PROTECT Theme 1 COVID-OUT WP 2.4.5 (2022) National Core Study Report: A Systematic Review of Risk Factors for Workplace Outbreaks of COVID-19

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The PROTECT COVID-19 National Core Study on transmission and environment was a UK-wide research programme improving our understanding of how SARS-CoV-2 (the virus that causes COVID-19) is transmitted from person to person, and how this varies in different settings and environments. This improved understanding is enabling more effective measures to reduce transmission – saving lives and getting society back towards 'normal'.

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A Systematic Review of Risk Factors for Workplace Outbreaks of COVID-19.

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Contents

Abstract

The risk of SARS-CoV-2 infection has been strongly linked with occupation, particularly within the health, social care, and transportation sectors. Our aim was to identify the risk factors associated with transmission and infection of COVID-19 in the workplace. We examined peer-reviewed and pre-print literature between 1st January 2020 and 25th October 2021. Randomised controlled trials, cohort, cross-sectional observational studies, and systematic reviews were included. Grey literature, government reports and modelling studies were excluded. PubMed, Embase, evidence-based medicine reviews, Web of Science Core Collection, CINAHL, medRxiv and World Health Organisation's COVID-19 databases were used. 47 studies of COVID-19 workplace outbreaks in 15 countries were examined.

Healthcare-based workplaces, primary food production, offices and custodial settings were the most frequently described. High-risk exposure factors were high density workplaces, close working, low use of personal protective equipment, shared rest areas, night shift working, shared accommodation and multiple site working. Subcontractor workers, staff shortages, low indoor air temperature, and low outside air intake rates with more physically demanding indoor work increased risk of transmission. Mitigation measures included testing, ventilation use, mandated face covering use and social distancing. The review highlighted gaps in infection prevention and control and preparedness for emerging hazards in all sectors.

Key words: COVID-19. Outbreak. Work. Employment. Sector. Risk factor. Mitigation. Workplace. Occupation. Infection prevention and control

The review was registered on PROSPERO, an international database of prospectively registered systematic reviews, and the PROSPERO submission (PROSPERO unique ID = CRD42021293677can be accessed here: https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=293677

The PROTECT COVID-19 National Core Study led by the Health and Safety Executive (HSE)'s Chief Scientific Adviser, Professor Andrew Curran, and was delivered by more than 70 researchers from 16 institutions across the UK. The PROTECT study began in October 2020, as part of the COVID-19 National Core Studies programme funded by HM Treasury until March 2023.

This systematic review was undertaken by a group of researchers funded by the PROTECT COVID-19 study. The researchers were from the University of Manchester, HSE, and the London School of Hygiene and Tropical Medicine.

This work was supported by funding from the PROTECT COVID-19 National Core Study on transmission and environment, managed by the Health and Safety Executive on behalf of HM Government. The contents of this publication, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect UK Government or HSE policy.

Background

Since the early stages of the COVID-19 pandemic attention focused on occupational risks for infection with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a highly transmissible novel virus which spread rapidly and caused coronavirus disease 2019 (COVID-19) (Hu et al, 2021). The World Health Organisation (WHO) declared a pandemic in relation to COVID-19 on 11th March 2020 (WHO, 2020). The introduction of rapid, nationwide infection prevention and control measures for the pandemic was challenging. Knowledge of existing infection control measures for viral infectious disease such as influenza, SARS (severe acute respiratory syndrome) MERS (Middle East respiratory syndrome) and other coronaviruses was important, and dependent upon strategies that usually prioritised hand hygiene, cleaning environments, testing for the disease and vaccination programmes. Respiratory infectious disease control in clinical and care settings may not translate well to non-clinical settings such as schools, workplaces, leisure, and travel. National and regional lockdowns and associated mandated restrictions aimed to control the spread of COVID-19 within the community using existing infection control measures. Essential industries such as energy, healthcare, food industry and logistics sectors remained open. In the UK, these industries were supported in pandemic risk management by statutory authorities such as the Health and Safety Executive and the UK Health Security Agency, incorporating Public Health England.

Numerous outbreaks were reported in food manufacturing and processing plants, in particular meat processing and warehousing sectors, for example in the distribution of foodstuffs. Outbreaks in warehousing and distribution of non-food, leisure and retail activities were widely reported during the pandemic.

The risk of SARS-CoV-2 infection has been strongly linked with occupation. People who worked in health, social care and transport identified as being at higher risk of infection and of more severe infection (Mutambudzi et al, 2021). Reasons suggested for this included factors such as inability to maintain a social distance at work, poor ventilation, use of shared accommodation, equipment, and facilities. There is also evidence that a range of other factors linked to work such as shared transport to and at work had a role in the risk of infection. The ability of individuals to work from home and to isolate when necessary, and workplace policies (for example SARS-CoV-2 testing policies and sickness absence policies) also played a role in workplace transmission of SARS-CoV-2 (Marmot et al, 2020; Anand et al, 2021).

The lifting of national lockdown restrictions during the period from June 2020 to July 2021 saw heterogeneous surges in infections in many parts of the world, including the UK. Previously described ‘key worker’ and ‘essential worker’ sectors continued to be affected during this time period. From December 2020 onwards many countries, including the UK began a roll out of a SARS-CoV-2 vaccination programme for protection against severe COVID-19 infection.

Risk factors for severe respiratory infectious disease in adults are well documented for seasonal influenza, particularly the 2009 H1N1 pandemic (Kang, et al 2016; Walsh et al, 2004). Individuals with chronic medical conditions, and notably cardiovascular and pulmonary disease and pregnancy are more likely to be severely affected by respiratory infection and per se SARS-CoV-2 infection. Due to levels of exposure, HCWs more at risk of SARS-CoV-2 infection. Respiratory infections and associated complications have a significant social and economic impact, particularly in high-risk individuals. We are yet to understand and realise the impact of long-term sickness absence and potential chronic co-morbidities from post-COVID syndrome (long COVID) and the impact of enduring prevalence both in the community and on workplaces (Lewis et al, 2022).

Since 2020 the body of knowledge and understanding of SARS-CoV-2 transmission has grown. This systematic review of the scientific literature examined workplace outbreaks of COVID-19 to identify risk factors for transmission and infection of COVID-19. The review considered environmental, organisational, behavioural, and demographic factors and how these factors might prevent and mitigate workplace outbreaks.

Methods

A review protocol was pre-published on PROSPERO: the PROSPERO submission (PROSPERO unique ID = CRD42021293677can be accessed here: https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=293677. The reporting of this review adheres to the standards for the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page et al, 2020)).

Search strategies used terms and associated words for 'workplace' and 'outbreaks', joined by the AND function. The database searches included randomised control trials, cohort studies, observational studies, and systematic reviews. The search strategy was modified for each specific database due to differences in MeSH terms and Boolean operators. Database searches were limited to articles where the full text was written and/or available in English in peer-reviewed and pre-print literature between 1st January 2020 and 25th October 2021. The database searches excluded grey literature, government reports and modelling studies.

The following databases were searched: PubMed, relevant Ovid databases including Embase and evidence-based medicine (EBM) reviews, Web of Science Core Collection, CINAHL and medRxiv, to identify pre-prints plus studies listed on these sites on the World Health Organisation's Covid-19 global research database (https://search.bvsalud.org/global-literature-on-novel-coronavirus-2019-ncov/) were searched using the search terms, limited to title/abstract (Table 1). Relevant studies cited in a UK SAGE (Scientific Advisory Group for Emergencies) report on COVID-19 risk by occupation and workplace (www.gov.uk, 2021a), UK Industrial Injuries Advisory Council Report (www.gov.uk, 2021b) reviewing the available evidence concerning the risks of contracting COVID-19 in occupational settings, and studies collected in a repository of research relating to COVID-19 and occupation by researchers working on the PROTECT project are included.

Table 1: Search terms used in the review

occupation	work	job	employment	sector	industry
labour	labor	health care	residential care	nursing home	factory/factories
occupational health	manufacturing /food manufacturing /processing	prison	social care	office	warehouse
workplace culture	workplace policies	absenteeism	presenteeism	plant	health care
AND					
COVID-19	coronavirus	SARS-COV-2	nCoV		
AND					
outbreak	surveillance	assessment	observational		

All articles yielded from the database searches were exported into Covidence between October 2021 and March 2022 (https://www.covidence.org/). The title and abstracts of papers identified by the database searches were screened on Covidence by two independent reviewers using pre-defined inclusion and exclusion criteria. Where title/abstract screening did not provide enough information to decide on inclusion, the full text was reviewed by two reviewers. Conflicts were resolved on a regular basis by consensus between two reviewers in the research team.

Two reviewers independently screened full text articles of the included studies based on the inclusion and exclusion criteria. Again, conflicts were resolved by consensus. Information extracted included date of publication, research location and setting, study design, outcome measurements and results on the potential transmission risk factors. At least one researcher extracted this data, checked by a second researcher.

Inclusion criteria

Inclusion criteria	
Studies of workplace COVID-19 outbreaks, published or translated into English in the peer-reviewed and pre-print literature between 1st January 2020 and 25th October 2021, were included along with the following criteria.	
Population	
	Any population that included workplaces in any country
Exposure Risk Factors, which might include	
	Factors included ability to maintain a social distance at work, and the role of ventilation, hygiene measures, PPE and shared facilities and equipment;
	Workplace policies included flexible working (including ability to work from home, flexible working hours), COVID-19 testing policies, vaccination policies, sickness absence policies;
	Characteristics of the workplace and workplace culture;
	Work-related factors included commuting and car sharing, and contact with colleagues outside work including shared accommodation

	Demographic factors included age, gender, ethnicity, household income, job role, vaccine status underlying health conditions and ability of individuals to isolate when necessary
Outcome:	
The definition of a workplace outbreak was based on the UK government definition of an outbreak:	
	Two or more test-confirmed cases of COVID-19 among individuals associated with a specific non-residential setting with illness onset dates within 14 days, and one of:
	Identified direct exposure between at least 2 of the test-confirmed cases in that setting (for example under one metre face to face, or spending more than 15 minutes within 2 metres) during the infectious period of one of the cases;
	Where there was no sustained local community transmission - absence of an alternative source of infection outside the setting for the initially identified cases (UKHSA, 2021).
Type of study:	
	Study based on observational data suitable to answer our research questions.
Exclusion criteria	
Purely modelling studies and articles where the full text was not written in English were excluded	
Studies focussing on household transmission and risks to families from health care workers and studies focussing on people other than workers or employees - including customers, residents, patients, prisoners, school pupils and students - within workplaces, were excluded	
Studies where it was not possible to examine risk factors for staff separately to risk factors for these other groups were excluded.	
Numbers and types of excluded studies:	
• studies that did not examine outbreaks (102), • did not focus on workplaces (25), • focussed on other populations such as patients or residents rather than on workers (32), • did not examine risk factors for workplace outbreaks (35). • where full text was not available (14) • or not available in English (5), • did not focus on COVID-19 (7) • or were identified as non-peer-reviewed (except for pre-print papers, which were included) and therefore excluded from the review (3).	

Strategy for data extraction and synthesis.

The Cochrane Handbook and Synthesis Without Meta-Analysis (SWiM) reporting guidelines were followed for the included studies. The SWiM guideline is a checklist to promote transparent reporting for reviews of interventions that use alternative methods of synthesis to meta-analysis of effect estimates, methods often described as "narrative synthesis" (Campbell et al, 2018). We used occupational setting, study design, geographical location, population, sample size, outcomes, and the potential transmission risk factors as categories for the narrative synthesis.

Data extraction

The included studies were assessed for data extraction by both title/abstract and full-text screening. A data extraction master (DEM) table recorded information using data fields detailed below in (a) to (j). Data were extracted by one researcher and reviewed by a second researcher. Conflicts reflected discrepancies over inclusion criteria and were resolved by consensus, sometimes involving a third reviewer. Each of the 47 articles was evaluated and data extracted on:

(a) study characteristics including study period, aim of study, sector and study population is described in the summary of study characteristics table in appendix 2.

