Occupation and SARS-CoV-2 in Europe: a review

Sarah Rhodes[1], Sarah Beale[2], Sarah Daniels[1], Matthew Gittins[1], William Mueller[3], Damien McElvenny[1,3] and Martie van Tongeren[1,4]

[1]Division of Population Health, Health Services Research & Primary Care, University of Manchester, Manchester, UK. [2]Institute of Health Informatics, University College London, London, UK. [3]Institute of Occupational Medicine, Edinburgh, UK. [4]Thomas Ashton Institute for Risk and Regulatory Research, University of Manchester, Manchester, UK.

Corresponding author: Sarah Rhodes (Sarah.A.Rhodes@manchester.ac.uk)

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Workers in healthcare, social care, education, transport and food production sectors saw elevated risks of SARS-CoV-2- and COVID-19-related hospitalisation and death compared to others early in the COVID-19 pandemic but this did not necessarily persist. https://bit.ly/3VzHd0t

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Abstract

Introduction Workplace features such as ventilation, temperature and the extent of contact are all likely to relate to personal risk of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Occupations relating to healthcare, social care, education, transport and food production and retail are thought to have increased risks, but the extent to which these risks are elevated and how they have varied over time is unclear.

Methods We searched for population cohort studies conducted in Europe that compared coronavirus disease 2019 (COVID-19) outcomes between two or more different occupational groups. Data were extracted on relative differences between occupational groups, split into four time-periods corresponding to pandemic waves.

Results We included data from 17 studies. 11 studies used SARS-CoV-2 as their outcome measure and six used COVID-19 hospitalisation and mortality. During waves one and two, the majority of studies saw elevated risks in the five groups that we looked at. Only seven studies used data from wave three onwards. Elevated risks were observed in waves three and four for social care and education workers in some studies.

Conclusions Evidence relating to occupational differences in COVID-19 outcomes in Europe largely focuses on the early part of the pandemic. There is consistent evidence that the direction and magnitude of differences varied with time. Workers in the healthcare, transport and food production sectors saw highly elevated risks in the early part of the pandemic in the majority of studies but this did not appear to continue. There was evidence that elevated risks of infection in the education and social care sectors may have persisted.

Background

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection started spreading in Europe from January 2020 with the first recorded death from coronavirus disease 2019 (COVID-19) in the following month [1].

There has been considerable focus on the role of occupation in the transmission of SARS-CoV-2 and debate as to what extent COVID-19 is an occupational disease [2, 3]. Many workers were expected to attend the workplace throughout the COVID-19 pandemic, while others were able to work from home or were forced into a period of unemployment due to the closure of workplace premises. Once in the workplace, workers in different occupations have varying levels of exposure to an airborne virus. There will be differing degrees and types of contact with other people [4], including whether or not a role involves caring for infected people, the closeness of proximity when working and the number of new contacts during the working day (*e.g.* when serving customers). Different environmental features such as ventilation, temperature, humidity [5], indoor versus outdoor work and the need to shout over noise [6], are all likely to contribute to the overall risk. Furthermore, workplace features not directly related to the work tasks, such as crowded lunchrooms or shared transport to the workplace are also likely to be important.

Understanding the role of the workplace in the risk of COVID-19 is complex. We are reliant on observational data, which are prone to bias. Bias in the ascertainment of outcomes is likely, as propensity for testing to identify SARS-CoV-2 infection is commonly related to occupation and varied with time. Testing was mandatory for some workers at some time points, *e.g.* healthcare workers. Furthermore, a care worker working with vulnerable older adults is likely to have different motivation to self-test than a self-employed construction worker working predominantly alone and outdoors. Ascertainment and reporting of SARS-CoV-2 may be related to applications for compensation for occupational injury/disease, which would also vary by occupation and time. Among healthcare workers, COVID-19 cases were recognised as work related at the beginning of the pandemic in many countries [7], but attributing the workplace in the role of transmission became much harder once the infection spread in the general population. Attributing cause of death to COVID-19 is subjective and can be difficult, especially in those with long-term health conditions; knowledge of a person's job may influence judgement and introduce bias. In addition, it is difficult to establish whether increased risks for some groups of workers relate to the working environment itself or to confounders such as socioeconomic status, ethnic group and behaviours outside working hours.

Mitigations put in place to reduce COVID-19 transmission have varied over time and between different areas of Europe [8]. Many of these mitigations would be expected to affect workplace transmission, *e.g.* lockdown, vaccinations, mask use, use of lateral flow tests, homeworking and increased ventilation. Furthermore, risks may vary due to immunity from prior infections and periodic effects due to an undulating background infection rate. These factors mean that differences between occupations in terms of risk are unlikely to be constant over time. In addition, occupation related risk factors for SARS-CoV-2 infection may not be the same as those for severe COVID-19 disease and therefore it is important to investigate whether or not increased risks of infection translate to increased risks of hospitalisation and mortality.

The authors of this review have published a number of studies relating to occupational risks of SARS-CoV-2 infection and COVID-19 mortality using large population cohort data. This review aims to combine results from these studies with similar studies relating to other European datasets where we would expect some consistency in results due to the similarities in pandemic timeline and workplace legislation. Combining evidence from multiple sources in different settings and using different methodologies allows us to look for commonalities to strengthen conclusions and inconsistencies that highlight uncertainties to guide future research.

Aims

We aimed to review and synthesise existing analyses of European population cohorts in relation to occupational risks of SARS-CoV-2 infection and COVID-19 hospitalisation and mortality to answer the following research questions:

1) Which occupations and work sectors have seen elevated risks of SARS-CoV-2 infection, COVID-19 hospitalisation and COVID-19 mortality in Europe, compared to low-risk occupations/general population/average risk?
2) To what extent do studies relating to differences between occupations and sectors in SARS-CoV-2 infection, COVID-19 hospitalisation and COVID-19 mortality in Europe agree in terms of direction and magnitude of relative differences?
3) How have differences between occupations and sectors in SARS-CoV-2 infection, COVID-19 hospitalisation and COVID-19 mortality in Europe changed over different waves of the COVID-19 pandemic?

