From the Pandemic

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Abstract

Recognition that an individual's job could affect the likelihood of contracting coronavirus disease 2019 created challenges for investigators who sought to understand and prevent the transmission of severe acute respiratory syndrome coronavirus 2. Considerable research resources were devoted to separating the effects of occupational from nonoccupational risk factors. This commentary highlights results from studies that adjusted for multiple nonoccupational risk factors while estimating the effects of occupations and occupational risk factors. Methods used in these studies will prove useful in future infectious disease epidemics and pandemics and may potentially enrich studies of other occupational infectious and noninfectious respiratory diseases.

Keywords

COVID-19; Occupation; Occupational respiratory disease

INTRODUCTION

It became clear early in the coronavirus disease 2019 (COVID-19) pandemic that certain jobs, especially those involving close contact with people, could put workers at an increased risk for exposure to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and subsequent infection.[1] Early attention focused on health care workers who had contact with sick patients, and other essential or frontline or high-risk (EFH) workers who were performing critical jobs and/or were more likely to have contact with coworkers or members of the public. Opportunities for exposure to the virus were not limited to workplaces, and researchers attempted to understand the role of occupation as a risk factor for COVID-19 separate from the effects of nonoccupational risk factors. One goal of this commentary/review was to examine the literature to identify types of occupations and occupational risk factors that were still associated with COVID-19 after controlling for a variety of nonoccupational risk factors. Another goal was to bring attention to selected methods that might be relevant for future studies of both infectious and noninfectious work-related respiratory diseases that are not exclusively due to conditions at work.

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METHODS FOR THE IDENTIFICATION AND REVIEW OF RELEVANT REFERENCES

We conducted a focused literature search of PubMed to identify articles that addressed the association of COVID-19 with occupation. We had already identified 12 articles related to this topic, and we used the Medical Subject Headings (MeSH terms) and titles of these publications to generate a simple search strategy that captured these articles as well as many others.[2–13] The search strategy was: (((COVID-19*[MeSH Terms]) OR (SARS-CoV-2[Title]) OR (COVID-19[Title])) AND ((Occupations[MeSH Terms]) OR (Occupation*[title]))). This yielded 1,017 references when applied in PubMed on October 26, 2023.

We reviewed titles of the 1,017 articles to judge whether the article was likely to yield information relevant to the topic of the frequency (prevalence or incidence) of COVID-19 relative to occupation or occupational risk factors and to exclude any non-English articles. This resulted in the exclusion of 821 references and the retention of 196. A review of abstracts for the 196 references resulted in the exclusion of another 116, leaving 80 for review based on full-text articles. Reviews of the 80 articles yielded 34 that were excluded and 46 that were retained. The most common reason for exclusion was the absence of multivariable modeling of the outcome to adjust for the effects of nonoccupational risk factors (n = 21; 62%), but also for only ecologic work-related data (n = 4), methods inadequately explained (n = 3), no work-related covariates in multivariable models (n = 3), and one each for inappropriate outcome (ie, long COVID), sample limited to spouses of workers rather than the workers themselves, and a duplicate reference. With further scrutiny of full-text articles, we excluded another 30 that were not inclusive regarding occupations. Among the 30 studies were 16 focused on health care alone, 11 that addressed only EFH workers, and three that addressed single occupational settings (ie, military, corrections) or a single company. We scrutinized the remaining 16 studies to eliminate any that did not have robust adjustment for potential nonoccupational confounders when the investigators analyzed the association of COVID-19 with work. We assigned these potential confounders to the three categories of demographic/personal health, socioeconomic, and community risk factors for COVID-19. Some studies used a model fitting strategy to determine which potential confounders to retain in a final model. In these instances, we gave studies credit for all variables they considered for inclusion, even if some variables were not included in the final model. We retained the 14 studies that had considered covariates in all three of the confounder categories and excluded the other two. Table I lists examples of covariates included in regression models for these studies. A detailed account of confounders for each study is available in Table E1 (in this article's Online Repository at www.jaci-inpractice.org). We used these 14 studies to address the question of occupational contribution to COVID-19 and as a source for examples of methodologic approaches.

The current literature search was intended to provide examples of relevant studies; it was not meant to be a comprehensive, systematic review such as those published by others.[17] Consequently, this article likely missed published articles about studies that highlighted various issues related to the association of COVID-19 with work. As planned, we addressed selected issues from the studies that we did review. For example, we did not address changes in the association of COVID-19 with occupations across waves of the pandemic, the effect of nonoccupational risk factors for COVID-19, or the interaction of occupational variables with confounders. These are issues that could inform the goals of other reviews.