(b) outbreak confirmation, identification, and duration

(c) baseline characteristics of the workforce such as age, gender, ethnicity, contract and work pattern

(d) qualitative assessment of risk factors such as workplace testing, sector, community prevalence

(e) quantitative assessment, for example number of workers in job role, number of workers screened, disease incidence, hospitalisations, measure of effect

(f) workplace interventions prior to outbreak, following outbreak and ongoing

(g) Standard Industrial Classification (SIC) UK code used (ONS, 2007, 2020 addendum)

(h) workforce behaviours in relation to controls such as social distancing, shared areas, use of PPE, out of work mixing

(i) organisational characteristics including testing regime, shifts and working patterns, management characteristics and engagement with OSH (Occupational Safety and Health) controls

(j) management of the workplace environment such as ventilation, managing shared commuting, workplace facilities and accommodation

The included studies had high heterogeneity within sectors and between studies representing different sectors which experienced COVID-19 outbreaks during the review period. Most outbreak investigations took place in 2020 when societal restrictions were in place, and this is reflected in many of the workplace settings being essential services and industries that were kept operating. Settings included healthcare-based workplaces – hospitals and health care centres (14) and long-term care facilities (LTCF) such as nursing and residential care (13) accounting for over half the studies. Primary food production workplaces included meat and poultry processing (8), including slaughterhouses, de-boning and cutting plants, and seafood processing. Settings also included offices (4) prisons and custodial judicial settings (2), a firefighter station/firehouse, an agricultural grower, a naval ship, an airport, and a school.

Many studies were descriptive, and the extracted information was limited to SARS-CoV-2 positivity rate or COVID-19 infection, with a description of intervention measures adopted to prevent and control the outbreaks. Fewer studies explicitly provided case definitions, referred to attack rates or incidence rates, or investigated individual and workplace risk factors associated with the outbreak.

Quality of included studies

Systematic reviews with combined qualitative and quantitative methods have several characteristics that require varied categories of quality assessment. The Mixed Methods Appraisal Tool (MMAT) was developed in 2006, revised in 2011 and further developed in 2018 (Hong et al, 2018). MMAT is a critical appraisal tool used in systematic mixed studies reviews using a criteria-based approach with five categories of study design: qualitative, quantitative randomised controlled, quantitative non-randomised, quantitative descriptive, and mixed methods. There are various approaches which involve the use of a scoring system for quality. We used the 2018 version of the MMAT (Hong et al, 2018 and MMAT, 2022) to assess the quality of the 47 studies included in this review.

Two authors independently reviewed each article for inclusion and examined the article using the MMAT to assess the quality of included studies. In this systematic review, the mixture of methods is between studies rather than within studies. Each study was assigned a summative score out of five, based on the number of criteria met, as in Piat (2021) and Edwards (2021) (Table 2). As suggested in MMAT write-up guidance (MMAT, 2020), scores were accompanied by descriptive text, to paint a much more informative picture, allowing an insight into which aspects of the studies are problematic. We reviewed how investigators established which risk factors would be examined, for example, if this was hypothesized, if it was based on government guidelines or on expert opinions, on observations such as onsite safety surveillance or worker interviews, or on learning from prior outbreaks such as the MERS outbreak. We included columns in the Data Extraction Master (DEM) document for each of the qualitative risk factors, although the way in which investigators established which risk factors would be examined was not stated for many studies examining individual risk factors. No articles were excluded using the MMAT.

Results

21,484 references were imported for screening and 8,329 duplicates were removed. 13,155 studies were screened against title and abstract, and 12,881 studies were excluded. 272 studies were assessed for full-text eligibility, and 225 of these were excluded (Figure 1).

Forty-nine studies met the inclusion criteria, with two duplicates identified during the data extraction process. The review yielded 47 studies of COVID-19 outbreaks in workplaces in 15 countries. 39/47 studies were carried out in 2020. 5/47 were carried out in 2021. Three outbreaks did not record the study period or date of the outbreak. Twenty-five of the 47 workplace studies examined outbreaks in workplaces with more than 250 employees. Thirteen of the 47 studies examined workplaces with fewer than 250 employees and nine of the 47 studies examined workplaces with fewer than 50 employees.

A complete list of included studies and the study characteristics is provided in Appendix 1.

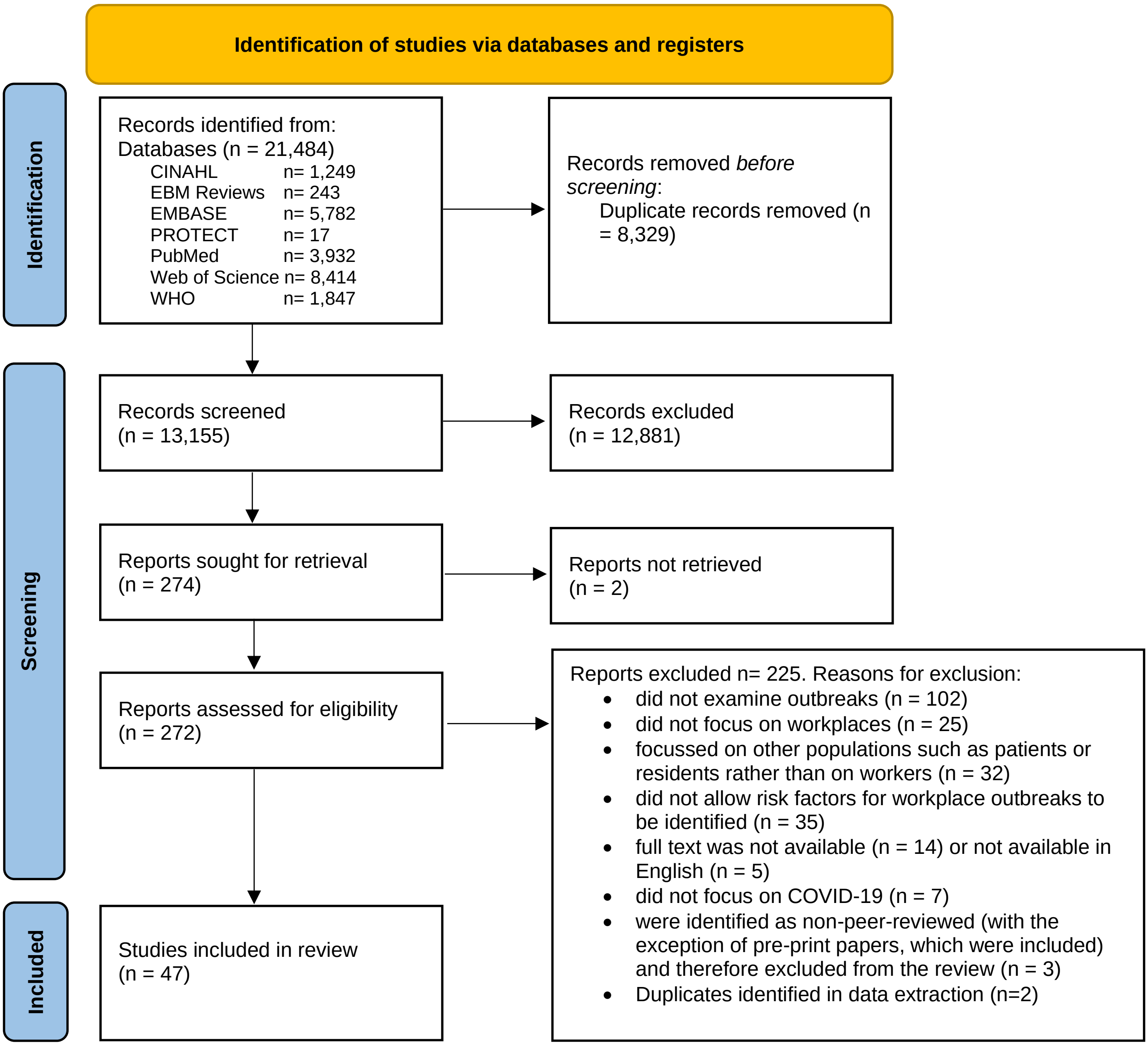
Of the 47 included publications, 13 studies were conducted in the USA, four in Germany, four in Italy, four in France and China, three in Canada, two in Singapore and two in the UK, with one study each in South Korea, Switzerland, Turkey, Israel, Denmark, Austria and Netherlands. One study did not report the country of origin. All the studies investigated

COVID-19 outbreaks associated with workplaces or occupation, and represented qualitative, quantitative non-randomised and quantitative descriptive methods.

The tools used to diagnose COVID-19 outcome were laboratory specimen reverse transcription polymerase chain reaction (RT-PCR), and whole genome sequencing (WGS) antibody and antigen testing, from workers (17); public health surveillance incorporating local, regional, and national testing and reporting networks including social network analyses (9); company surveillance and screening of employees, such as interviewing workers, questionnaires, and workplace risk assessment outcomes (20); One study did not record the tools used.

Risk factors for workplace outbreaks were assessed on how they could be prevented or mitigated based on measures that were reported to have been used. For example, social distancing at work, environmental adjustments such as improving ventilation or adding physical barriers, use of personal protective equipment (PPE), symptomatic or asymptomatic testing, vaccination and workplace training and education. The tools used to assess this outcome were interviews (12), company and workplace surveillance records (11), workplace environment risk assessment, employee medical records, and self-administered questionnaires (9), national surveillance databases, infection control department data (4), observations (2), other health data analysis, unclear tools and methods, or not recorded (9).

Figure 1 PRISMA flow chart



*Number of records identified from each database by time period (21,484 total):

CINAHL 1/1/21-25/10/21: n = 1,249	EBM Reviews 1/1/21-25/10/21: n= 243	EMBASE 1/1/21-25/10/21: n=5,782	PROTECT 1/1/21-25/10/21: n= 17
PubMed 1/1/21-25/10/21: n= 3,932	Web of Science 1/1/21-25/10/21: n= 8,414	WHO 1/1/21-25/10/21: n= 1,847	

Template from: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Quality appraisal findings

Two-thirds (66.0%, 31) of the studies were of high quality (i.e., MMAT summative score 80% or above), 14.9% (7) were of moderate quality (i.e., summative score between 60% and 79%) and 19.1% (9) were of low quality (i.e., summative score of less than 60%). See tables 2 and 3.

Table 2 Quality assessment scores for included studies

Score (% of quality criteria met)	number of studies	%
0/5 (0%)	1	2.1%
1/5 (20%) 1*	4	8.5%
2/5 (40%) 2*	4	8.5%
3/5 (60%) 3*	7	14.9%
4/5 (80%) 4*	13	27.7%
5/5 (100%) 5*	18	38.3%
total	**47**	**100.0%**

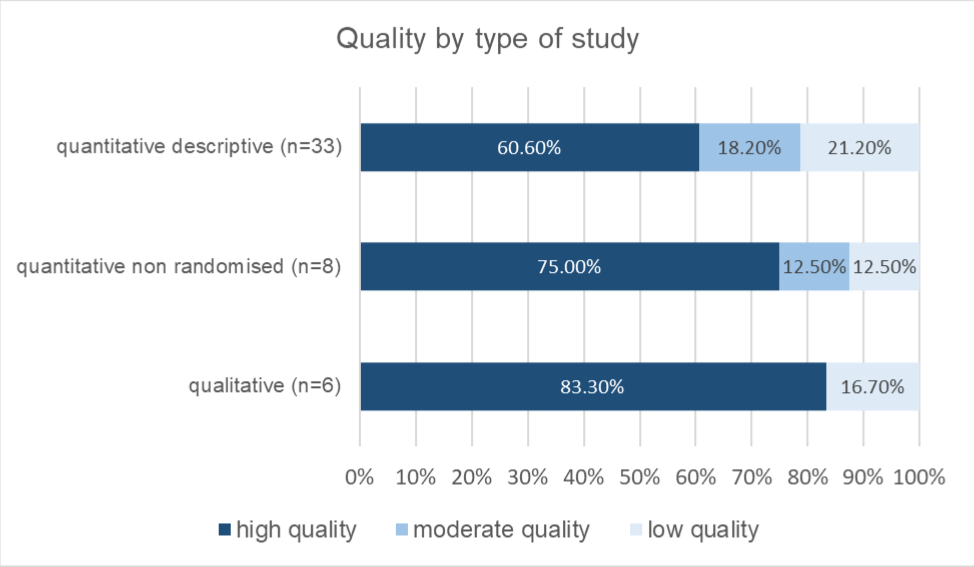
Table 3 Numbers in each quality category

	number of studies	%
High quality (4* or 5*; 80% or above)	31	66.0%
Moderate quality (3*; btw 60% and 79%)	7	14.9%
Low quality (0*, 1* or 2*; less than 60%)	9	19.1%
total	**47**	**100.0%**

Six studies were purely qualitative. Five of these studies were high quality (83.3%), consisting of interviews, with four fulfilling all five quality criteria on the MMAT (Gold et al 2021, Sarti et al 2021, Weissberg et al 2020, and Yau et al 2021) (Figure 2). One study was low quality, fulfilling only one quality criteria (Poupin et al, 2021). This study whilst an outbreak investigation did not evaluate the measures in place against the cases identified before or after measures were implemented.