Methods

We adopted a systematised approach [9]; our search strategy, inclusion criteria (supplementary table S5) and risk of bias assessment are all well specified but were not pre-specified in a protocol before the review process started due to time limitations in preparing this commissioned review. Our review included articles that use data from general population cohorts in Europe that compare risks of SARS-CoV-2 infection, hospitalisation due to COVID-19 or COVID-19 mortality between two or more different occupational groups or work sectors. Studies had to either use relative effects to compare groups to a reference category or report sufficient detail to allow relative differences to be derived to allow a valid comparison. We took a population cohort to be either a complete population relating to a geographical area or a subset of a population designed to represent the population in general. An appropriate reference category was an occupational group perceived to be low risk or the general population. Appropriate outcomes were SARS-CoV-2 infection determined *via* any test result (including serological antibody test) or self-reported infection, hospitalisation relating to COVID-19 or death from COVID-19 ascertained *via* any method. We excluded studies relating to a single work sector, *e.g.* a population of healthcare workers, or that used a job exposure matrix to compare aspects of workplace exposure rather than occupations or sectors. We also excluded studies that focused on long COVID-19 as an outcome. Only studies published in peer-reviewed journals were included (as a surrogate for quality).

We used articles already known to the authorship team and manually scanned bibliographies and citations relating to those articles. In addition, we searched Ovid Medline and Web of Science using search terms "(occupation* or industr* or sector*).ti,ab. AND (covid* or SARS-Cov-2).ti,ab. AND (cohort or population or registry or survey or database).ti,ab".

Descriptive study-level data on infection/mortality data source, age range, time period covered, region and covariate adjustment set were extracted from the published papers.

We extracted relative effect sizes (odds ratios, relative risks and incidence ratios) where available with 95% confidence intervals from studies comparing occupational risks to a reference category (*e.g.* nonessential workers, total population). We created a separate table for each of five key sectors highlighted as likely to be at high risk by multiple authors, as follows: healthcare, social care, education, transport, and food production and retail [10–12]. Where a study reported analyses relating to multiple different occupational/ sector groupings, we chose, in order of preference: 1) one that split into the most time periods and 2) the broadest available grouping. We used sector (industry) groupings where possible (rather than occupation) relying on definitions provided in the original article most closely aligned with our own understanding of these sectors (for example, educators reported as working in the social care sector were reported in the social care group). Risk estimates were approximated for studies where only plots, and not quantitative estimates, were presented. We extracted data on multiple subgroups where no overall sector category was available (*e.g.* extracting data on both healthcare professionals and medical support staff for the healthcare sector). We split results by COVID-19 wave using the following definitions: wave one (January–November 2020), characterised by dominance of wild-type SARS-CoV-2 and stringent public health restrictions in most European countries during periods of high community transmission [13]; wave two (December 2020–May 2021), characterised by dominance of the alpha variant and stringent restrictions in most European countries; wave three (June–November 2021), characterised by dominance of the delta variant and relaxation of public health restrictions in most European countries; and wave four (December 2021 onwards), characterised by dominance of the omicron variant and relaxation of most public health restrictions across Europe. Dates used to group results varied somewhat across studies and results were allocated to the wave with the greatest time overlap to the definition above. In some studies, multiple waves were amalgamated into a single period.

We have avoided pooling results due to expected heterogeneity and some overlap in study populations. For each study, for each sector and time period we categorised the result as showing either evidence of highly elevated risks (a confidence interval for a relative effect estimate entirely above two), moderately elevated risks (a confidence interval for a relative effect estimate entirely above one or a confidence interval for a prevalence that was entirely above that of the reference category or appropriate study conclusions suggesting a relative increase), evidence of reduced risks (confidence intervals entirely below one or entirely below the reference category), unclear whether risks are reduced or increased (confidence interval that includes one or overlaps with the reference category) or varies by subgroup (subgroups within the same sector differ in terms of conclusions made in relation to confidence intervals), using colour coding. Where studies did not report relative effects (studies that reported incident ratios only or excess mortality), we categorised their result as above but left the effect estimate blank. Note that these judgements were based on the confidence interval reported by the original source (before any rounding).

In addition, to consider additional workplace sectors not included in the five areas that we focused on, we exacted conclusions from each study relating to our research aims. We also extracted the three individual occupation or sector groups reporting the highest levels of risk, as characterised by the highest point estimates of relative effects or highest prevalence rates to reveal any subgroups with increased risks that may have been hidden within the broader groupings used. We also filled in the Newcastle Ottawa Scale for cohort studies [14].

Results

There were 14 eligible studies that were already known to the research team through previous literature reviews, previous work on this topic and through looking at reference lists. Our new literature search generated 3384 studies, 12 of which were already included and 23 of which were put forward for full text screening. Of these 23 studies, only one was considered eligible and a further two studies were then suggested during peer review (supplementary figure S1). We included 17 studies that used European population cohorts to compare COVID-19 outcomes by occupational group, described in table 1. 11 studies had SARS-CoV-2 infection as their outcome measure [15–25], two studies used hospitalisation for COVID-19 [26, 27] and four used COVID-19 mortality [28–31]. Seven studies used data from the UK, two from Denmark two from Sweden and one from each of Italy, Norway, Germany, the Netherlands, Spain and Belgium. Note that one study from Spain [25] presented incidence rates for 133 different job codes but only aggregated data relating to the healthcare sector; we included data on the healthcare sector only for this study as results from other sectors were impossible to interpret due to their volume and imprecision.

Table 2 summarises evidence relating to the healthcare sector. During wave one, 10 out of 11 studies that reported infection data saw an elevation in risk for the healthcare sector. During wave two, six out of eight studies reported elevated risks. During wave three, two out of four studies saw increased risks and one saw reduced. During wave four, two out of three studies saw increased risks and one reduced. Data on hospitalisation was reported for wave one only for one study [27] and amalgamated over the entire pandemic for another [26]. Elevated risks in wave one were seen in most subgroups and when averaged over the entire pandemic. Data on mortality was largely restricted to wave one only, when again risks were elevated for most subgroups, after which point evidence was inconclusive.