RESULTS AND COMMENTARY

Characteristics of the final 14 references

Consistent with how the studies were selected, the final 14 were inclusive regarding the types of occupations: six with all types of workers, six with analyses of data for both EFH workers and all workers, and two with all non–health care workers. Half were conducted in the United Kingdom, two each in Denmark and the United States, and one each in Brazil, Sweden, and the Netherlands (Table II). The study period for 11 studies was either entirely in 2020 (n = 3) or partially in 2020 (with n = 7 in 2020–2021 and n = 1 in 2020–2023), and the other three were entirely in 2021. The criteria for a COVID-19 case varied and included mortality (n = 4 studies), hospital admission or setting (n = 3), and results from PCR (n = 6) and serologic (n = 2) tests. Sample sizes ranged from 451 to approximately 14 million, with over 100,000 participants in eight studies and fewer than 4,000 in only three studies.

All 14 studies with robust adjustment for nonoccupational risk factors reported statistically significant elevated effect estimates for occupational variables, including both occupational categories and risk scores based on occupations. These results suggest that certain work settings presented a meaningful risk for exposure to SARS-CoV-2. Many of the 12 studies that investigated the association of COVID-19 with occupations implicated the same types of occupational categories. The most common groups were health care, teaching or education, and social care (including carers and childcare). Positive results were less commonly reported for transportation, retail or wholesale trade, protective services or security, and personal services including cleaning and housekeeping.

Two of the 14 studies reported only associations of COVID-19 with risk scores assigned to occupations rather than with the occupations themselves. A study of all occupations conducted in the Netherlands used an international COVID-19 job exposure matrix (JEM) to yield scores based on transmission-related risk, mitigation efforts, and precarious work.[19,20] Adjusted odds ratios for a positive test for SARS-CoV-2 infection were elevated for many of the risk metrics for the complete study period and for three pandemic waves within the study period. The second study evaluating associations with occupational risk scores was conducted in the United Kingdom and addressed working adults in non–health care jobs.[13] Researchers linked job data to the Occupational Information Network (O*NET) JEM[26] to yield scores for job characteristics relevant to the risk for transmission of SARS-CoV-2 and used two variables for the likelihood of remote work. They reported elevated adjusted hazard ratios for increases in scores for exposure to diseases or infections and the inability to perform a job remotely. Risks for COVID-19 were not reduced for jobs that required outdoor work.

Three other studies reported the association of COVID-19 with occupational risk factors as well as occupations. One of these studies was conducted in Sweden and used two JEMs to assess multiple dimensions of the job-related risk for COVID-19.[22] The investigators reported elevated adjusted odds ratios for the dimensions of the nature of contact with others, contaminated workspaces, working mostly inside versus mostly outside, never maintaining social distancing, close physical proximity, and exposures to diseases or infections. Another study was conducted in the United States and investigated associations of COVID-19 with non–health care occupational and industry groups, and used a JEM to assess job-related risk for COVID-19.[29] The JEM was the Council of State and Territorial Epidemiologists SARS-CoV-2 Occupational Exposure Matrix,[25] which the researchers used to categorize occupations on public-facing work, the extent of working indoors or outdoors, physical proximity to others while working, and a combined exposure index. The authors concluded that SARS-CoV-2 infection was associated with close physical proximity and the combined exposure index, although the adjusted models did not yield statistically significant effect estimates. The third study was conducted in the United Kingdom, and the researchers concluded that self-reported work-related close contact had an intermediate role between occupation and COVID-19.[3] These findings are discussed further in the section on directed acyclic graphs (DAGs).

Six of the 14 studies applied two different approaches by investigating both EFH occupations and all (or nearly all) occupations. Investigating a set of EFH occupations that were identified *a priori* is consistent with testing the hypothesis that these occupations were risk factors for disease. In contrast, considering all, or nearly all occupations as potential risk factors was more consistent with generating rather than testing hypotheses. Researchers who pursued the second approach often applied prior knowledge when selecting occupations to populate the low-risk reference group and may have had suspicions about the likely high-risk occupations, but still generated results for all occupations not included in the reference group.