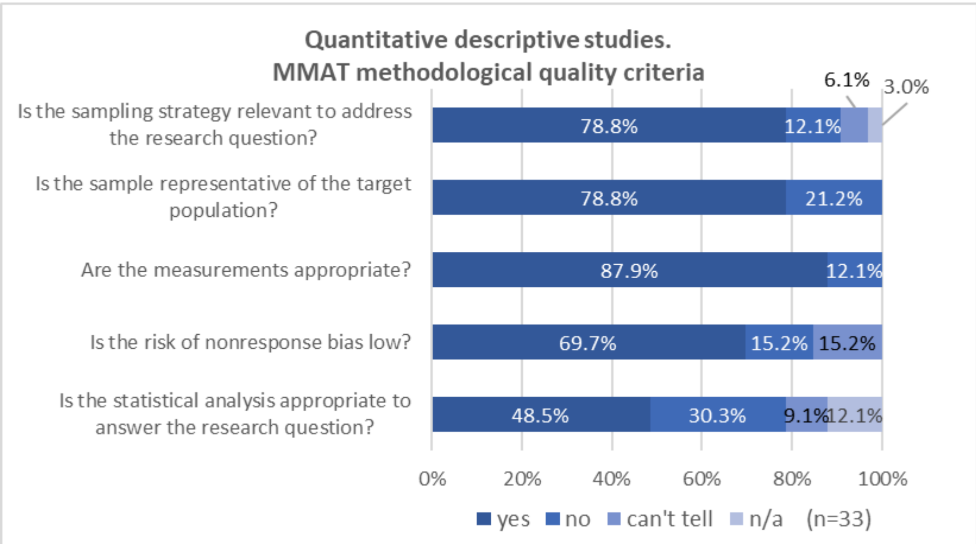
Of the eight quantitative non-randomised studies, 75% (6) were high quality, with one moderate and one low quality. The studies by Goldenfeld et al 2021 and Krone et al 2020 fulfilled all five MMAT quality criteria. The study with a low-quality score was more of an observation of an outbreak and its interventions, without clear research questions (Ariza-Heredia et al, 2021).

Figure 2 MMAT quality rating by type of study



Of the 33 quantitative descriptive studies, 60.6% (20) were high quality, 18.2% (6) were moderate quality and 21.2% (7) were low quality. 12 studies fulfilled all five quality criteria (Giuliani et al 2021, Kasper et al 2020, Liu et al 2021, Mallet et al 2021, Murti et al 2021a Noel et al 2021, Park et al 2020, Steinberg et al 2020, Venkatachalam et al 2021, Waltenburg et al 2020, Wang et al 2020 and Wee et al 2020). Most of the quantitative descriptive studies used appropriate measurements, with representative samples and relevant sampling strategies (Figure 3). Poorly described statistical analysis appropriate to answer the research question, together with a lack of clarity in the risk of non-response bias, most impacted the quality assessment of the low quality studies.

Figure 3 MMAT Quantitative Descriptive Study Quality Criteria



All the included studies were independently quality assessed by two researchers. There were limitations in categorising articles due to ambiguity of study design, where clear and quantifiable study aims were not always identifiable. There were examples of unclear methodologies and outcome assessment tools. Acquiring information and knowledge about COVID-19 was a priority and this may be reflected in lower methodological quality of some outbreak investigations during this period.

Outbreak setting

Healthcare settings: hospitals, clinics, and long-term care facilities (LTCF)

SIC 86101, 86102,86220,87100,87200,87300,87900

27 studies investigated outbreaks in healthcare settings, variously described as hospitals, health clinics and long-term care facilities [1 2 3 4 6 8 12 14 16 17 19 20 21 23 27 28 29 32 33 36 38 39 41 42 43 45 47]. Outbreak cases were identified by workplace testing and laboratory confirmation [19 20 21 23 26 27 32 36 38 39 41 42 43], contact tracing and screening [1 2 4 8 12 14 16 17 27 28 29 33 47], public health information systems and reporting networks [3 27], and self-reporting [12 33]. This was unclear or not mentioned in four studies [6 12 23 32]. In all articles study participants were 18 years old and above. High heterogeneity across this sector related to the approaches of identification of infection, outbreak confirmation and assessment of workplace risk factors. There was missing information across most of the studies on the baseline characteristics of the workers – mean age of participants, mean or median age of workers involved in the outbreak is not included in many of the studies. Gender and ethnicity, socio-economic data, education status and employment contract status were mostly not recorded.

Outbreak risk factors for COVID-19 among HCWs included job roles where staff had frequent contact with infected patients and items such as infected bedding [3 8 12 16 17 20 23 26 27] and patients not complying with infection prevention and control (IPC) measures[33]. Rovers et al[33] concluded that 'extra attention for psychiatric departments is necessary during a pandemic' due to the lack of patient compliance with IPC measures, along with psychiatric HCWs being generally 'less familiar with outbreak management' (during the study period 13th March 2020 to 14th April 2020). Other factors included long shifts, night shift work [21 41 45], staff shortages [3 45], and lack of sickness pay arrangements to prevent presenteeism [22 40]. Workplace risk factors and risk factors in the job role were not consistently recorded across the studies, with just one study recording the contractual basis for employment [20]. The details of the studies, including setting, population, measures of outcome and intervention, and the duration of outbreak are described in the Summary of Study Characteristics Table, Appendix 2.

During the study period 31st March 2020 to 4th April 2020, Asad et al [3] described a cluster of COVID-19 in a hospital in the early phases of the epidemic, when UK lockdown was in place. Clinical surveillance software was used to identify staff cases epidemiologically linked to the cluster and this was documented in a case series report. SARS-CoV-2 PCR testing of symptomatic patients and asymptomatic HCWs was undertaken. Twelve days after onset from the index case, 17 staff from the ward/unit were symptomatic and isolating at home. In the workplace, personal protective equipment, (for example eye protection and surgical masks) was not in routine use in accordance with government guidelines at the time, which was especially significant during routine close contact patient care. It was difficult to maintain social distancing as the hospital environment was crowded; it was common to work in close contact with staff on the ward, and to be in close contact during breaks in crowded break areas. There was a lack of universally available PPE. Staff shortages and rigid management systems were barriers to some mitigations such as quarantine, testing of pre-symptomatic staff and reporting of symptoms. Hand hygiene compliance was high. Implementation of infection control committees mandated the outbreak interventions but did not prevent 23 out of 29 staff on the ward developing COVID-19 over a 14-day period. Although Asad et al[3] do not explicitly state the research question, there is a clear objective to identify the transmission routes and source of infection of the outbreak. However, it is unclear which data collection tools were used to assess risk factors in this study.

Celebi et al [8] reported infection rates of 8.3% in HCWs in COVID-19 units and 3.4% among HCWs in non-COVID-19 units (RR=2.45 CI=1.06-5.65, P=.027) during the study period 20th March 2020 to 20th May 2020. Environmental service personnel (ESP) such as cleaners had a higher positivity rate than HCWs and medical doctors. Control measures included mandated use of surgical face coverings, ventilation of rest rooms, food not to be consumed in break rooms, and further training on infection control. The study did not explain how long this intervention lasted. The supportive intervention was the screening (by RT-PCR) of workers. The authors carried out interviews with HCWs and found that inappropriate use of PPE whilst caring for patients with COVID-19 and staying in the same rest room as other HCWs without wearing a face covering were significant risk factors for COVID-19 transmission to HCWs. Household contact with a COVID-19 case was also a risk factor. We argue that early in the pandemic this was a lower risk than later in the pandemic where there was increased community prevalence and many pandemic control restrictions had been lifted.

A study of laundry workers by Goldenfeld et al[12] assessed routes of transmission in 49 hospital laundry workers during the period 20th July 2020 to 4th August 2020. 12/49 laundry workers handled dirty laundry, transporting sorting and sanitising laundry from COVID-19 patients. 11/49 laundry workers were infected ([AR (Attack Rate)] 22%). Workplace risk factors were improper use of personal and protective equipment (PPE) and face coverings, lack of social distancing and engaging in shared commuting and shared social spaces in the workplace. Primary interventions were screening using PCR tests of HCWs who exhibited symptoms associated with COVID-19 or had been in contact with others with suspected or confirmed COVID-19, along with wearing of face coverings and assessing activities and workflow. Workers were banned from shared commuting, eating, and smoking together.

Kabesch et al [18] investigated an outbreak in a maternity and prenatal unit in Germany where 9/10 workers were infected (study period 9th March 2020 to 5th April 2020). Size and density of break rooms and eating halls, proximity to colleagues and patients, and low community prevalence at the time were discussed. The source of the outbreak is unclear but occurring in March 2020 the authors referred to an infected worker visiting a high prevalence ski resort that became an epicentre of infection. Mitigations were testing and contact tracing, mandatory face coverings, break room social distancing and exclusions from work of infected personnel from entering the workplace - sickness and quarantine were described as well-managed with frequent hygiene audits and staff training for behaviour change to encourage maximum compliance with mitigations during the 21-day outbreak period. Staff members who had close contact with infected colleagues were closely monitored for symptoms and tested regularly whilst continuing to work, but there was no measurement or assessment of these interventions.

A skilled nursing facility in the USA had several outbreaks over a 2-month period between March and May 2020. Karmarkar et al[17] reported that job role, close contact with other staff members, failure to implement IPC and community prevalence were risk factors. Reasons for the outbreak included insufficient testing strategies, lack of PPE, not wearing facemasks and inability to maintain social distancing. This study described reporting of symptoms being less likely where there were restrictions on working in other facilities. Mitigations and control measures were regular monitoring and observation of staff symptoms and practice against IPC policy requirements. Workplace factors associated with a low risk of exposure were IPC measures, including on-site public health assistance, universal use of face masks by staff for source control and viral containment[4], use of recommended PPE for all resident care units, regular monitoring of IPC practices, and self-quarantine for close staff contacts of COVID-19 cases.

A large outbreak in a nursing home was reported by Krone et al[19] which lasted 58 days (AR 27%). Risk factors were proximity to patients and high community prevalence (study period 8th March 2020 to 4th May 2020). General screening using reverse transcription PCR (RT-PCR) for SARS-CoV-2 was introduced. A lack of PPE use, minimal IPC trained staff, lack of mask wearing, and inability to maintain social distancing were workplace risk factors. Patient compliance with IPC measures were also a factor. This studied briefly reflected upon symptomatic, positive staff feeling obliged to work. It referred to the provision of incentives for working in a single care home though this was not discussed.

Within the nursing care home sector Ladhani et al[20] described an increased risk of infection for staff working across different care homes in a quantitative cross-sectional study in the UK carried out between 10th April 2020 and13th April 2020. Workplace risk factors included staff with jobs that involved working across the six care homes in the group and a high community prevalence of COVID-19. IPC interventions had been implemented before the outbreak including closure to visitors or new residents, and self-isolation of symptomatic staff. 15-18% of staff working in a single care home were infected during a period of 17.5% community sero-prevalence. SARS-CoV-2 positivity was 15% (2/13), 16% (7/45) and 18% (30/169) among staff working in a single care home who respectively reported no, occasional, and regular contact with residents. SARS-CoV-2 positivity was 47% (7/15) among permanent staff who had regular contact with residents and occasionally worked across different care homes, whilst 58% (7/12) among staff with regular resident contact who frequently worked across different care homes. Clusters involved staff only, some working across different homes and among staff reporting minimal contact with residents. Bank, agency, and casual staff were recorded but it is unclear what percentage of the workforce have this type of contract. This study reported a 3-fold increase in risk if staff worked across multiple care homes rather than a single care home. Genomic sequencing identified staff only clusters which supports staff to staff transmission. Interventions to control and prevent future outbreaks included a call to limit working across multiple care homes, increased screening, and reporting.

Loconsole et al [23] examined an outbreak in a hospital setting among three healthcare workers working in the same shift on February 21st, 2021. Individual risk factors were proximity to infected colleague as whole-genome sequencing (WGS) confirmed all strains were VOC202012/01-lineage B1.1.7. Two were vaccinated, one refused vaccination. The study did not explore the health implication of a non-vaccinated healthcare worker beyond the need for improved PPE nor is it clear if the index case was vaccinated or non-vaccinated.