Table 3 summarises evidence relating to the education sector. During wave one, six out of 10 studies that reported infection data saw an elevation in risk for the education sector. During wave two, five out of six studies reported elevated risks. During both wave three and wave four, three out of three studies saw elevated risks of infection. There was no evidence of elevated risk of hospitalisation or mortality for the education sector in any of the studies that we found at any of the time points, with one study [30] suggestion a reduction in excess mortality during wave three.

Table 4 summarises evidence relating to the social care sector. During wave one, five out of eight studies saw elevated risks for the social care sector. During wave two, five out of five studies saw elevated risks. None of the studies saw elevated risks during wave three, while one out of three saw elevated risks in wave four. For hospitalisation and death, elevated risks were seen for four out of six studies in wave one, two out of three in wave two, one out of three in wave three and one out of two in wave four.

Supplementary table S1 summarises evidence for the transport sector. For infections, four out of seven studies saw elevated risks of infection for the transport sector in wave one and four out of five for wave two. There was little evidence of elevated risks of infection for the transport sector during waves three and four, with only one study [17] that amalgamated data over all four waves reporting elevation. For hospitalisation and mortality, elevated risks were seen in wave one and wave two for some subgroups with bus and tram drivers and taxi and cab drivers seeing highly elevated risks in some studies although not all. Only one study [29] looked longitudinally at waves one to four in the transport sector and they saw elevated risks during waves one and two, but not three and four.

Supplementary table S2 summarises evidence for the food production and retail sector. During wave one, four out of seven studies saw elevated risks of infection for the food production sector and during wave two, four out of six. There was little evidence of elevated risks of infection for the food sector during waves three and four, with only one study [17] that amalgamated data over all four waves reporting elevation, and one study [22] reporting slightly lower risks than other workers during wave three. Only one study [29] saw elevated risks in severe disease or mortality relating to food production and retail which were in wave one.

Table 5 describes the conclusions made by the authors of the individual studies and the three groups with highest estimates of increased risk. Studies described increased risks relating to healthcare, social care, transport, education and food production, and changes in risk over time. Occupational groups that appeared in the list of highest relative differences that are not already covered by our five sectors of interest were workers in a weaving factory, athletes and sports players, cleaners, hospitality, police and protective services, activities of sports clubs, and activities of football clubs.

Supplementary table S3 shows a quality assessment using the Newcastle–Ottawa Scale. Supplementary table S4 describes ascertainment of exposure and outcome for each study.

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TABLE 1 Description of epidemiological studies relating occupational risks of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection and coronavirus disease 2019 (COVID-19) hospitalisation and mortality

Reference	Data source	Outcome effect measure	Age range (years)	National region	Time periods	Reference group	Maximum adjustment set
Airoldi *et al.* [15]	Private healthcare centre testing (Centro Polispecialistico Privato Medicina del Lavoro)	Seroprevalence proportion and 95% confidence intervals	<20–>80 (working age)	Italy	Wave one: April–August 2020	Population average	None
Ballering *et al.* [24]	Dutch Lifelines cohort study and Lifelines COVID-19 cohort	Infection odds ratio	Over 18	Netherlands	March–August 2020	People who were neither healthcare nor education workers	Age, sex, education, chronic disease, disease-prevention behaviour, household members
Beale *et al.* [16]	Virus Watch cohort	Infection risk ratios	16 and over	England and Wales	Waves one and two: February 2020–May 2021 Wave three: June–November 2021 Wave four: December 2021–April 2022	Other professional and associate occupations	Age, sex, ethnic group, deprivation, health, income, household size
Biarnés-Martínez *et al.* [25]	Catalonia primary care database and centralised database of diagnostic tests	Infection cumulative incidence	16–65	Spain	1 March 2020–16 September 2021	Nonhealthcare workers	Age and sex
Billingsley *et al.* [28]	Swedish administrative and population registers linked to cause of death register	Mortality hazard ratios	20–66	Sweden	12 March 2020–23 February 2021	Skilled workers in IT, economics or administration	Age, sex, living in Stockholm, country of birth, highest achieved educational degree and individual net income
Bonde *et al.* [26]	All Danish employees from records in the work classification module at Statistics Denmark, as a subset of the Danish occupational cohort with exposure data	Incidence rate ratio for counts of COVID-19 hospital admissions if a SARS-CoV-2 PCR swab test was positive up to 14 days prior to admission and if the hospital stay was >12 h	20–69 at 1 January 2020	Denmark	1 January 2020–14 December 2021	Occupations classified to the lowest level of potential occupational exposure to SARS-CoV-2 by an expert-rated COVID-19 JEM	Adjustment for sex, age, duration of education, number of hospital admissions for one or more of 11 chronic diseases in the 10 years preceding start of the pandemic, country of origin, geographical region, number of household members, probability of tobacco smoking, BMI, family positive PCR swab test (at least one member of the family besides the index person with positive PCR test during the previous 2–3 weeks, yes/no) and COVID-19 vaccination (from date of second vaccination until end of follow-up)

Continued

TABLE 1 Continued

Reference	Data source	Outcome effect measure	Age range (years)	National region	Time periods	Reference group	Maximum adjustment set
Bonde *et al.* [17]	Nationwide register-based cohort of all Danish residents	Incidence rate ratios for infection	20–69	Denmark	Week 8 of 2020–week 50 of 2021 Data split into four waves but time periods not specified	Low-level exposed employees according to a COVID-19 JEM	Sex, age, education, chronic disease, country of birth, region, household members, smoking, BMI, COVID-19 vaccination and occupational test frequency
Cherrie *et al.* [29][#]	ONS mortality database of all registered deaths	Proportionate mortality odds ratios	20–64	England and Wales	Wave one: January–September 2020 Wave two: October 2020–May 2021 Wave three: June–October 2021 Wave four: January–June 2022[#]	Nonessential workers	Age, sex, deprivation, region, urban/rural and population density
Green and Semple [18]	ONS CIS: a cohort using random sampling designed to be representative of UK population	Infection odds ratio	Over 18	UK	August 2020–January 2021	ICT workers	Age, gender, ethnic group, travel abroad, household size, geographical area and month
Magnusson *et al.* [19]	Beredt C19 database with national surveillance data linked to population registry and employee registry	Infection odds ratio	20–70	Norway	6 February–17 July 2020 and 18 July–18 December 2020	Other individuals of working age	Age, sex, own and maternal country of birth, and marital status
Matz *et al.* [30, 49]	ONS mortality database of all registered deaths	Excess mortality	20–64	England and Wales	2020–2021	Same group over previous 5 years	None
Mutambudzi *et al.* [27]	Baseline UK biobank data 2006–2010 linked to SARS-CoV-2 test results from Public Health England	Risk ratio for severe COVID-19 defined as hospital admission with positive SARS-CoV-2 or death with COVID-19 as contributing cause	50–65 in 2020	England	16 March–26 July 2020	Nonessential workers	Age, sex, assessment centre, country of birth, ethnicity, area-level socioeconomic deprivation quartile and education level, shift work, manual work, job tenure, and work hours, number of chronic conditions, longstanding illness/disability, and lifestyle-related factors (BMI, smoking and alcohol)