The studies that employed both approaches provided the opportunity to examine differences in methods and findings. The final six rows of Table II list characteristics of the six studies. In some of these studies, the methods for defining EFH and reference groups differed between the approaches. For example, in a study that used data from blood donors in the United States, job categories for essential workers were based primarily on industry with some consideration of occupation, whereas job categories in the analyses for all workers were based solely on occupation.[12] Two of the six studies used the same reference group for both approaches,[2,27] but the other four studies used two different reference groups, non-EFH workers when studying EFH workers and a group of low-risk workers (eg, corporate managers; computer and mathematics occupations) when studying all occupations.[10–12,28] Despite these differences, it was possible to make general comparisons of the two sets of results from the six studies. Both approaches identified many of the same types of occupations already reported for all 12 studies, notably health care, teaching or education, social care, and transportation. However, results differed between the approaches. For example, positive results for protective services or security and for personal services including cleaning and house-keeping were more common from analyses of all versus EFH jobs. For five of the six studies, selected occupations had positive results from the analyses with all occupations but not with EFH occupations. Specifically, researchers in Denmark reported five occupations with elevated effect estimates from the analyses of all occupations that were not identified when focusing on high-risk jobs: medical imaging and equipment operators, early childhood educators, chefs, food and related products machine operators, and construction managers.[27] In a study conducted in the United Kingdom, investigators reported elevated effect estimates for COVID-19 death from the all-occupations analyses that were in the non–essential worker group: sales occupations, elementary security occupations, process operatives, and managers and directors in retail and wholesale.[28] Three studies reported positive results for several occupations that had little or no overlap with EFH worker categories in the same study. These occupations were leisure and personal service from one UK study[2]; secretarial and related, customer service, and elementary administration from another study in the United Kingdom[11]; and food preparation and serving-related, building and grounds cleaning and maintenance, sales and related, legal, office and administrative support, and a final category of management, business and financial operations from a study conducted in the United States.[12] These 19 occupations from the five studies were scattered across many occupational categories, but there was some grouping in business or administration (n = 6), sales or customer service (n = 3), and food preparation and serving (n = 2). Another study that used the two approaches provided an example in which the two sources of results overlapped to an extent, but each approach also had unique outcomes.[10] The associate professional and technical occupations group from the all-occupations analysis had an elevated effect estimate and encompassed a variety of work settings, including some but not all occupations in the essential groups of health care workers and social and education workers that also had positive results.[10] Studies that examined both EFH occupations and all occupations reported many similar results, but the combination of results from the two approaches appeared to provide a more comprehensive account of occupations with elevated effect estimates for COVID-19.

The COVID-19 pandemic brought attention to the fact that work is an important social determinant of health.[30] As demonstrated in the current review regarding COVID-19, certain jobs increased a patient’s risk for exposure to airborne SARS-CoV-2. Similar to other social determinants of health, such as race and annual income, information about an individual’s job is useful to include routinely in public health surveillance systems, not just during a pandemic or epidemic. For example, the same jobs at risk for exposure to SARS-CoV-2 may also be at risk for exposure to other airborne infectious agents. Moreover, understanding an individual’s work is relevant to estimating the risk for many noninfectious as well as infectious diseases. This includes diseases such as asthma, for which the onset and exacerbation can be related to both nonoccupational and occupational exposures. This information can also support recommendations regarding preventive measures for individual patients in clinical settings as well as for groups of workers.

METHODS FOR STUDYING OCCUPATIONAL RESPIRATORY DISEASES THAT ARE NOT EXCLUSIVELY DUE TO WORK

We think the pandemic brought new attention to research methods that might also prove useful when investigating other respiratory diseases, both infectious and noninfectious, which can be caused or exacerbated by both occupational and nonoccupational factors. These include methods for characterizing occupational exposures and nonoccupational socioeconomic risk factors, and a strategy for considering how these factors relate to each other, when to include them as covariates in regression models, and how to interpret the resulting coefficients.