Noel et al[28] screened HCWs for SARS-CoV-2 between March and April 2020 using a RT-PCR test when they presented to an occupational physician with symptoms, and if they were contact cases. HCWs presenting with anxiety about infection were also tested. There were 5,704 HCWs in the setting, of whom 1714 (30%; 1,714/5,704) were tested. 8% were positive for SARS-CoV-2 with 24.3% of positive cases being asymptomatic. Lower rates of positivity were found in the COVID-19 unit compared to the non-COVID-19, due to greater PPE provision and stricter controls in the COVID-19 unit. HCW's aged 50 years and above were less likely to test positive (3.8%) than younger HCWs (9.1%) ($p<0.001$). This work did not explore if the increased positivity rate was because of occupational or community transmission. Clinical examination and the use of nebuliser therapy was described as a risk factor and working in non-COVID-19 units did not increase the risk of infection. HCWs testing positive for SARS-CoV-2 were also working in non-COVID units. Awareness of infection prevention and control measures in the acute and intensive units, with increased training and being better informed made HCWs more aware of the risks and the need for controls. For all the IPC patient-centred controls, this study identified break times as a risk factor for contamination, as per Çelebi et al[8]. Similarly, respiratory transmission of other pathogens during break times was discussed by Gehanno et al (1999) and Pascual et al (2006).

Venkatachalam et al[39] reported on a sentinel surveillance strategy of healthcare workers in Singapore between January 2020 and March 2020 to test the efficacy of infection prevention measures early in the pandemic. Mitigations were fever areas, single rooms, cohort rooms with social distancing, patients wearing surgical masks, use of appropriate ventilation systems and PPE to be supplied and worn.

Wei et al[43] described an outbreak among HCWs where the index case was a physician treating a patient in Wuhan. There were no data on the timelines and the date of the outbreak. 14 HCWs were infected but it is unclear if this was from the index case as the article implies this was a 'super spreader' event or caused further person to person transmission however there was no discussion of risk factors or mitigations.

Zollner et al[47] (study period 22nd March 2020 to 14th April 2020) and Murti et al[27] (study period March 2020 to April 2020) reported on a first wave outbreak in a long-term care facility (LTCF), with a focus on implementation of outbreak measures, mitigations, and controls. Segregation, isolation, and PPE controls were put in place and credited for ending the outbreak. These measures were not evaluated because of the delay in recognition of symptoms/positive cases due to mild or atypical symptoms presenting early in the pandemic which contributed to disease transmission in LTCF's.

Yau et al[45] reflected on organisational characteristics for night working staff in a long-term care facility, describing staff not being provided with the same support and training as daytime staff and often limited staffing overnight. This study described management characteristics as top-down with a 'punitive management style' and recorded communication breakdowns and poor adherence to protocols from staff. These factors were barriers to some mitigations such as quarantine and the testing and reporting of symptoms. Sleep quality and performance was investigated by Wang et al[41] using the Pittsburgh Sleep Quality Index test and found that HCWs had high scores relating to poor sleep time and quality. The authors described how tiredness, stress and lack of sleep could increase HCWs risk of COVID-19 infection. Stress related to nursing profession and work, and factors associated with workload management and interpersonal relations were significantly higher in infected than uninfected nurses.

Meat poultry and seafood processing plants: SIC 10110, 10120, 10130,10200

Between 1st March 2020 and 30th April 2020, Castro et al[7] investigated a large rural poultry processing plant in the US which employed 500 workers per shift. The investigation was in conjunction with a Federal Qualified Health Centre to understand infection rates in poultry meat plant employees and their contacts. Workplace factors associated with a high risk of exposure to SARS-CoV-2 included crowding, poor ventilation, long shifts, and limited worker protection. 270/758 workers screened were positive. Study findings reflected upon ethnicity, with a higher proportion of Hispanic workers in cases compared to total tested ($p <.001$). Household size was significant for community transmission, with a higher proportion of cases who reported living in a household of <5 persons ($p = 0.02$). The study characterised a socioeconomically vulnerable workforce, comprised of racial/ethnic minorities, Spanish speaking, uninsured for healthcare cover, living in poverty, and often without recognised citizenship. This study described limited adherence to mandatory mask wearing and physical distancing but the reasons for this were not explored. Some workers continued to work despite active upper respiratory symptoms. Mitigations included additionally funded health centre outreach activities, with a mass testing event for workers, their families and other household contacts to increase testing rates. The study described the good relationships between health centres, local industry, and other stakeholders (hospitals and county health department) as key to controlling the outbreak. Health centre staff knowledge and awareness of risk factors (crowding in the workplace, long shifts etc.) and knowledge of the community and vulnerable sub-groups (Hispanic workers with high prevalence of chronic conditions and reduced access to health care) were key factors in the early identification and response to the outbreak.

Gunther et al[13] reported an outbreak in a meat processing plant in Germany, May to June 2020. Workplace factors associated with an elevated risk of exposure were a combination of low temperature, low fresh air exchange rates, recirculated cooled, unfiltered air and increased respiratory rates in employees due to demanding physical work in the meat processing plant. These factors may have promoted longer distance airborne transmission. Difficulty maintaining or working to social distancing within these areas along with the described low temperature, low fresh air exchange rates and recirculated air were variously explored as risk factors. Although transmission outside the factory from shared accommodation and commuting was considered for some cases, transmission was most likely to have occurred on the meat processing line at more than two metre distances from the asymptomatic primary case.

Hou et al[15] reported on a poultry processing plant in China during the period January-February 2021. Environmental risk factors for transmission were sharing a dressing room and other confined spaces at work. Using commuter transport to work was described as a risk factor. It was not clear why the AR was higher in the night shift workforce (AR 48.3% *vs* 8.2%, $p<0.001$); general workforce AR10%. Based on attack rate the workplace factor for high risk of exposure was night shift work. The night-shift exposure infection odds ratio (OR) was 10.51 (95%CI: 5.90–18.71).

An assessment of associations between workers' socio-demographic and occupational characteristics and risk of SARS-CoV-2 infection in a French meat processing plant outbreak was carried out in May 2020 by Mallet et al[25]. An outbreak cluster occurred in the pork processing section. 1,179 workers who worked in pork processing were tested (87.5% of the 1,347 workers were screened), surveyed, interviewed and employee records were evaluated. 140 occupational cases were identified, 80.7% (113) of these were identified by a positive reverse transcription polymerase chain reaction (RT-PCR) test in a screening campaign and the remaining 19.3 % (27) of the cases were identified through hospital or outpatient sampling. All worked in the same pork-cutting workshop. The AR was 11.9% in the company, rising to 16.6% in the cutting department. Health authorities were aware of the presence of many non-French speaking workers who were difficult to investigate through contact-tracing. Foreign-born workers were reported as accounting for half of the cases involved in the outbreak (52.1%) compared to a quarter (25.4%) of non-cases. Of the cases, 45.0% were Eastern European workers and 47.1% were non-French speakers. Deboning and cutting workers had RR 3.68 (2.41-5.64) compared to other workers outside the deboning and cutting department; of the Eastern European cases, 95.2% worked in the deboning and cutting department, RR 2.67(1.76-4.05) compared to other workers in the same department. 66.7% of the Eastern European workers were employed by subcontracting companies. 37.9% of total workforce were temporary workers and 23.7% were employees of subcontractors. Of the 140 occupational cases, subcontracting companies accounted for 50.7% (RR 5.09 (3.25-7.97)) and temporary workers 30.7% (RR 1.80 (1.11-2.93)).

Afternoon and morning shift workers had RR 3.72 (1.92-7.22) and RR 1.98 (1.00-3.94) respectively, compared to workers who worked days, nights, or flexitime. Multivariable Poisson regression analyses have shown that: subcontractors had RR 2.98 (1.81-4.99) compared to regular and veterinary administration workers; the elevated RR 1.34 (0.81-2.23) for temporary workers was not statistically significant. Contact tracing forms were completed by 118 occupational cases (84.3%), 64 (54.2%) were foreign-born. Specifically, 62 cases (52.5%) reported carpooling to and from work with one or more other workers and 49 cases (41.5%) reported carpooling to and from work with 1 to 4 other workers. 40 cases (33.9%) reported sharing their accommodation with at least one other worker. Carpooling or sharing accommodation was more frequently reported by the Eastern European cases: 67.3% compared to 39.7% for the other cases (p = 5.10, Pearson's Chi^2).

Overall, the AR was 11.9% (140/1,179), 16.6% in the deboning and cutting department, 28.4% in Eastern European workers within the deboning and cutting department. ARs were lower among other workers: 4.6% for workers of the primary processing activities, 4.1% for the third stage processing activities, and 2.7% for transverse functions. In terms of subgroups of workers, the AR was 16.5% (12.1–22.6) in subcontractors with a risk ratio of 2.98 (1.81–4.99) and 7.4% (5.3–10.3) with a risk ratio of 1.34 (0.81–2.23) for temporary workers.

Pokora et al[31] carried out a study during late June 2020 to early September 2020 on transmission risk factors in German meat processing plants. Twenty-two meat and poultry processing facilities participated in the study, with a total of 19,072 employees, 880 with COVID-19 infection. Overall, 78.9% of the employees had to work in areas of the temperature below 12˚C and for 60.2% of employees the minimum distance of at least 1.5 m could not be guaranteed. Temporary and contract workers did not have increased risk of COVID-19 infection when compared to regular workers. However, in the same analysis but in the sample with information on outdoor air flow (OAF), temporary and contract workers had statistically significant increased risk of infection with Adjusted Odds Ratios (AOR) of 1.38, 95%CI 1.07-1.77.

In total, 7,798 employees of the sample worked in the plants with many infected employees. 949 (12.2%) of workers had missing information on the distance variable. An additional 83 subjects working in cooled areas (1.1% (overall 562 subjects, 7.2%)) were excluded from the analysis because they had missing information on the temperature variable and 244 subjects (3.1% (overall 1044 subjects, 13.39%)) were excluded from the analysis because they had missing information on the type of work break, resulting in 6,522 employees eligible for the main analysis. Of these employees, the authors collected information on the air flow volume per employee for 2,786 employees (35.7%), who were eligible for sub-analysis. 73% of the study population included in this sub-analysis were temporary or contract workers.

AOR were adjusted for the possibility to distance at least 1.5 metres, rest and meal break rules, and employment status. Information on interventions and prevention efforts was available for 20 (91%) facilities. Overall, 16 (72%) facilities reported a SARS-CoV-2 testing strategy, 11 (50%) planned to improve or already had improved ventilation, 10 (45%) installed physical barriers, and 6 (27%) required universal face covering. Across all models, employees working at less than 1.5 m between workers had a higher chance of testing positive (AOR 1.86; 95% CI 1.55–2.22). Pokora et al[31] also reported variation in the type of face coverings used between companies – use of FFP2 masks was associated with lower rates of infection in employees and were used in companies with zero affected people.

Steinberg et al[37] reported on a large meat processing facility in the USA employing 3,645 employees. During the study period March 2020 to April 2020, high employee density in work with prolonged close contact between employees over the course of a shift was identified as a risk factor. Attack rates were higher in the cut (30.2%), conversion (30.1%), and harvest (29.4%) department groups where numerous employees tended to work close to each other (less than two metres) on the production line. The attack rate among non-salaried employees was higher (26.8%) compared to salaried employees (14.8%). Salaried employees typically had workstations that could be adjusted to maintain distancing and did not work near other employees on the production line like the non-salaried employees. Contact between employees in shared areas (e.g., cafeterias, locker rooms, and equipment dispensing locations) might have facilitated the rapid spread among employees in different departments.

Waltenburg et al[41] evaluated 239 meat and poultry process facilities with recorded outbreaks between March 2020 through to 31 May 2020. The study described meat and poultry processing facilities in 23 US states employing 112,616 workers. 14 US states reported to the study. Of the 9,919 (61%) cases, studies reported race/ethnicity with 5,584 (56%) in Hispanics, 1,842 (19%) in non-Hispanic blacks, 1,332 (13%) in non-Hispanic whites (whites), and 1,161 (12%) in Asians. Ethnicity was a risk factor; among 9,919 COVID-19 cases in 21 states with reported race/ethnicity, 87% occurred among racial and ethnic minority workers (but demographic characteristics of total worker populations in affected facilities were not available for comparison). The article does not mention the workplace factors associated with high-risk of exposure; however, it does talk about the interventions and prevention efforts implemented in 111 meat and poultry processing facilities. The prevention methods with the most uptake included worker screening (using temperature check) on entry, (80%); requirement of universal face covering (77%), adding hand hygiene stations, educating employees on community spread (70%) and installing physical barriers between workers (69%). The prevention methods with the least uptake included removing financial incentives (e.g., attendance bonuses) (only 18% did so); closing the facility temporarily (62% did not do this); and offering SARS-CoV-2 testing to employees (32% did not offer).