Continued

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TABLE 1 Continued

Reference	Data source	Outcome effect measure	Age range (years)	National region	Time periods	Reference group	Maximum adjustment set
Nafilyan *et al.* [31]	ONS mortality database linked to 2010 census	Mortality hazard ratios	40–64	England and Wales	24 January–28 December 2020	Nonessential workers	Sex, age, region, population density and urban/rural classification, index of multiple deprivation decile group, household deprivation, social grade, household tenancy, type of accommodation, household size, multigenerational household, household with children, BMI, CKD, learning disability, cancer and immunosuppression, and other conditions
Nwaru *et al.* [20]	Swedish national database of notifiable diseases and healthcare utilisation	Infection hazard ratio	20–65	Sweden	January 2020–February 2021	Nonessential workers	Age, gender, marital status, immigration status, healthcare region and pre-existing conditions
Reuter *et al.* [21]	German national cohort (NAKO)	Infection incidence rate ratio	Currently employed	Germany	February–August 2020	Nonessential workers	Age, sex, migration background, study centre, weekly working hours and self-employed status
Rhodes *et al.* [22]#	ONS CIS: a cohort using random sampling designed to be representative of UK population	Infection hazard ratio	20–64	England, Scotland and Wales	Waves one and two: April 2020–February 2021 Wave three: March–December 2021 Wave four: January–August 2022	Nonessential workers	Age, sex, ethnicity, deprivation, region, household size, urban/rural neighbourhood and current health conditions
Verbeeck *et al.* [23]	National registry of confirmed COVID-19 cases linked to Dimona database of active employees	14-day incidence of infection	Active employees	Belgium	29 September–12 October 2020 and 16–19 October 2020	Average over all sectors	Unclear

BMI: body mass index; CIS: Coronavirus Infection Survey; CKD: chronic kidney disease; ICT: information and communication technology; IT: information technology; JEM: job exposure matrix; ONS: Office for National Statistics. #: including additional data on later waves provided in [50].

TABLE 2 Effect estimates and evidence for the healthcare sector, grouped by outcome