Job-exposure matrices used to study COVID-19

Characterization of work by the studies in Table II was typically accomplished by coding study participants' jobs using a coding scheme for occupation, industry, or a combination of occupation and industry. This was followed by making comparisons among occupations directly or by assigning levels of risk to occupations using a JEM specific to COVID-19. Several studies[18,20,27] used an international JEM for COVID-19,[19] one study[29] used the Council of State and Territorial Epidemiologists SARS-CoV-2 Occupational Exposure Matrix,[31] another study[13] used the O*NET JEM to characterize jobs according to four dimensions considered relevant to transmission of the SARS-CoV-2,[26] and a study conducted in Sweden by Torén and colleagues[22] used two JEMs: the Danish version of the international JEM[19] and one developed in Sweden based on the O*NET.[23]

Elements of JEMs developed for studying COVID-19 might be useful when studying the onset of other infectious diseases among working adults. In fact, researchers in Sweden have already pursued this approach. A 2023 publication reported a study that used selected dimensions of the international COVID-19 JEM[19] when investigating the association of invasive pneumococcal disease with work.[32] The researchers used outputs from the JEM to develop exposure variables for the number of coworkers in close proximity, the nature of contacts with others at work, contamination of workspaces, whether the location was indoors or outdoors, and social distancing. Invasive pneumococcal disease was associated with several of these variables, most notably close contact with fellow workers or people from the general public and working outdoors.[32] These researchers applied similar methods when investigating occupational risks for influenza A and B.[33] The same JEM or other JEMs employed when studying COVID-19 may also be useful when studying noninfectious respiratory diseases. For example, because respiratory infections may contribute to the onset[34] and exacerbation[35] of asthma, elements of JEMs used to study COVID-19 may help to assess exposures when studying the association of these respiratory outcomes with work.

Characterizing socioeconomic risk factors

All 14 studies described in Table II included nonoccupational socioeconomic covariates as potential confounders. Some studies included deprivation factors such as household income or the number of household members from individual-based data; others included area-based indices with composite measures of several different domains of deprivation (Table E1). For example, the English Index of Multiple Deprivation[36] is the official measure of small area deprivation in England, and similar indices have been developed for Wales, Scotland, and Northern Ireland. The English Index of Multiple Deprivation is based on seven domains: Income Deprivation; Employment Deprivation; Education, Skills and Training Deprivation; Health Deprivation and Disability; Crime; Barriers to Housing and Services; and Living Environment Deprivation. Another example is the area-based Townsend Deprivation Index, a UK census-based index composed of four census variables: households without a car, overcrowded households, households not owner-occupied, and persons unemployed.[15,16] Three of the studies in Table II used the first index[2,11,28] and two used the second index.[10,13]

Although not used in studies discussed in this commentary, the US Centers for Disease Control and Infection has employed three area-based indices of vulnerability for studies during the COVID-19 pandemic. These are the US Centers for Disease Control and Infection Social Vulnerability Index, the US COVID-19 Community Vulnerability Index, and the Pandemic Vulnerability Index. The domains that comprise each of these indices were described and compared in a recent review.[36] There is overlap in the socioeconomic domains included in the indices of deprivation and the indices of vulnerability discussed earlier. Although these research tools might be a useful approach when individually linked measures are unavailable, the inclusion of area-based indices in multivariable models has the potential to lead to misclassification because, as discussed by McCartney and colleagues,[37] individuals are given the average deprivation level of the area, whereas in fact many highly deprived individuals do not live in the most deprived areas.

Our impression is that socioeconomic factors have been deployed inconsistently in studies of occupational respiratory diseases, possibly confounding the effect of occupation, and should be considered in future studies.

Directed acyclic graph

In recent years the use of causal inference techniques in analyzing observational study data has become prominent. In a 2019 overview article published in the *Annals of the American Thoracic Society*, 47 editors of 35 respiratory, sleep, and critical care journals gave guidance in relation to the analysis and reporting of causal inference studies.[38] The first of three key principles related to how to select variables for inclusion in models. A preferred method was the use of DAGs. It was also noted that "p value- or model-based methods" or the "identification of multiple independent predictors" through statistical selection methods are not optimal for controlling confounding in causal inference modeling.[38]

In the 14 papers profiled in Table II, six used a DAG to guide the construction of multivariable models for causal inference.[2,3,11,18,22,29] Five of these papers had DAGs available in either the main body of the paper or the supplemental information. Explanations regarding the characteristics of DAGs and their use in causal modeling can be found in publications.[39] There is also free software available for developing DAGS at DAGitty — draw and analyze causal diagrams.[40] This website hosts DAGitty, which is Web browser-based, and also has a learning section.