Porter et al[32] evaluated 13 separate COVID-19 outbreaks in seafood processing facilities in Alaska from summer to early autumn in 2020. Most of the workers in the seafood processing plants were out-of-state workers or seasonal workers. The study findings suggest that requiring entry testing and quarantine might have reduced importations of SARS-CoV-2 into remote seafood processing facilities and prevented COVID-19 outbreak occurrences. The authors suggested that incorporating additional measures, such as serial testing and restricting work during quarantine, might further reduce the infection risk to seafood processing workers and the communities in which they work.

Prisons SIC 84230

We reviewed two studies into COVID-19 outbreaks in prisons[10 47].

Whilst prison settings were investigated in some detail many conflated prison population and prison staff exposures and controls which made it difficult to assess for workplace mitigations and controls. We have excluded studies which focused on prison inmate populations.

A quantitative cross-sectional study was conducted by Guiliani et al[10] between 20th February and 30th April 2020, at a large prison in the Lombardy region of Italy during Italy's first COVID-19 wave. Socio-demographic data including clinical information and movements within the prison, along with sick leave data, was analysed as part of the study. Attack rate (based on either a positive PCR test or COVID-19 symptoms) was higher in custodial staff (CS) than in HCWs. 94 out of 535 (17.6%) CS were affected along with 7 out of 80 (8.8%) HCWs. Risk factors related to high risk of exposure included staff participation in emergency riot control operations at another prison. Other risk factors included CS sharing workspaces, including offices and vehicles, as well as break spaces. Shared accommodation was also a factor among CS housed in the prison compound, and in common with detainees, transmission was more common between individuals with a shared culture or language. Although it was not possible to identify chains of transmission, the virus spread first among CS and then among detainees, which suggests that CS introduced the infection into the prison. Control measures included reductions in the number of staff and visitors entering the prison. Access to the prison was limited to essential staff. Family visits and judicial proceedings were replaced by telephone and video calls. Referral to community health services, along with staff transfers within and between prisons, were deferred unless urgent. In addition, a rigorous contact tracing procedure was developed.

Zawitz et al [47] reported a mixed-methods cross-sectional study conducted at a prison in Chicago, USA, between 1st March and 30th April 2020, during the first COVID-19 wave. The prison is a large facility with average daily number of detainees of around 5,800 along with more than 2,500 staff. This study documented cases of COVID-19 amongst staff and inmates, then described the interventions that took place, based on an assumption of what the risk factors were.

Prevalence was 279 positive RT- PCR tests out of 2,577 workers who were screened. Data on staff who tested negative were not available.

During the outbreak, formerly closed prison cells were opened to increase physical distancing, and movement of staff between units was restricted. Education was provided to staff on COVID-19 control, and aerosol-generating procedures were eliminated in communal areas. Temporary screening of staff, including delivery personnel on entry was implemented along with universal masking for staff and detained persons. Strict quarantine, medical isolation, and testing were introduced, together with implementation and enforcement of social distancing of more than six feet, increased access to soap and alcohol-based hand sanitizer, and enhanced cleaning and disinfection practices. During the study period the prison population decreased from 5,579 to 4,054 due to measures including releasing individuals to electronic monitoring. Visits to detainees were also stopped.

Guiliani et al[10] asserted that rigorous intervention strategies coupled with widespread diagnostic testing and syndromic surveillance limit introduction and mitigate transmission of SARS-CoV-2 infection in detention facilities. Restriction of movement within the jail was thought to be one of the most critical measures in controlling the outbreak along with flexible and non-punitive leave policies that allowed sick employees to stay at home.

Risk factors associated with high risk of exposure in staff in prisons primarily related to 'management of the workplace environment' (Clayson et al, 2022). Overcrowding was recorded in prisons where there were prisoner outbreaks. Other risk factors were unprotected proximity such as closer physical contact and lack of preventive measures. Risk factors also included elevated levels of virus circulation and poor adherence to hygiene controls amongst prisoners.

The transmission dynamics in high-density settings with lack of outside air flow and recycling cool air was summarised by Lehnertz et al[21] as a high-risk outcome in LTCFs, prisons and meat processing plants.

The prison and LTCF outbreaks emphasised the significant role that community-dwelling staff played in introducing COVID-19 into some settings as cases among staff often preceded cases in detained persons or residents in care facilities. Prisons and LTCF's are high risk for COVID-19 spread. Once introduced, reducing the spread of COVID-19 in a high-density prison environment is challenging (Simpson & Butler, 2020).

Offices SIC 82110, 82200

Weissberg et al [44] describe an outbreak which commenced on 10th March 2020 in an open-space office, focusing on the ventilation system which provided air renewal within 1 hour in the open office space, and within 15 min in a conference room, respectively. There was no recirculation of air or strong directed airflow. Windows could be tilted, but not completely opened. Although there was no evidence that the lack of ventilation played an active role in this outbreak, a higher air change rate might have been beneficial to lower transmission risk, especially after droplet- and aerosol-generating procedures. In this study the workers engaged in singing a 'happy birthday' serenade to a co-worker.

Sami et al[34] examined workplace factors associated with high risk of exposure in a study population employed by a US government department during the period 23rd April 2020 to 29th April 2020. Shared workspace, shared breakroom, and spending more than 10 minutes within 6 feet of co-workers were described as high risk. Environmental risk factors such as bus, train, subway, taxi and rideshare travel, and attendance at social gatherings of fifty or more persons were discussed but were not found to be statistically significant in this study. The study however referred to characteristics of residing with a COVID-19 positive household member as potentially associated with SARS-CoV-2 infection and transmission in the workplace ($p=0.001$).

Sarti et al[35] used a case study to describe a cluster outbreak amongst office workers in Italy in November 2020. Workplace factors associated with high risk of exposure were high staff occupancy in poorly ventilated office spaces with a lack of mask wearing. Use of face masks and plexiglass screens along with more than one metre social distancing was described as lowering risk of exposure. However, the retrospective study concluded that these measures might not be sufficient to control transmission. The paper did not describe the pattern of time spent in the space beyond the typical working day of and it did not report on outside airflow rates but described poorly ventilated office spaces. It described infection prevention controls, and organisational rules for using shared areas in the business organisation as effective, along with employee health surveillance.

Park et al[29] described the epidemiological characteristics of an outbreak in a call centre in South Korea in March 2020 using RT-PCR to identify 97 confirmed cases. All cases were in one floor of an office block with an attack rate of 43.5% for the office floor. The call centre building floor was a high-density work environment in comparison with other floors in the building (building AR 8.5%) and whilst there was inter-building/floor interaction this cluster was confined to the floor described in the study. The authors propose that the duration of interaction and close contact was the likely risk factor for transmission but did not evaluate this by measuring or assessing interventions.

Various settings including schools, firefighters' station, naval ships, and airports

Murti et al [26, 27] described workplace outbreaks in Ontario, Canada, between March 2020 and September 2020 using data from the integrated Public Health Information System, the Toronto Public Health Coronavirus Rapid Entry System, the Ottawa Public Health COVID-19 Ottawa Database, the Middlesex-London COVID-19 Case and Contact Management tool and Ontario Case and Contact Management database. This study aimed to explore the overall disease burden, reporting on household transmission linked to workplace outbreaks in Manufacturing, Agriculture, Forestry, Fishing, Hunting, Transportation and Warehousing sectors. As per Bui et al[5] who concluded that workplace outbreak-associated cases had the highest incidence in the Wholesale Trade (377 per 100,000 workers) and Manufacturing (339 per 100,000 workers) sectors (study period 6th March 2020 to 6th June 2020). These studies found workplace factors associated with high risk of exposure were the lack of physical distancing and not using PPE. Environmental risk factors were shared dormitory-style housing and congregate living.

Kasper et al[18] presented an outbreak of COVID-19 on US Navy aircraft carrier U.S.S. Theodore Roosevelt (SIC 84220) where SARS-CoV-2 spread quickly among the crew. The study period was 23rd March 2020 and 18th May 2020. 26.6% of the 4779 ship's crew tested positive for SARS-CoV-2. Ethnicity of positive cases was described, 42.7% were White, 20.5% were Hispanic, 19.6% Black, 8.0% Asian or Pacific Islander, 9.2% described as Other. Crew members who were clinically described as obese had a statistically significant increased risk of COVID-19 infection, OR=1.33 (95%CI, 1.11-1.61). Workplace factors and environmental factors associated with a high risk of exposure were described as those working in tighter spaces e.g., reactor (OR 1.73 (95%CI,1.29-2.36)), departments. These areas appeared more likely to have confirmed or suspected COVID-19 cases than those working in a combination of open-air and confined conditions (e.g., air and deck crew). Members of the medical department, who wore personal protective equipment (PPE) when evaluating crew members had a lower attack rate (16.7%, 8 cases among 48 personnel) than the overall crew, despite being at highest risk because of exposure to patients with COVID-19 in a small space. Infection by rank status differentiated between enlisted crew: 1231 (92.5%, n=1331) and officer status: 98 (7.4%), n=1331. Primary intervention in this military setting was restriction of movement to minimise community exposure at the point in the pandemic. Crew members who worked in confined spaces appeared more likely to become infected. Transmission was facilitated by close-quarters conditions and by asymptomatic and pre-symptomatic infected crew members. Half of those who tested positive for the virus never had symptoms.

Between 20th July 2021 to 3rd August 2021, Liu et al[22] studied an outbreak amongst airport cleaners and airport staff (SIC 6210, 6220) (airline ground staff, auxiliary police officers, drivers, and restaurant staff). The study relied on recorded anonymised data of 220 cases from Nanjing government databases. Baseline characteristics of the workers were not collected. Individual risk factors were described as limited health literacy and a lack of awareness towards health and safety in the workplace. Defects of management were noted as a risk factor and mitigations included the supply of face coverings and PPE. Workplace factors associated with high risk of exposure were the type of job; particularly cleaners who were responsible for the cleaning and disinfection of domestic and international flights. Proximity of airport cleaners with other airport staff was also observed as a risk factor. Environmental risk factors were described as sharing of cleaning tools such as brooms, duster cloths, dust collectors, and shared use of the rest room. Disease frequency by occupational role = Mean (SD (Standard Deviation)); Airport cleaner = 69 (31.4); Other staff working at the airport = 29 (13.2).

Miller et al[25] reported a large study of orchard and warehouse employees (3,013) at a large fruit grower (SIC 5148) with both indoor and outdoor work environments in the USA during the first COVID-19 wave between May 2020 and August 2020. 3,739 of 4,955 employees took part in the study. 3,013 orchard employees had a valid SARS-CoV-2 test result or COVID-19-like symptoms in the absence of a test. 726 warehouse employees had a valid test result. Amongst both employees in the warehouse and in the orchard, a statistically significant increased risk (RR 2.8 (2.1-3.8)) of infection among orchard employees living in the community compared to those living in the farmworker housing was observed. There was an increased risk of SARS-CoV-2 infection for employees in packing and sorting fruit (RR 2.7 (1.4-5.2)) and in other fruit packing support (RR 2.4 (1.2-4.7)), who work primarily indoors in a large group, compared to forklift operators, who worked alone and partially outdoors. Cumulative incidence among tested warehouse employees was 23% (170/726), with substantial variation across job roles. Positive test results were received by 28% (84/304) of employees who worked in packing and sorting fruit, 24% (30/126) of those in other roles in the packing and sorting area, 10% (9/86) of forklift operators, 7% (8/110) of employees in other warehouse roles, and 6% (3/49) of office employees. This study acknowledged limitations due to the potential for unmeasured confounding of asymptomatic cases, as initially, asymptomatic employees were not systematically tested (until late May 2020).

Gold et al[11] reviewed eight elementary schools in the same district for outbreak factors during late 2020, early 2021 SIC (85200). The study found educator-to-educator transmission was a source leading to increased likelihood of educator to student transmission across the nine clusters in a school district, with educator-to-educator transmission in two clusters. Educator-to-student transmission was concluded in half of the student cases. School staff were interviewed and were tested for COVID-19. 13 educators were positive for COVID-19. Out of work mixing and cross-school meetings were described as risk factors for transmission. No reference was made to shared spaces and controls in those areas.