<table>
<tr><th>Outcome</th><th>Study (country)</th><th>Subgroups</th><th>Wave one January–November 2020</th><th>Wave two December 2020–May 2021</th><th>Wave three June–November 2021</th><th>Wave four December 2021 onwards</th></tr>
<tr><td>SARS-CoV-2 infection</td><td>Airoldi et al. [15] (Italy)</td><td>Health services</td><td>#</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Ballering et al. [24] (Netherlands)</td><td>Healthcare</td><td>1.7 (1.3– 2.2)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Beale et al. [16] (UK)</td><td>Healthcare</td><td colspan="2">2.1 (1.8–2.5)</td><td>0.9 (0.7–1.1)</td><td>1.2 (1.1–1.4)</td></tr>
<tr><td></td><td>Biarnés-Martínez et al. [25] (Spain)</td><td>Healthcare</td><td colspan="3">#</td><td>NA</td></tr>
<tr><td></td><td>Bonde et al. [17] (Denmark)</td><td>Healthcare</td><td colspan="2">8.2 (6.7–10.1)</td><td>1.7 (1.6–1.8)</td><td>0.65 (0.6–0.7)</td></tr>
<tr><td></td><td>Green and Semple [18] (UK)</td><td>Healthcare</td><td colspan="2">1.3 (1.1–1.5)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Magnusson et al. [19] (Norway)</td><td>Nurses</td><td>3.3 (3.1–3.4)</td><td>1.2 (1.0–1.3)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Physicians</td><td>3.0 (2.8–3.4)</td><td>1.2 (1.1–1.4)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Dentists</td><td>3.0 (2.0–4.5)</td><td>0.8 (0.5–1.2)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Physiotherapists</td><td>2.0 (1.2–2.9)</td><td>0.7 (0.5–1.0)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Nwaru et al. [20] (Sweden)</td><td>Healthcare workers</td><td colspan="2">1.9 (1.9–2.0)</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Reuter et al. [21] (Germany)</td><td>Medicine and dentistry</td><td>4.6 (2.0–9.0)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Nursing, emergency medicine and obstetrics</td><td>2.8 (2.0–5.2)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Rhodes et al. [22] (UK)</td><td>Medical support staff</td><td colspan="2">1.6 (1.3–1.9)</td><td>0.9 (0.7–1.0)</td><td>1.1 (1.0–1.2)</td></tr>
<tr><td></td><td></td><td>Healthcare professionals</td><td colspan="2">1.2 (1.0–1.3)</td><td>0.5 (0.4–0.6)</td><td>1.1 (1.0–1.1)</td></tr>
<tr><td></td><td></td><td>Other health professionals and healthcare associates</td><td colspan="2">1.3 (1.1–1.4)</td><td>0.8 (0.7–0.9)</td><td>1.2 (1.0–1.4)</td></tr>
<tr><td></td><td>Verbeeck et al. [23] (Belgium)</td><td>Human health</td><td>#</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>Hospitalisation</td><td>Bonde et al. [26] (Denmark)#</td><td>Nursing professionals</td><td colspan="4">1.9 (1.4–2.5)</td></tr>
<tr><td></td><td></td><td>Medical practitioners</td><td colspan="4">2.0 (1.3–3.3)</td></tr>
<tr><td></td><td></td><td>Dental assistants and therapists</td><td colspan="4">1.0 (0.5–1.8)</td></tr>
<tr><td></td><td></td><td>Healthcare assistants</td><td colspan="4">3.5 (2.3–5.4)</td></tr>
<tr><td></td><td></td><td>Physiotherapists</td><td colspan="4">1.3 (0.6–2.7)</td></tr>
<tr><td></td><td></td><td>Medical laboratory technicians</td><td colspan="4">1.9 (1.1–3.2)</td></tr>
<tr><td></td><td></td><td>Psychological therapists</td><td colspan="4">2.5 (1.4–4.7)</td></tr>
<tr><td></td><td></td><td>Cleaners and helpers</td><td colspan="4">1.5 (0.9–2.7)</td></tr>
<tr><td></td><td></td><td>Recreational therapists</td><td colspan="4">2.4 (1.1–5.0)</td></tr>
<tr><td></td><td></td><td>Dentists</td><td colspan="4">1.2 (0.5–2.8)</td></tr>
<tr><td></td><td></td><td>Hospital attendants (porters)</td><td colspan="4">1.9 (1.1–3.6)</td></tr>
<tr><td></td><td></td><td>X-ray technicians</td><td colspan="4">2.2 (1.0–4.7)</td></tr>
<tr><td></td><td></td><td>Midwifery professionals</td><td colspan="4">1.1 (0.3–4.2)</td></tr>
<tr><td></td><td>Mutambudzi et al. [27] (England)</td><td>Healthcare workers</td><td>7.7 (5.6–10.6)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Healthcare professionals</td><td>9.0 (5.2–15.5)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Medical support staff</td><td>6.4 (3.6–11.5)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Health associate professionals</td><td>7.7 (5.3–11.0)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td>COVID-19 mortality</td><td>Billingsley et al. [28] (Sweden)</td><td></td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>Cherrie et al. [29] (UK)</td><td>Healthcare professionals and associates</td><td>1.9 (1.6–2.2)</td><td>1.1 (0.9–1.3)</td><td>0.8 (0.6–1.1)</td><td>1.0 (0.7–1.4)</td></tr>
<tr><td></td><td></td><td>Medical support staff</td><td>2.1 (1.7–2.6)</td><td>1.3 (1.0–1.7)</td><td>1.2 (0.9–1.7)</td><td>1.2 (0.6–1.8)</td></tr>
<tr><td></td><td>Matz et al. [30] (UK)</td><td>Healthcare</td><td>#</td><td>#</td><td>#</td><td>NA</td></tr>
<tr><td></td><td>Nafilyan et al. [31] (UK)</td><td>Support staff (male)</td><td>1.7 (1.2–2.5)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Support staff (female)</td><td>0.8 (0.6–1.1)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Health associate professionals (male)</td><td>1.9 (1.4–2.5)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Health associate professionals (female)</td><td>1.2 (1.0–1.5)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Health professionals (male)</td><td>1.5 (1.0–2.2)</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td></td><td>Health professionals (female)</td><td>0.5 (0.1–1.4)</td><td>NA</td><td>NA</td><td>NA</td></tr>
</table>

Red: evidence of highly elevated risks; pale red: evidence of moderately elevated risks; green: evidence of reduced risks; blue: unclear whether risks are reduced or increased; yellow: varies by subgroup. COVID-19: coronavirus disease 2019; NA: not applicable; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2. #: relative effect estimates not reported.

TABLE 3 Effect estimates and evidence for the education sector, grouped by outcome

Outcome	Study (country)	Subgroups	Wave one January–November 2020	Wave two December 2020–May 2021	Wave three June–November 2021	Wave four December 2021 onwards
SARS-CoV-2 infection	Airoldi *et al.* [15] (Italy)	Education	#	NA	NA	NA
	Ballering *et al.* [24] (Netherlands)	Education	1.4 (1.1–1.8)	NA	NA	NA
	Beale *et al.* [16] (UK)	Primary teaching	2.1 (1.4–3.0)		1.7 (1.1–2.7)	1.9 (1.4–2.5)
		Secondary teaching	1.7 (1.2–2.5)		1.8 (1.2–2.7)	1.5 (1.1–2.0)
	Biarnés-Martínez *et al.* [25] (Spain)		NA	NA	NA	NA
	Bonde *et al.* [17] (Denmark)	Education	1.1 (0.9–1.3)	1.4 (1.4–1.5)	1.3 (1.2–1.4)	1.5 (1.5–1.6)
	Green and Semple [18] (UK)	Teaching and education	1.3 (1.1–1.4)		NA	NA
	Magnusson *et al.* [19] (Norway)	Preschool teacher	0.7 (0.6–0.9)	1.2 (1.1–1.3)	NA	NA
		Primary school teacher	0.8 (0.8–0.9)	1.2 (1.2–1.2)	NA	NA
		Upper secondary school teacher	0.8 (0.6–0.9)	1.1 (1.0–1.2)	NA	NA
		University teacher	1.1 (0.9–1.2)	0.8 (0.7–0.9)	NA	NA
	Nwaru *et al.* [20] (Sweden)	Teachers	1.4 (1.4–1.5)		NA	NA
	Reuter *et al.* [21] (Germany)	Teachers in schools of general education	1.4 (0.8–2.8)	NA	NA	NA
		Education and social work	1.2 (0.9–2.2)	NA	NA	NA
	Rhodes *et al.* [22] (UK)	Education	1.4 (1.3–1.5)		1.4 (1.3–1.5)	1.2 (1.1–1.3)
	Verbeeck *et al.* [23] (Belgium)	Education	#	NA	NA	NA
Hospitalisation for COVID-19	Bonde *et al.* [26] (Denmark)#	Primary school teachers	1.2 (0.9–1.5)			
		University/higher education teachers	0.7 (0.4–1.0)			
		Secondary education teachers	0.9 (0.5–1.5)			
		Early childhood educators	1.2 (0.8–1.9)			
		Vocational education teachers	0.8 (0.4–1.3)			
		Preschool child helper	1.4 (0.8–2.5)			
		Education managers	0.6 (0.2–1.5)			
		Cleaners	1.6 (0.9–2.9)			
	Mutambudzi *et al.* [27] (England)	Education workers	1.6 (0.9–2.9)	NA	NA	NA
COVID-19 mortality	Billingsley *et al.* [28] (Sweden)	Teachers	0.8 (0.6–1.5)	NA	NA	NA
	Cherrie *et al.* [29] (UK)	Education	1.2 (1.0–1.4)	1.0 (0.9–1.2)	1.1 (0.8–1.4)	0.6 (0.4–0.9)
	Matz *et al.* [30] (UK)	Education	#	#,¶	#	NA
	Nafilyan *et al.* [31] (UK)	Teaching and educational professionals (male)	0.9 (0.7–1.2)	NA	NA	NA
		Teaching and educational professionals (female)	0.8 (0.7–1.1)	NA	NA	NA