A DAG is a technique used by researchers to lay out known or presumed causal relationships (pathways) among variables of interest for a study. Prior information is used to describe the exposure of interest, the outcome of interest, and covariables that can be confounders or fulfill other roles in relation to the pathway between the exposure and the outcome. Directed acyclic graphs are useful when investigating causal relationships because they provide information about which variables to include or exclude in a multivariable model so that the causal pathway of interest can be correctly estimated. Furthermore, a DAG guides the interpretation of coefficients of covariates in a multivariable model. This helps researchers avoid mutual adjustment errors (also termed Table 2 fallacy[41]) in the interpretation of each variable's coefficient as representing an estimate of the total effect of that variable.

As seen in the DAGSs presented in the five publications mentioned earlier, different researchers may conceptualize the pathways among variables of interest differently, especially for complex DAGs with many variables and many pathways among variables. Nevertheless, having the DAGs in the publications enables readers to understand the assumptions made by the researchers.

An aspect of DAGs and causal interpretation that is important to understanding the effect of occupation on COVID-19 is the differences in a total effect, a direct effect, and an indirect effect through a mediator (ie, an intermediate step between the exposure and the outcome).[42] One take-home message is that if variables that are mediators of the exposure of interest and the outcome of interest are included in a multivariable model, the coefficient for the exposure of interest should not be interpreted as a total effect. An example of mediation analysis in relation to occupation and SARS-CoV-2 serologic status is given in the publication by Beale and colleagues,[3] the first study listed in Table II. The authors found that the frequency of work-related close contact (mediator) accounted for the effect of occupation for most of the occupational groups. However, for workers in health care and indoor trade, process, and plant occupations, there were also direct effects of occupation on SARS-CoV-2 serologic status over and above the effect of the frequency of work-related close contact. This indicated that for those occupational groups other unknown mediators were part of the causal pathway between occupation and infection.

CONCLUSIONS

Occupation is a risk factor for COVID-19, consistent with evidence from the studies summarized in this commentary that reported such associations after adjusting for multiple potential confounders. Many of the positive results were for the association of COVID-19 with occupations considered to be essential, frontline, or high-risk. The substantial resources devoted to understanding risk factors for COVID-19 highlighted research methods and data requirements that could benefit public health efforts during subsequent infectious epidemics and pandemics. These same methods have the potential to improve future investigations of other infectious and noninfectious diseases, notably respiratory diseases that have both occupational and nonoccupational risk factors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

COVID-19	Coronavirus disease 2019
DAG	Directed acyclic graph
EFH	Essential or frontline or high-risk
JEM	Job exposure matrix
MeSH	Medical Subject Headings
O*NET	Occupational Information Network
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2

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TABLE I.

Examples of nonoccupational risk factors for COVID-19 that were considered potential confounders when studying the association of COVID-19 with work

Category		
Demographic/personal	**Socioeconomic**	**Community**
Sex or gender	Education	Geographic region
Age	Household members, n	Pandemic wave
Race	Household with children	Transport use
Ethnicity	Income	Urban/rural classification
Body mass index	deprivation index[14–16]	Population density
Smoking		
Chronic conditions		
COVID-19 vaccination		

TABLE II.

Characteristics of 14 studies that controlled for multiple types of potential confounders when investigating the association of COVID-19 with occupations and occupational risk factors

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates*		Occupational risk factors†
							All occupations	EFH occupations	
Investigated all occupations									
Beale 2023[3]	February 1 to June 8, 2021	United Kingdom, England and Wales	Test+ serologic test, anti-N reactivity	Subset of Virus Watch study cohort who were observed longitudinally (n = 3,775)	11 occupational categories	Single referent group: other professional and associate occs (office-based occs)	Total effect: Health care Indoor trade, process, and plant Leisure and personal service Transport and mobile machine workers Indirect effect: Effect of all occs mediated by work-related close contact (self-reported) Direct effect: Health care Indoor trade, process, and plant	NA	Yes
Bonde 2023[18]	2020–2021	Denmark	Test+ RT-PCR test	National test registry, workers traced for SARS-CoV-2 test results (total n = 2,031,499)	205 non—low risk occs based on international JEM[19] with >100 male and >100 female employees (n = 1,569,737)	77 low-risk occs based on international JEM[19] (n = 461,762)	49 occs in economic sectors: Social work Residential care Education Health care Public service, defense and security Accommodation and food service Transportation and storage Other economic activities	NA	No
Eekhout 2023[20]	June 2020 to August 2021	Netherlands	Test+ PCR or rapid antigen test	Linked several public databases (n = 207,034 workers)	Studied occupational risk factors based on international JEM[19]	Defined based on international JEM[19]	NA	NA	Yes†