Durand et al [9] described on outbreak at a fire station in France (SIC 84250) where the firefighters were permanent members of staff. Workplace risk factors associated with high risk of exposure were 24-hr on-call shifts; working and living in close contact with one another, including eating meals together, shared accommodation and bedrooms, and shared washing and changing facilities. This outbreak occurred within the same shift group of firefighters. There was low-level community prevalence: 93/ 2,000,000 by 13th March 2020 for Bouches-du-Rhône, where the fire station is located. The overall AR was 27% (23/85) and transmission from asymptomatic cases was not demonstrated or discussed in the article. Working patterns were a maximum of 48 hours and rest period for at least 48 hours. Many hygiene mitigation measures were in place, but mask wearing was not mandatory, even in a vehicle, except during medical rescue interventions.

In many of the studies, drawing conclusions from employer held data was not possible due to high heterogeneity in the presentation of socio and ethnographic data, with data on the baseline characteristics of the study population missing in almost three-quarters of the included studies. 35/47 studies did not include data on ethnicity, 34/47 studies did not record employment contract-type information and 44/47 studies did not record socio-economic status of study participants.

Discussion

The risk of SARS-CoV-2 infection has been strongly linked with occupation, particularly within the health, social care and transportation sectors. HCWs were described as disproportionately affected by post-COVID syndrome (long COVID) (Neinhaus 2021) and the UK Industrial Industries Advisory Council reported on the large body of supporting evidence for increased risk of infection, subsequent illness and death in HCWs (IIAC, 2022). Several studies reported the risk factors for a SARS-CoV-2 workplace outbreak, however, there was a wide variability in the epidemiological methods reported in the literature, including outbreak and case definitions, study population and data analysis. Our aim was to examine the literature on workplace outbreaks and identify the risk factors associated with transmission and infection of COVID-19. Workplace factors associated with a higher risk of exposure were discussed in relation to high-density settings and social distancing. Several studies referred to situations where transmission due to close contact, for example within < 2m for more than 15 minutes, was significant [4 13 18 26 27 29 31 33 34 35 37]. The impact of close working was more pronounced in high-density settings, especially where there were crowded or confined workplaces [7 8 10 15 18 22 24 25 29 37 44 47].

Ventilation and access to outside air/outside air flow was described in several outbreaks [8 14 21 39]. Recent evidence from SARS-CoV-2 outbreak investigations examined by Duval et al (2022) suggests that SARS-CoV-2 containing droplets and aerosols from infected persons can travel at distances of over 2 metres. Conclusions were drawn from indoor non-healthcare settings with one or more factors contributing to > 2m transmission distances. Insufficient indoor air ventilation with outside air or indoor air ventilation systems with directional air flow are thought to contribute to longer travel distances. Applying this to indoor workplace settings and associated environments, shouting and loud talking, increased respiratory rates from physical work associated with job role, and recirculating of cooled unfiltered air may have increased longer distance transmission in the outbreaks in this review.

As our knowledge has grown around the mechanics and dynamics of virus particle and aerosol transmission, and our understanding of the importance of ventilation in the workplace for other hazardous substances is longstanding, this was not always reflected in the studies included in this review. Several studies discussed the role of ventilation and the internal air environment [8 13 14 21 31 39], with many not referring to ventilation as a workplace intervention for mitigation or, without adequate ventilation, few references were made to the increasing risk of transmission. The lack of mention of ventilation in the reported studies may be reflective of the focus on hygiene advice early in the pandemic, as majority of the studies in the review were carried out in 2020, when there was little attention on outside air intake and air changes per hour in workplaces.

Controls such as wearing of face coverings, social distancing and hygiene factors were widely reported in the included studies. Variability in compliance was observed, even in highly managed settings, and in some cases other IPC controls were in place, but not face coverings[9 11 22 26 27 35]. The type of face coverings used was not specified in most studies, except for a small number of studies in healthcare settings. These were either N95 masks (respirator with the highest level of protection)[12 42], or FFP2 masks (with slightly less protection)[47]. Whilst there is evidence to support wearing of face coverings to reduce transmission of SARS-CoV-2 from infected persons, including transmission from HCW to HCW[36], the use of face coverings in preventing long-range transmission of infection is unclear. Duval et al (2022) identified 13 out of 18 studies where the suspected primary index case was asymptomatic, pre-symptomatic or close to symptom onset at time of transmission. In these examples, as most cases were pre-symptomatic, the importance of testing and tracing to prevent both workplace and community transmission at pace is a factor to consider early in future epidemics.

Night shift working was a workplace factor associated with a risk of exposure. This may be because resource and staff ratios may be reduced during this period, depending upon the setting, and associations with tiredness and sleep quality may affect IPC compliance. Night shift working often saw high positivity rates compared with day shift work [7 15 21 41 45].

Break room sharing, communal food halls, other shared eating spaces and dressing room sharing was associated with a high risk of exposure [8 14 17 18 19 20 23 24 25 28 39]. Many workplaces prevented consumption of food in shared spaces and introduced rules for break rooms during the outbreak. Management of these spaces under general IPC procedures and outside of outbreak scenarios was not described in any of the studies and suggests that managing rest areas for workers was a difficult area to control outside of an outbreak scenario. Ochoa-Leite et al (2021) concluded that HCWs may undervalue the risk of co-worker transmission compared to patient transmission and overlook protective measures during break and mealtimes.

Staff shortages were described in the outbreaks included in this review. This may reflect the use of temporary, agency and subcontractor workers reported in several studies[17 25 31 37 41] with elevated infection rates in these workers compared to regular or salaried workers. Attack rates were higher in cold temperature work areas in food processing facilities and this risk was elevated even higher for temporary and subcontract workers in these environments. Contract status and examples of permanent and secure contract benefits were noted in the studies, one example describing how access to mitigations – PPE, working from home, screening – were not available to contractor and temporary workers[37].

Shared accommodation, shared commuting and transportation within temporary and subcontractor workers were also reported as a work-related factor for elevated risk of exposure, particularly in the food and agricultural sector [7 14 18 25 32 34 37 41]. Employees of subcontracting companies and employees who work across multiple sites were recorded as presenting a three-fold increase in likelihood of infection in bank and agency staff in care homes (Ladhani et al[20]) and in meat processing and cutting plants (Mallet et al[25]). Understanding the working patterns of temporary and agency staff is essential in managing transmission risk.

Cohorting such as worker ‘bubbles’ or groups designed to minimise contact with other employees was variously described as a workplace factor associated with a lower risk of exposure. Whilst this was not demonstrable for some cohorting early in the pandemic, such as firefighter shifts[9], this mitigation was positively reported as an infection control measure [1 9 15 17 19 20 37 47].

Importantly many of the studies in this review were undertaken early in the pandemic and did not or could not make a statistical evaluation of community prevalence. The role of community prevalence and its impact on workplace transmission could not be reliably assessed. Knowledge of enduring or community prevalence to inform control of workplace outbreak risk factors could be important for successful workplace mitigation strategies. An extensive body of work has been generated on workplace risk factors during the review period, however there is no consensus and questions remain regarding action levels of community prevalence which are considered high or significant enough to cause workplace transmission. Community prevalence could be particularly important in areas of high-density, high subcontractor, temporary and agency workforces, in cold environments, and where there is employer-provided shared accommodation and shared transport and is linked to inability to work from home and lack of sick pay. The impact of high community prevalence rates is likely to be exacerbated where there is a lack of ability to work from home or there is absence of sickness pay and such. Community prevalence has featured in other work and it remains an important consideration in the context of workplace outbreaks. See figure 4 and 5.

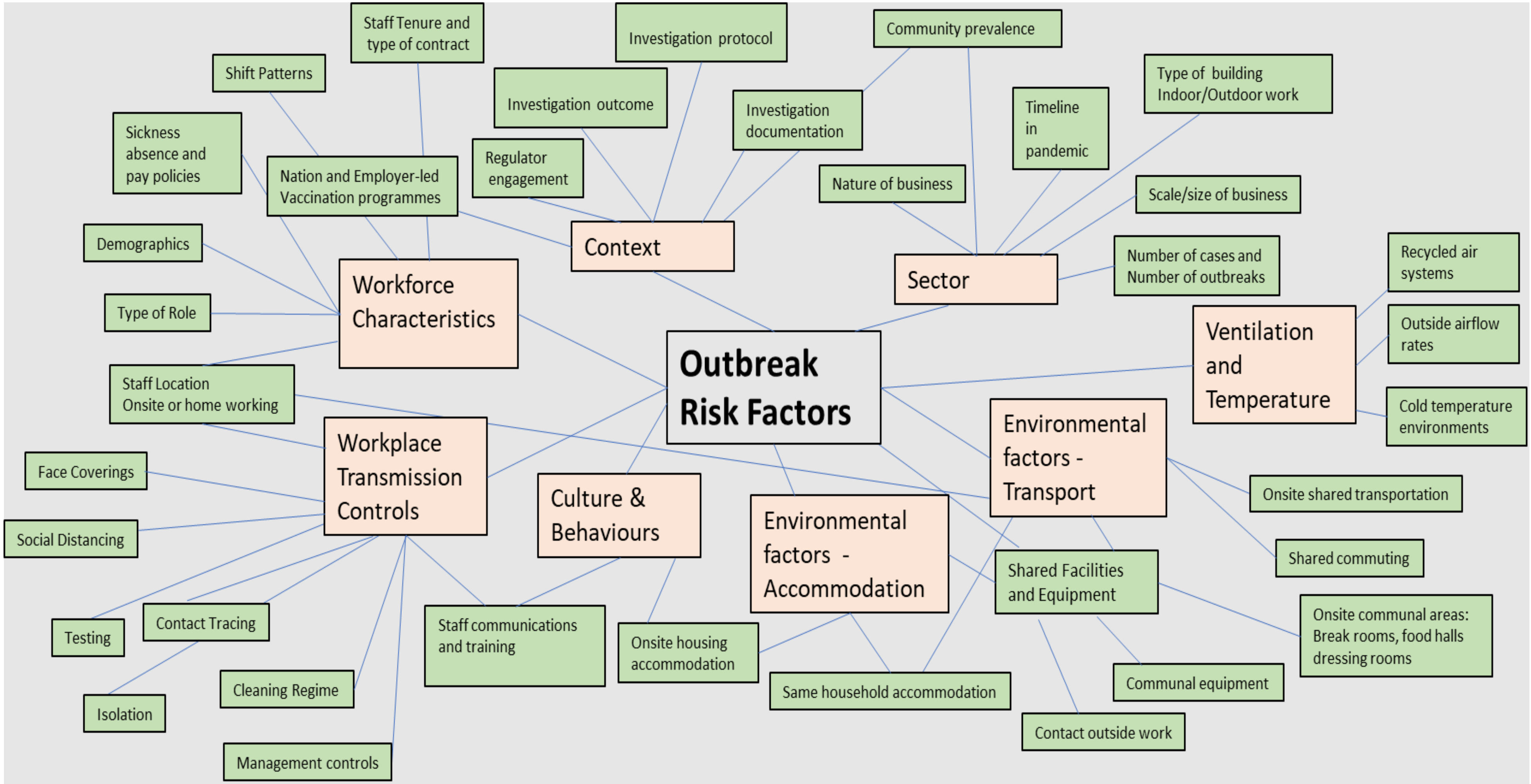
Workplace inattention to infection prevention and control measures outside of healthcare was notable with a lack of mention in 90% of the studies reviewed. This suggests that IPC measures may not have been in place or were not widely known, including as part of emergency planning and response arrangements.

IPC should feature in infectious disease risk management practices outside of pandemic situations. Emerging infections and diseases are increasingly likely to challenge national systems and workforces. For example, the 2022 monkeypox outbreak was declared a global health emergency, with non-endemic and endemic cases reported in countries across widely disparate geographical areas (WHO, 2022). Guiliani et al [10] reported that outbreaks in prison facilities require active case management and syndromic surveillance to control and prevent infection and highlighted that a multidisciplinary task force, involving both healthcare and prison management staff who were able to implement interventions at pace and to monitor their effectiveness, was key to managing the outbreak. The authors suggested that educating workers about PPE use and hygiene measures led to an increase in compliance with control measures, and a decrease in workers' anxiety about COVID-19 transmission.

Mitigations may be more successful with comprehensive implementation of IPC measures in the workplaces and across local areas. Knowledge of local community structures and an understanding of the social, cultural, and economic status of workers and residents featured prominently in large rural outbreaks in the US. IPC was a measure looked for by researchers in all the included articles and whilst description of its prominence varied, connected local healthcare systems, and the role of well-resourced health centres (qualified staff, financial resources, analytical equipment) were described as important for future infection surveillance and response[15 17 18 19 26 39]. Local management of patient and employee health records and connecting data to national surveillance systems in a time of crisis is an area of future policy and research, echoing the observations by Wee et al[42] of the integrated surveillance system being important in disease control. Developing our understanding of community incidence and enduring prevalence, and evaluating how community prevalence changed during the pandemic, could inform understanding of workplace transmission through integration with local and national surveillance systems for prevention and control.