Pale red: evidence of moderately elevated risks; green: evidence of reduced risks; blue: unclear whether risks are reduced or increased; yellow: varies by subgroup. COVID-19: coronavirus disease 2019; NA: not applicable; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2. #: relative effect estimates not reported; ¶: excess mortality when compared to previous 5 years but similar to nonessential workers.

Discussion

The majority of evidence relating to occupational differences in COVID-19 outcomes is limited to the first wave. Out of 16 studies in our review, only seven provided data relating to wave three onwards. In particular, only two studies looked at mortality outcomes after the first wave [29, 30], possibly due to low

TABLE 4 Effect estimates and evidence for the social care sector, grouped by outcome

Outcome	Study (country)	Subgroups	Wave one January–November 2020	Wave two December 2020–May 2021	Wave three June–November 2021	Wave four December 2021 onwards
SARS-CoV-2 infection	Airoldi *et al.* [15] (Italy)	Nursing home workers	#	NA	NA	NA
	Ballering *et al.* [24] (Netherlands)		NA	NA	NA	NA
	Beale *et al.* [16] (UK)	Social care	1.6 (1.3–1.9)		1.2 (0.9–1.5)	1.2 (1.0–1.4)
	Biarnés-Martínez *et al.* [25] (Spain)		NA	NA	NA	NA
	Bonde *et al.* [17] (Denmark)	Social work	1.0 (0.8–1.2)	1.3 (1.2–1.3)	1.2 (1.2–1.3)	1.4 (1.3–1.4)
		Residential care	3.1 (2.3–4.0)	1.3 (1.2–1.4)	0.7 (0.6–0.8)	1.0 (0.9–1.0)
	Green and Semple [18] (UK)	Social care	1.4 (1.2–1.7)		NA	NA
	Magnusson *et al.* [19] (Norway)	Childcare worker	0.9 (0.8–1.0)	1.3 (1.3–1.3)	NA	NA
	Nwaru *et al.* [20] (Sweden)		NA	NA	NA	NA
	Reuter *et al.* [21] (Germany)	Geriatric care	4.6 (2.0–9.0)	NA	NA	NA
		Education and social work	1.2 (0.8–2.0)	NA	NA	NA
	Rhodes *et al.* [22] (UK)	Social care	1.3 (1.2–1.4)		1.0 (0.9–1.0)	1.1 (1.0–1.1)
	Verbeeck *et al.* [23] (Belgium)	Residential care	#	NA	NA	NA
Hospitalisation for COVID-19	Bonde *et al.* [26] (Denmark)	Special teaching professionals	1.1 (0.8–1.6)			
		Nursing aides (institutions)	1.4 (1.1–1.9)			
		Homecare aides, private homes	1.2 (0.9–1.6)			
		Nursing aides (private homes)	1.7 (1.2–2.3)			
		Teachers/daycare assistants: 0–3 years	1.2 (0.9–1.8)			
		Teachers/daycare assistants: 4–7 years	1.6 (1.1–2.3)			
		Teachers/daycare assistants: 7–15 years	0.9 (0.4–2.1)			
		Nursing professionals	1.8 (1.2–2.8)			
		Family daycare workers	1.0 (0.6–1.7)			
		Social work and counselling professionals	0.9 (0.4–2.1)			
		Cleaners	1.4 (0.8–2.4)			
		Primary school teachers	1.1 (0.4–2.5)			
		Kitchen helpers	2.0 (0.7–5.6)			
		Physiotherapists	1.0 (0.4–2.5)			
	Mutambudzi *et al.* [27] (England)	Social care workers	2.13 (1.25–3.63)	NA	NA	NA
COVID-19 mortality	Billingsley *et al.* [28] (Sweden)	Care workers	0.74 (0.5–1.3)	NA	NA	NA
	Cherrie *et al.* [29] (UK)	Social care	1.6 (1.4–1.8)	1.5 (1.3–1.6)	1.2 (1.0–1.4)	1.3 (1.0–1.6)
	Matz *et al.* [30] (UK)	Social care	#	#	#	NA
	Nafilyan *et al.* [31] (UK)	Social care (male)	1.2 (1.0–1.5)	NA	NA	NA
		Social care (female)	1.2 (1.0–1.4)	NA	NA	NA

Pale red: evidence of moderately elevated risks; green: evidence of reduced risks; blue: unclear whether risks are reduced or increased; yellow: varies by subgroup. COVID-19: coronavirus disease 2019; NA: not applicable; SARS-CoV-2: severe acute respiratory syndrome coronavirus 2. #: relative effect estimates not reported.