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates*		Occupational risk factors†
							All occupations	EFH occupations	
Green 2023[8]	August 2020 to January 2021	United Kingdom, England	Test+ PCR test	n = 363,651 adults from Covid Infection Survey, a representative longitudinal survey. Approximately half were employed or self-employed	14 work sectors	Information and communications technology work sector	Seven work sectors: Teaching and education Health care Social care Transport (including storage, logistic) Retail sector (including wholesale) Hospitality (eg, hotel, restaurant) Manufacturing or construction	NA	No
Menezes 2023[21]	April 2020 to May 2021	Brazil	Test+ RT-PCR test	Random sample of working adult patients in primary care program who had COVID-19 test (n = 1,724 cases and n = 1,741 controls)	Nine occupational categories	Other university-level professionals	Five occupational categories: Housekeeping and maintenance Food retail and production Industry, construction, and agriculture Health care and caregiving Police and protective services	NA	No
Torén 2023[22,‡]	October 2020 to December 2021	Sweden	Severe case was PCR test+ and hospital admission or mortality owing to COVID-19	Cases from national registry of communicable diseases: n = 5,985 severe COVID-19 cases. Controls from national population registry: n = 24,315	**1** All occs **2** Occupational risk factors based on two JEMs (international JEM[19] and Swedish JEM[23])	**1** Occs with lowest risk, based on two JEMs **2** Homeworkers or persons not working with others	Severe COVID-19 associate with occs: Teachers' aides Primary school teachers Early childhood educators Childcare workers Nursing professionals Certified specialist physicians Health care assistants Bus and tram drivers	NA	Yes†

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates*		Occupational risk factors†
							All occupations	EFH occupations	
							Elementary workers NEC		
Investigated non–health care occupations									
Wong 2023[24]	November to May 2021	United State	Test+ PCR test	451 adult workers: n = 212 positive and n = 239 negative for SARS-CoV-2	**1** Major occupational groups and major industry groups **2** Occupational risk factors based on CSTE SOEM[25]	**1** Combination of low-risk occs based on US Occupational Safety and Health Administration guidance[24,25] **2** Lower level of risk based on CSTE SOEM[25]	Major occupational groups: Management Sales and related Major industry groups: Transportation and warehousing	NA	Yes†
Yanik 2022[13]	August 5 to November 10, 2020	United Kingdom, England	Test+	Subset of UK Biobank participants: working adults who reported job data (n = 115,451)	Occupational risk factors as based on O*NET JEM[26]	Reference group based on O*NET JEM[26]	NA	NA	Yes†
Investigated all occupations and EFH occupations									
Beale 2023[2,§]	November 2020 to March 2022	United Kingdom, England and Wales	Test+ any clinical test of infection	Subset of Virus Watch study cohort who were aged ≥16 y old with self-reported occupation and who completed ≥1 monthly survey (n = 15,190)	**1** 12 frontline occupational groups **2** 10 inclusive occupational groups	Single referent group: other professional and associate occs (office-based occs)	Five occupational groups: Health care Social care and community protective services Teaching, education, and childcare Leisure and personal service//	Doctors Nurses Carers Teachers primary Teachers secondary Teaching support occs	No
Bonde 2023[27]	2020 and 2021	Denmark	Hospital admission for COVID-19	National study of employees aged 20–69 y. At-risk occs (nonreferent), n = 1,620,231. Referent group, n = 369,341	**1** High-risk occs based on international JEM[19] with >2,000 employees **2** 155 occs with >2,000 employees	Single referent group: low risk based on international JEM[19] (mainly office workers)	Health care: Generalist medical professionals Health care assistants Medical and pathology laboratory techs Psychologists	Health care: Medical professionals Health care assistants Medical laboratory techs Psychological therapists X-ray techs	No