The studies of healthcare outbreaks such as Asad et al[3] and Yau et al [45], whilst taking into consideration the study limitations, identify themes and critical factors for outbreak management (see Figure 4) that concur with the findings in Clayson et al (2022) and Lewis et al (2022). These include early identification of cases, the suite of public health interventions implemented, external expert support and assistance, staff training and education, personal protective equipment use and supply, workplace culture, organizational leadership and management, effective coordination and communication, and sufficient staffing. High-density workplaces and transmission dynamics relating to proximity between staff and service users were discussed and reflected on the introduction of infection by staff to prison populations (Guiliani et al[10]). Similarly, this has been widely explored in domiciliary care throughout the pandemic [21.]

Figure 4: Summary of Outbreak Risk Factors Identified in the 47 studies (adapted from Clayson et al 2022)



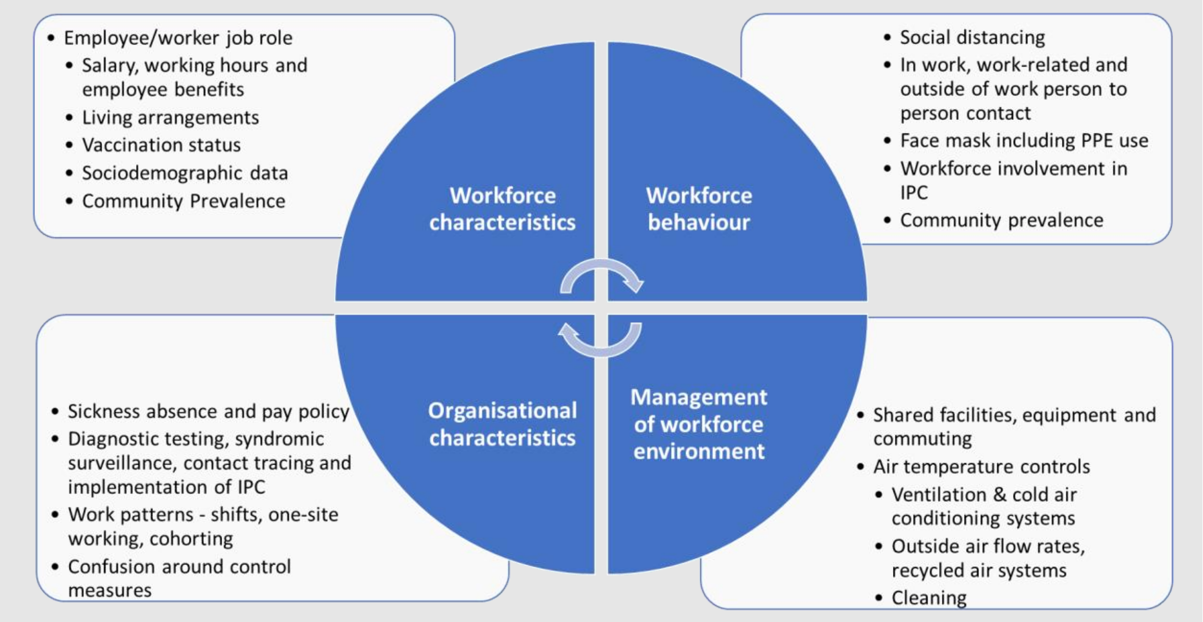
Workplace leadership and management is critical to improving and maintaining behavioural and environmental infection prevention and control measures especially in high-density workplaces. Workplace characteristics associated with risk factors and mitigations for infection were evident in the included studies, in particular workforce and organisational characteristics and management of the workforce environment (Figure 5).

Wee et al[42] described encouraging individual responsibility to report symptoms and the setting up of an institution-wide integrated surveillance strategy as an important development in containment of COVID-19 in detecting clusters and evaluating interventions for prevention and control. The integrated strategy in this example brought together surveillance for early case detection, outbreak investigation and containment, and compliance with IPC for individual-level protection. Organisational and management culture is critical in such strategies being operational and effective in containing outbreaks.

Organisational characteristics associated with risk factors and mitigations included the extent of engagement by leaders and managers. Senior leaders and mid-level managers spending too little time in the workplace was a risk factor described in large facility outbreaks. Other risk factors were lack of senior leadership engagement, lack of mid-level manager presence and supervisor visibility, and how much time they spent in the workplace. Leadership and management influence the type, rate and likelihood of maintaining control measures over time and strongly influence the success of control measures (Gold et al[11]). Hale and Dayot[14] described collaboration across the organisation and departments as important mitigation measures to prevent future outbreaks. Mitigations to lower the risk of exposure were improved visibility, communication, consultation, and implementation of clear policy and practice on IPC to limit confusion around control measures.

The studies in this review highlighted gaps in the management of the workforce environment. It was evident that workforce health data is not readily accessible in local, regional, and national datasets, and are not collected for all persons employed in many occupations and settings. Whilst larger organisations may be more likely to collect this data, there are opportunities for innovations for collecting demographic data about employees in a systematic way to provide insight into the workforces. Access to national occupational health programmes for employers and employees is a conduit for future preparedness and long-term improvements to employee health and wellbeing. Whilst observations on occupational health services cannot be drawn from the review, the widespread lack of mention reflects the variance in engagement by sector and business type.

Figure 5: Workplace characteristics associated with risk factors and mitigations adapted from Clayson et al, 2022



Organisational characteristics such as examples of strong leadership and cogent management imply that controls are established, and that worker adherence is good. Studies included in this review suggested that this is not a reliable indicator. In one included study[11] mandated face covering use was observed to be high during on-site inspection, but interview results reported that outside of inspection there was variable compliance, with lack of, or inadequate face coverings. Conversely, strong organisation controls featured in an outbreak among workers in high occupancy, sharing close quarters conditions for extended periods of time[18]. Mandatory face coverings and cleaning regimes were in place, but the confined environmental conditions negatively affected the implementation of mitigation measures.

Organisational attitudes towards asymptomatic workers needs further investigation. Many of the included studies referred to high asymptomatic rates in the testing regimes. Prevention of transmission and screening is essential in high-risk industries. Age differences in attack rates need further exploration to direct appropriate training and resources in behavioural compliance and acceptance of measures. Much talk of COVID-19 serious infection was centred on 50 + age groups, with disease often described as mild in younger age groups early in the pandemic. Noel et al[28] noted that age groups over 50 years old had a lower attack rate because of fear of disease and were more likely to maintain IPC measures.

Categorisation of symptoms early in the pandemic meant that atypical symptoms were missed in the workplace and community, and these contributed to outbreaks at work. Whilst most articles met the outbreak definition it was difficult to separate the workplace outbreaks from community transmission. This is problematic particularly where there are calls for classification of COVID-19 as an occupational disease. Controlling infectious disease transmission in the workplace is imperative for all industry, and whilst healthcare settings warranted greater attention early in the pandemic, equal attention should be directed to industries outside of healthcare and the measures used in those settings. Competent hazard identification, hazard analysis, risk assessment and management practice cannot be overstated. Longstanding focus on safety compliance in many workplaces may have resulted in a dearth of public health knowledge amongst HSE (health, safety, and environment) managers, reflected in poor understanding of biological risk management, particularly outside of healthcare settings.

Strength and limitations of this review

This systematic review critically evaluated studies of SARS-CoV-2 workplace outbreaks to assess the risk factors for infection and mitigations for prevention of infection. These included workforce characteristics, workforce behaviours, organisation/employer characteristics and management of the workplace environment. The 47 studies included in this review used real world evidence from observational studies undertaken in majority indoor workplaces. Some outdoor workplaces such as fruit and vegetable picking experienced outbreaks associated with indoor packing activity and shared accommodation. Extensive inclusion criteria were applied to the data collection tool which was screened by at least two reviewers at each stage of the quality assessment and data synthesis. The types of studies included were heterogeneous in study design, study size, location, and sector.

Selected studies were of outbreak investigations of human-to-human transmission. This review assessed evidence from retrospective outbreak investigations without evidence from comparable settings where outbreaks had not occurred.

This review did not assess the impact of vaccination on outcomes for COVID-19. We know that most outbreak investigations suffered from persistent community COVID-19 outbreaks linked to an inability to control for mixing of occupational and non-occupational cases, and a lack of testing tools and rapid testing methods for full screening of affected occupational groups. Public policy changed frequently in noticeably short time frames. Changing regulations around preparedness and response, along with issues of managing employee availability and business continuity, were widespread. Many of the included studies did not sufficiently investigate time, place, and person information to generate hypotheses and so most studies are not hypothesis driven.

The role of community prevalence and the impact on workplace transmission could not be reliably described as the majority of included studies did not report community prevalence.

Outbreak investigations where transmission occurred in large numbers of vaccinated employees could not be included because mass vaccination programmes had not been established during the time of this study. This review could not assess how vaccine uptake and population immunity within communities and workforces might influence adherence to mitigation and control measures.

Risk factors such as age were often considered jointly for workers and other groups (e.g., detainees) in prisons, which made it more difficult to assess the impact of these risk factors on workers.

The Cochrane Review of Workplace Interventions (Pizarro et al, 2022) found only 1 study that formally evaluated workplace interventions to reduce transmission risk. The dearth of work in this area, and the variability in study design and intervention evaluation highlighted in this review, indicates a gap in research of workplace interventions.

Conclusions

The majority of included studies in this review (more than 80%) focused on the infections and transmission within medium and large enterprises. Included studies analysed data from a wide range of data sources including workplace and local epidemiological surveillance, interviews, observations, national surveillance, outbreak investigation databases, employee records and workplace environmental risk assessments.

The most reported mitigation strategies were related to workforce behaviours and workforce characteristics such as wearing face coverings, adhering to cohorting, one site working and being on a secure and salaried contract. Syndromic surveillance, contact tracing, implementing IPC and establishing working relationships with health agencies and public health departments were reported mitigations in the included studies.

The most reported factors associated with a high risk of exposure were related to workforce characteristics and behaviours and were described as lack of social distancing and face covering wearing, where there was greater likelihood of close contact working and where there was sharing of break, rest, eating and dressing rooms. Contractual arrangements such as temporary and subcontractor employment characteristics, and socioeconomic factors related to lack of sickness absence pay, living arrangements such as shared worker accommodation, high-density workplaces and being in an area of high community prevalence were described as factors associated with a high risk of exposure. These were followed by night shift working, staff shortages, long working days, shared transportation, and multiple site working.

Ventilation and access to outside air/outside air flow was described as a risk or mitigation factor in only four studies. At the start of the pandemic there was a global focus on cleaning of contact surfaces, fomite transmission and hand hygiene, followed by social distancing and face covering mitigations. Hazard control using ventilation was not exploited, possibly due to fears of spreading the virus. Included studies described reduced air changes, cold air conditioning and recycled air systems, and low outside air flow as risk factors for transmission.

Consistently reliable community prevalence data was not always available during the period of this review and the majority of included studies did not report community prevalence. In the UK, Directors of Public Health reported that UK postcode data on COVID-19 prevalence rates was not available until March 2020 (Lewis et al, 2022). Community infection data could be valuable to employers' mitigation efforts, especially where workers live near the worksite.

Recommendations and implications for policy and practice (especially winter 2022)

Infection Prevention Control measures should form part of standard occupational safety and health arrangements for all employers, including infection prevention control training, improvements to risk assessment processes and audit of IPC.

Resources should be directed to influence the factors which contribute to presenteeism. Included studies strongly suggest that economic instruments such as hourly rates of pay, employee benefits and employment conditions could be used to minimise presenteeism. This could also minimise multi-site working and multiple employments which were factors in community and workplace transmission.

More connected systems and accessibility to employer data on occupational health, social, economic, and ethnographic data through improved access to occupational health services is overdue. Supporting resources for all employers to maintain data systems is a potential area of future research. It has frequently been reported that addressing sickness pay gaps may have helped minimise workplace transmission in some sectors. Political will and an assessment of fiscal benefits of such measures should be undertaken to inform debate in this area.