TABLE 5 Conclusions relating to review aims and three occupations or sectors with highest elevation of risk

Study (country)	Authors' main conclusions	Three occupations/sectors reporting highest levels of risk (overall or seen during any time periods)
Airoldi *et al.* [15] (Italy)	Differences by occupation during the first wave, with elevated risk in logistics, weaving factories, nursing home workers and chemical industry	Logistics Weaving factory Nursing home
Ballering *et al.* [24] (Netherlands)	Among healthcare workers, males more likely than females to be diagnosed with or tested for COVID-19	Only healthcare and education included
Beale *et al.* [16] (UK)	Occupational differences vary with time	Primary school teachers Carers Nurses
Biarnés-Martínez *et al.* [25] (Spain)	Healthcare occupations most affected Less qualified workers also have high incidence	Auxiliary nurses Medical professionals Nursing professionals
Billingsley *et al.* [28] (Sweden)	Differences in COVID-19 mortality for workers related to traditional risk factors	Taxi and bus drivers Service sector Cleaners
Bonde *et al.* [26] (Denmark)	Employees in several occupations within and outside healthcare are at substantially increased risk of COVID-19 There is a need to revisit safety measures and precautions to mitigate viral transmission in the workplace during the current and forthcoming pandemics	Healthcare assistants Psychological therapists Bus and tram drivers
Bonde *et al.* [17] (Denmark)	Modestly elevated risks in numerous occupations	Food and related products machine operators Ambulance workers Athletes and sports players
Cherrie *et al.* [29] (UK)	Differences in odds of death from COVID-19 declined over time	Taxi and cab drivers Bus and coach drivers Medical support staff
Green and Semple [18] (UK)	Highest prevalence in hospitality sector, with high levels of infection for those employed in transport, social care, retail, healthcare and educational sectors Inequalities by work were not consistent over time	Social care Hospitality Healthcare
Magnusson *et al.* [19] (Norway)	Healthcare had higher odds of COVID-19 during the first wave than others of working age In the second wave, bartenders, waiters, food counter attendants, transport conductors, travel stewards, childcare workers, preschool and primary school teachers had high odds of infection Bus, tram and taxi drivers had an increased odds of infection in both waves	Nurses Physicians Dentists
Matz *et al.* [30] (UK)	Excess mortality for essential workers higher than nonessential workers Highest excess mortality in 2021 seen by social care workers	Social care Healthcare Other essential
Mutambudzi *et al.* [27] (2020) (England)	Found a seven-fold higher risk for healthcare workers and a two-fold higher risk for social care and transport workers, compared with nonessential workers	Healthcare professionals Medical support staff Health associate professionals
Nafilyan *et al.* [31] (UK)	Working conditions play a large role in COVID-19 mortality, especially in occupations with close contact	Taxi and cab drivers or chauffeurs Elementary occupations Care workers and home carers
Nwaru *et al.* [20] (Sweden)	Working in essential occupations associated with elevated infection risk, which was particularly marked in healthcare occupations	Healthcare workers Teachers Service sector workers
Reuter *et al.* [21] (Germany)	Higher infection risks seen in essential occupations and personal related services, especially healthcare Infections more common in higher status positions at the beginning of the pandemic	Geriatric care Medicine and dentistry Nursing, emergency services and obstetrics
Rhodes *et al.* [22] (UK)	Elevated risks for healthcare workers reduced over time but persistent high risks for education	Bus and coach drivers Police and protective services Education
Verbeeck *et al.* [23] (Belgium)	In the presence of sanitary protocols, many sectors with close contact with others saw considerably higher COVID-19 incidence than other sectors	Secondary education Activities of sports clubs Activities of football clubs

COVID-19: coronavirus disease 2019.

numbers of deaths precluding meaningful analysis. This restricts our understanding of what happened to differences between occupations in the latter part of the pandemic as restrictions were eased.

There is evidence from multiple studies that occupational differences were not static as the pandemic progressed. Four studies [16, 17, 22, 29] looked at longitudinal changes in COVID-19 outcomes, and each of these saw differences in the direction of effect at different time points, with the magnitudes of effects generally become less pronounced with time. This suggests perhaps that the role of occupation in the overall transmission rate became less important once mixing outside the workplace was allowed.

Several studies of theoretical occupational risks from COVID-19 identified high risks for the healthcare sector [12, 32]. While there is clear and consistent evidence of highly elevated risks for the healthcare sector in the very early part of the pandemic, these did not necessarily persist over time. In fact, some studies saw evidence of reduced risks of infection during the third and fourth wave although with a slight uptick by wave four in two of the studies. We can only speculate as to the reasons for this but protection from prior infections, rapid access to effective personal protective equipment and early access to vaccinations are all likely to have contributed to a reduction in risk compared to other workers [33].

There was little evidence of elevated risks in the education sector in the first wave of the pandemic when schools were largely closed. From the second wave onwards, there were persistent elevated infection risks based on evidence from both the UK and Denmark. Whether this translates to increased risks of severe outcomes is unclear, with none of the studies observing any elevation in risk of hospitalisation or death, although evidence was largely related to the first wave only. Furthermore, a UK study focussing on deaths amongst teachers in 2020 found that COVID-19 mortality for teachers was generally proportionate to their mortality from other causes with some weak evidence that risks for secondary school teachers were elevated only slightly [34]. These findings are consistent with a Scottish case–control study [35] which found elevated risks of infection for teachers once schools were open but no evidence of increased risks of severe COVID-19. A Swedish case–control study conducted largely in 2021 [36] did find elevated risk of both infection and severe COVID for a number of groups of workers in the education sector. A study of workplace contact patterns found a very high likelihood of intense space sharing for education workers [4], which is likely to explain elevated rates of infection.

There was inconsistency in results relating to the social care sector and this is perhaps due to variation in definitions of social care between countries, and variation by subgroup. While some workers in the social care sector have people-facing roles (*e.g.* care home staff, nursery workers) others are likely to have work remotely during the pandemic (*e.g.* social workers), and this mixture of occupational roles is likely to have diluted any overall effect. One study [26] which amalgamated hospitalisation data across all four waves saw elevated risks for nursing aids, and nursing professionals and some day care assistants but not for other subgroups.

The transport sector saw elevated risks of both infection and severe disease in some subgroups during the early part of the pandemic, particularly bus and tram drivers and taxi drivers. A study specifically looking at a cohort of public transport workers in Italy also saw elevated risks of SARS-CoV-2 infection for bus drivers but not other workers [37]. Again, this is a sector with a mixture of public-facing and nonpublic-facing roles. Bus, taxi and tram drivers are all likely to come into contact with a large number of members of the public in a nonventilated space, and they were perceived to have been particularly at risk before recommendations about ventilation and mask wearing came into practice [38, 39].