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates* — All occupations	Occupations with elevated effect estimates* — EFH occupations	Occupational risk factors†
					across all non–low risk industrial sectors		Medical imaging and equipment operators‖ Health professionals NEC Social care: Nursing professionals Social work associate professionals Home-based personal care workers Transportation: Bus and tram drivers Education: Early childhood educators‖ Food service: Chefs‖ Manufacturing: Food and related products machine operators‖ Construction: Construction managers‖	Recreational therapists Hospital attendants (porters) Social care: Nursing professionals Nursing aides (institutions) Nursing aides (private homes) Teachers and daycare assistants for children aged 4–7 y Transportation: Bus and tram drivers	
Cherrie 2022[28]	January 2020 to October 2021	United Kingdom, England and Wales	Mortality owing to COVID-19	Deaths for people aged 20–64 y, n = 136,567, including 16,625 COVID-19 cases	**1** 12 essential occupational groups **2** All occs	**1** Nonessential worker group **2** Corporate managers (excluding Retail)	Health professional Caring personal services Bus and coach drivers Care workers and home carers Taxi and cab drivers and chauffeurs Sales occs‖ Elementary security occs‖ Process operatives‖ Managers and	Health care professionals and associates Medical support staff Social care Food retail and distribution Food production Taxi and cab drivers Bus and coach drivers Van drivers Other transport workers	No

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates*		Occupational risk factors†
							All occupations	EFH occupations	
							directors in retail and wholesale‖		
Mutambudzi 2020[10]	March 16 to July 26, 2020	United Kingdom, England	Test+ in hospital setting or mortality owing to COVID-19	n = 120,075 UK Biobank participants	**1** Essential workers in three broad occupational categories and eight detailed occupational categories **2** All workers in major occupational groups	**1** Nonessential workers, separately for both broad and detailed essential worker categories **2** Managers and senior officials	Associate professional and technical occs	Broad groups: Health care workers Social and education workers Detailed groups: Health care professionals Medical support staff Health associate professionals Social care workers	No
Nafilyan 2022[11]	January 24 to December 28, 2020	United Kingdom, England and Wales	Mortality owing to COVID-19	Study people aged 31–55 y at 2011 census and assumed to have stable employment in 2011 and 2020 when aged 40–64 y (n = 14,295,900)	**1** Essential occs **2** All occs	**1** Nonessential workers **2** Corporate managers and directors	Women: Taxi and cab drivers and chauffeurs Elementary cleaning occs excluding cleaners and domestics Men: Taxi and cab drivers and chauffeurs Large goods vehicle drivers Health professionals Caring personal services Care workers and home carers Other elementary occs Secretarial and related occs‖ Customer service occs‖ Elementary	Women: Taxi and cab drivers and chauffeurs Social care Men: Taxi and cab drivers and chauffeurs Van drivers Medical support staff Health associate professionals Social care	No

Reference (first author)	Period	Country	COVID-19 outcome	Study population	Occupations at risk	Occupational reference group	Occupations with elevated effect estimates*		Occupational risk factors†
							All occupations	EFH occupations	
							administration occs‖		
Shah 2023[12]	May to December 2021	United States	Test+ serologic testing, anti-N reactivity	Blood donors, n = 46,612 with codable occs and complete information: 6,081 cases and 40,531 controls	**1** Essential occ **2** All occs	**1** Nonessential occs **2** Computer and mathematics occs	Education, training, and library Health care practitioners and techs Health care support Protective services Community and social service Food preparation and serving-related‖ Building and grounds cleaning and maintenance‖ Sales and related‖ Management, business and financial operations‖ Legal‖ Office and administrative support‖	Education workers Health care workers First responders	No

anti-N reactivity, positive for antinucleocapsid antibodies; *CSTE SOEM*, Council of State and Territorial Epidemiologists SARS-CoV-2 Occupational Exposure Matrix; *EFH*, essential/frontline/high-risk; *JEM*, job exposure matrix; *NEC*, not elsewhere classified; *occs*, occupations; *techs*, technicians; *O*NET*, Occupational Information Network; *Test+*, positive test.

*Elevated effect estimates were statistically significant, typically at $P < .05$.

†Results for occupational risk factors are summarized in the text.

‡For the study by Torén and colleagues,[22] we considered only severe COVID-19 cases because regression models for regular cases did not include sufficient covariates to control for potential confounding.

§Beale and colleagues[2] also conducted analyses with all other workers as the reference group when studying all occupations, but results from those analyses are not presented in this table.

‖For the studies of both all occupations and EFH occupations: occupational categories with elevated effect estimates in data analyses for all occupations that were not identified in analyses of high-risk occupations in the same study[27] were in the nonessential worker group in the same study[14] or had little or no overlap with frontline or essential worker categories in the same study.[2,11,12]