The food and drink industry received considerable focus during the pandemic [40], particularly after a number of large outbreaks in meat production facilities [41–43]. However, the evidence for increased risks in this sector from the epidemiological studies in this review is limited and concentrated only in the very early part of the pandemic. Definitions and groupings vary from study to study with both food production jobs and those in food retail showing some evidence of elevated risks either early in the pandemic or on average over the four waves.

Results seen in Europe are largely mirrored in the USA. One cohort study of infections [44] saw elevated risks for occupations relating to healthcare and protective services and another [45] saw highest risks for personal care and service workers, healthcare practitioners and support staff, and protective service workers. One study of mortality [46] saw highest proportionate mortality ratios for workers in community and social services, transportation and warehousing, healthcare and social assistance and administrative, support and waste services industries and another [47] saw highest rates of excess mortality and COVID-19 mortality in agriculture, transportation or logistics, manufacturing, facilities, and emergency sectors.

Our review revealed several less-studied occupational groups that may warrant further investigation. Interestingly, work relating to sporting activity was revealed as having highly elevated risks in two of our studies. While some sporting activity is outdoors, there are some factors relating to sports activities that could increase exposure to SARS-CoV-2 such as high humidity, shouting and deep breathing.

A heavy focus on the healthcare sector seen in this review was also identified by a large systematic review of 196 occupational seroprevalence studies [48] which found that over half of the prevalence estimates obtained related to healthcare studies. For major Standardised Occupational Classification (SOC) groups the review found that the highest median seroprevalence estimate was for "Personal Care and Service Occupations", although heterogeneity in terms of time of reporting and classification of occupation makes this result difficult to interpret.

While it is not possible to make conclusions about the extent to which changes in increased risk with time relate to improved primary prevention and/or acquired immunity it is clear that elevated risks persisted for longer in some sectors than others. It is important that when preparing for future outbreaks of airborne viruses that prevention strategies such as robust PPE and early vaccines target not only healthcare workers but other occupations at increased risk such as those in the education, social care and transport sectors. It is also important to monitor variation in relative risks over time to help reveal the impact of mitigation strategies and/or levels of natural immunity developed within each sector; more consistent and detailed approaches to this are recommended.

Although we filled in the Newcastle–Ottawa Scale for the included studies, it was felt that this scale did not fully capture the risk of bias relating to ascertainment of COVID-19 outcomes. Although most studies captured outcomes using either registry data or independent testing conducted by a third party, several of these outcomes would be at risk of bias due to testing strategies or propensity for testing related to occupation. Two studies [18, 22] are related to the same cohort which used regular PCR tests for all participants, regardless of symptoms or occupation and two studies used antibody tests [15, 16] (of a sub-cohort in one case). These would not be at risk of bias relating to testing strategies. Studies using "hospitalisation due to COVID-19" or "death from COVID-19" may be less prone to bias than studies of infection that largely rely on self-testing. However, there would be some subjectivity in attributing COVID-19 to be the cause of death or serious illness, particularly early in the pandemic when access to tests was not universal (*e.g. via* workplace tests for healthcare workers). Compensation claims for work-related COVID-19 were also likely and meant that there were financial implications relating to a COVID-19 diagnosis for those working in occupations perceived to be high risk. Note that serological studies address different biases in terms of detecting symptomatically atypical or asymptomatic infections, which may still be associated with transmission risk, so the inclusion of multiple outcomes is a strength of this review.

Most studies attempted to control for confounding by adjusting for age, ethnic group, socioeconomic factors and comorbidities. Two studies [24, 27] adjusted for work-related factors, such as shift work, social distancing and type of work, which may have been an over-adjustment when trying to capture the total elevation in risk related to working a particular occupation compared to a low-risk group. One study [49] took confounding into account by comparing excess mortality during the pandemic to a pre-pandemic period. This study also used all deaths rather than only those attributed to COVID-19 thus eliminating any bias in outcome ascertainment related to diagnosis. The fact that different studies with different methodologies and different inherent biases showed consistent results, particularly in the early part of the pandemic, strengthens conclusions to some extent.

Limitations

This review is reliant on published estimates of relative differences between occupational groups by time period. Different studies used different time periods and different occupational groups, which makes comparison difficult and potentially misleading. Combining different time periods or occupations into the same broad category can mask individual periods/occupations with high risks. Conversely, using categories that are too granular leads to low statistical power, as characterised by wide, uninformative confidence intervals seen in some studies.

All of the included studies were conducted in Western Europe and a high proportion (41%) were conducted in the UK. Results may not generalise to other parts of Europe.

Data extraction, assessment of bias and drawing of conclusions has been carried out by the authors of some of the original studies. We acknowledge that there is subjectivity in all of these processes that may have led to a biased interpretation. This review was conducted without a peer-reviewed protocol. Screening and data extraction were conducted by a single reviewer only with verification by a second reviewer for a sample of studies. It is difficult to make firm conclusions about which occupations and sectors have increased risks from COVID-19 or to quantify these increases. The review does, however, highlight the complexities of the topic and suggest directions for future research.

Conclusions

Evidence on occupational differences in COVID-19 outcomes in Europe largely concentrates on the early phases of the pandemic and analysis of longer-term outcomes is warranted. Occupational differences became less pronounced over time. Highly elevated risks in the healthcare sector were seen consistently in the early phase of the pandemic but did not appear to persist. Persistent elevation in risk of infection was observed widely for the education sector but it is unclear whether this led to an increase in severe illness and mortality. The social care sector experienced elevated levels of infection and severe disease for some subgroups that may have persisted for longer than other sectors. Transport and food production saw elevated risks of both infection and severe disease in the early part of the pandemic but there is little evidence that this continued to the later waves.

Questions for future research

- How did the risks of severe COVID-19 outcomes vary by occupation from the latter half of the pandemic onwards?
- Are there reasons why the education sector saw high levels of SARS-CoV-2 infection without excess risks of severe disease from COVID-19?

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