Current systems for capturing health and safety measures in a workplace often do not capture workplace infection data. The reduced availability of widespread testing tools and screening assays for often-affected occupational groups may impair preparedness and response for any autumn or winter surges. This review indicates a need for well-designed epidemiological studies that control for confounding factors and selection bias, and control for mixing of occupational and non-occupational cases to provide a comprehensive analysis of the associated workplace risk factors for COVID-19 and other severe respiratory infections. This review advocates the importance of building local level interventions to minimise the risk of workplace outbreaks by reducing community transmission rates. Limitations on the effectiveness of local interventions are the need for investment in housing occupancy mitigations, improving housing standards and a need to understand the diverse nature of work and the structural inequalities that contribute to the factors which increased the risk of workplace outbreaks. A recent UK government publication outlined a greater role for local public health teams in tackling inequalities in health (HM Government, 2022). However, it is crucial this is supported by additional and long-term resourcing of public and environmental health teams for improvements to be achieved.

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Appendix 2 – Summary of study characteristics

Author	Study No:	Year	Country	Study design	Study period	Study population (number recruited; number screened; positive for COVID-19)	Description of site of outbreak and number of workers employed by company (if reported)	Outcome assessed	Study data collection tools for assessed outcome	Study data collection tools for assessed risk factors	MMAT# Study quality (up to 5*)
Andersen et al	1	2021	Denmark	QUAN, descriptive study	16th Nov 2020-1st Jan 2021	Care home staff (n = 193; n = 190; n = 49	114 bed residential care home and 4 units (193 workers).	COVID-19 infection, COVID-19 related mortality, COVID-19 related hospitalisation	Company surveillance screenings of staff and residents	Whole genome sequencing	***
Ariza-Heredia et al	2	2021	USA	QUAN non-randomised, case study	20th Nov 2020-7th Dec 2020	Employees at a cancer centre (NR; n = 63; n = 8 (cluster 1), n = 4 (cluster 2), n = 2 (cluster 3))	University of Texas MD Anderson Cancer Centre, with ~680 hospital beds (~22,000 workers). Cluster 1: ancillary services unit; cluster 2: staff who worked on same inpatient floor but different units; cluster 3: 2 staff in same office)	COVID-19 infection	Contact tracing, facility observations, infection prevention assessments, employees questionnaire	Unclear	*
Asad et al	3	2020	UK	QUAN descriptive	31st Mar 2020-14th Apr 2020	HCWs (NR; n = 29; n = 23)	A tertiary care university hospital, medical ward with 29 medical staff members.	COVID-19 infection	Company surveillance, self-isolation data, telephone interviews	Unclear	**
Brandt et al	4	2021	Germany	QUAL, case study	14th Mar 2020-mid Nov 2020	All employees in urologic department (NR; n = 154, n = 13)	Hospital - Department of Urology and Paediatric Urology (154 staff in department)	COVID-19 infection	Risk assessment	Interview	****

Bui et al	5	2020	USA	QUAN descriptive	6th Mar 2020 - 6th June 2020	Workers from all Utah industries that are non-healthcare, non-congregate living, and non-educational settings (NR; NR; n = 1389)	Multiple workplaces (1,305,130 workers from 20 industry sectors)	COVID-19 infection, COVID-19 related hospitalization	National database on workforce	National database on workforce, workers' age, sex and ethnicity	***
Castaldi et al	6	2021	Italy	QUAN descriptive	1 January 2021 - 9 May 2021	HCW's	Nursing home	SARS-CoV-2 infection	Regional Surveillance System for Infectious Diseases of Lombardia Region	Regional Surveillance System for Infectious Diseases of Lombardia Region	0/5
Castro and Sloane	7	2021	USA	QUAN non-randomised, cross-sectional	1st Mar 2020 - 30th Apr 2020	Clinic patients: Poultry processing plant employees and family members (data on a subset of 270 adults reviewed for analysis; n = 758; n = 270)	Large poultry-processing facility situated in a rural area served by a FQHC (Federally Qualified Health Centres) (500 workers each shift)	COVID-19 infection	Analysis of health centre network data from FQHCs (Federally Qualified Health Centres). Personal communication with 'health centre staff and leadership'.	Analysis of health centre network data from FQHCs. Personal communication with 'health centre staff and leadership'.	****
Çelebi et al	8	2020	Turkey	QUAN non-randomised, case control	20th Mar 2020 - 20th May 2020	HCWs (n = 47 infected cases and n = 134 controls (non-infected); n = 703; n = 50 (7 doctors, 28 nurses, 12 cleaning personnel, 2 lab technicians and 1 nutrition service worker))	Teaching hospital with 630 beds (1562 HCWs)	COVID-19 infection	Data analysis of covid tests on HCWs presenting with symptoms, or who had been in close contact with an infected person.	Interviews, face to face (n = 35) or by telephone (n = 150), with HCWs using a 33-item questionnaire with a mix of closed and open-ended questions.	****
Durand et al	9	2021	France	QUAN descriptive	Data collection began 17 days after 16th Mar 2020	Firefighters (n = 85; n = 91 included 85 firefighters; n = 23 (symptomatic = 19, asymptomatic = 4)	A fire station in Marseille, France (91 firefighters)	COVID-19 infection	Laboratory analysis; used preceding week work schedule to trace contacts within the fire station	Face-to-face interview	****

Giuliani et al	10	2021	Italy	QUAN descriptive	Feb 2020-April 2020	Prisoners and prison staff (NA; NR; custodial staff n = 28, HCW n = 7)	Prison settings	COVID-19 infection	Lab specimen	Data gathered at the time of medical consultation	*****
Gold et al	11	2021	USA	QUAL	1st Dec 2020 - 22nd Jan 2021	Educators and Students (NA; NR; n = 13 educators and n = 32 students	School - eight public elementary schools in a single school district	COVID-19 infection	Lab specimen	Semi-structured virtual interviews	*****
Goldenfeld et al	12	2021	Israel	QUANT non-randomised	20th July 2020 - 4th Aug 2020	Laundry workers (n = 49; n = 49; n = 11)	The laundromat facility employed 49 workers in a university medical centre in Israel which had 1600 acute care beds including up to 250 for COVID-19 admissions (49 in the laundromat, 9,500 HCWs in total in the medical centre).	COVID-19 infection	Interviews and PCR testing and sequencing	Interviews and direct observation (epidemiological investigation)	*****
Gunther et al	13	2020	Germany	QUANT non-randomised	May-June 2020	6,289 employees in a meat processing plant, particularly the 147 early shift workers (no specific study recruitment. Data were collected as part of public health outbreak investigation and control; n = 6,139; n = >1,400 positive cases between 17th-23rd June 2020	A large meat processing plant in Germany (6,289 workers).	COVID-19 infection, having a positive COVID-19 test, and the viral genotypes of SARS-CoV-2 that cause COVID-19	PCR tests and genome sequencing	Environmental measurements and using company administrative data	****
Hale & Dayot	14	2021	NR	QUANT non-randomised case study	Mar 2020-Apr 2020	Hospital food service workers (NA; NR; n = 10)	Hospital food and nutrition department	COVID-19 infection	Lab specimen	Company surveillance	***
Hou et al	15	2021	China	QUANT descriptive	Jan-Feb 2021	Workers in the Zhengda company (chicken processing plant) (NA;	Zhengda company slaughterhouse, and a residential building where an infected	COVID-19 infection, having a positive COVID-19 test, and the viral	Using the local public health data, including the positive cases,	Using the local public health data, including mobile phone data on	***

						all workers screened; over 90)	employee from Zhengda company resided (~900 workers).	genotypes of SARS-CoV-2 that cause COVID-19	genome sequencing, as well as surveys	locations and movements and CCTV	
Kabesch et al	16	2020	Germany	QUANT descriptive	9th March 2020 to 5th April 2020	HCWs (NR; unclear; n = 36)	Maternity and perinatal centre	COVID-19 infection	Surveillance	Surveillance	*
Karmarkar et al	17	2021	USA	QUANT descriptive	22nd Mar 2020 - 4th May 2020	Staff at a skilled-nursing facility (NR; n = 725 (includes staff and residents); n = 16: 12 clinical care providers, 3 environmental services personnel, and1 administrator)	780-bed large skilled-nursing facility and rehabilitation centre with 2 towers and a pavilion (1,704 workers).	COVID-19 infection, COVID-19 related mortality, COVID-19 related hospitalization	Company surveillance, and symptom checking, targeted testing, and repeat point prevalence survey using PCR tests	Whole Genome Sequencing, and company risk assessment	****
Kasper et al	18	2020	Western Pacific Ocean, The U.S. Navy	QUANT descriptive	23rd Mar 2020 - 18th May 2020. All crew members were followed up for a minimum of 10 weeks	Ship's crew (n=4779; n = 4779; 1331 total (1271 (26.6% of crew) with confirmed, 60 with suspected COVID-19). Rank Status - Enlisted: 1231 (92.5%), officer: 98 (7.4%), unknown: 2 (0.2%); Crew type - Ships crew: 786 (59.1%), augmented crew: 501 (37.6%), unknown: 44 (3.3%); Department - Air: 65 (4.9%), combat support division: 38 (2.9%), Deck: 4 (0.3%), engineering: 67 (5.0%), medical: 8 (0.6%), reactor: 138 (10.4%), supply: 139 (10.4%), weapons, 94 (7.1%)	Ship - nuclear-powered aircraft carrier (crew of 4,779 personnel)	COVID-19 infection, COVID-19 related hospitalization and death	Company surveillance	Medical surveillance data, company roster, symptom tracker, health records, self-reported symptoms	*****

Krone et al	19	2020	Germany	QUAN, non-randomised experimental study	8th Mar 2020 - 4th May 2020	Nursing home staff (NR; n = 135; n = 37)	The nursing home consists of three buildings - building A (three-storeys containing 45 beds), building B (six storeys containing 105 beds) and building C (three storeys containing 24 beds). 160 residents between their early sixties and aged up to over 100 years old (average age 86 years) were living at the home. Total number of workers employed by company NR.	COVID-19 infection, COVID-19 related mortality	Daily swab testing	Company surveillance	*****
Ladhani et al	20	2020	UK	QUANT descriptive	10th Apr 2020 - 13th Apr 2020	Care home staff working during the investigation days (NR; n = 254, n = 53)	Six London care homes, mainly nursing or mixed nursing/residential homes of different sizes, providing care for 43–100 residents with 20–130 staff (254 of 474 staff were working during the study period across the six care homes)	COVID-19 infection	Company surveillance	Self-reported symptoms, self-reported contact with residents and whether they worked in different care homes, whole genome sequencing	****
Lehnertz et al	21	2021	USA	QUANT descriptive	6th Mar 2020 - 30th June 2020	LTCF residents and staffs; inmate population; correctional staff members; meat-	LTCFs, correctional facilities, and meat-processing plants	Positive COVID-19 infection result	Use of available laboratory specimens positive for SARS-COV-2 for Whole Genome	Interview of persons with laboratory-confirmed SARS-COV-2 for epidemiological data	***

						processing facility workers (NA; NR; LTCF A Staff: 38, LTCF B Staff: 76, LTCF C Staff: 56, LTCF D Staff: 21, Correctional Facility A Staff: 82, Correctional Facility B Staff: 210, Meat-processing plant A employees: 432, Meat-processing plant B employee: 724)			Sequencing from Minnesota Department of Health Public Health Laboratory or from other clinical laboratories serving Minnesota		
Liu et al	22	2021	China	QUANT descriptive	20th July 2021 - 3rd Aug 2021	Airport cleaners, other staff working in the airport (such as airline ground staff, auxiliary police officers, drivers and restaurant staff), peasants/retirees/the unemployed, other occupations, and children/adolescents. The outbreak occurred in the airport, but the study includes people from Nanjing that are thought to be associated with the airport outbreak (NA; NR; n = 220 Workers n=98)	Nanjing Lukou International Airport; but the study area is Nanjing	COVID-19 infection	Official media platform and epidemiological investigation reports issued by the Nanjing government	Interview	*****
Loconsole et al	23	2021	Italy	QUANT descriptive	27th Feb 2021 - 2nd March 2021	HCWs (NA; NR; n = 3, 2 physicians and 1 nurse)	Hospital setting	COVID-19 infection	No statement on how cases were found; laboratory test was conducted following finding of the cases	NR	*
Mallet et al	24	2021	France	QUANT descriptive	May 2020	Workers in the pork section of a meat processing plant (n =	On the industrial site, the pork and cattle activities were carried	COVID-19 infection and COVID-19 related	Interviews, screening, PCR testing and	Survey, interview, employee records	*****

						1179; n = 1179; n = 140)	out in two separate areas. The investigations were carried out in the pork section where the cluster occurred (1,347 in the pork section of the plant).	hospitalisation and mortality	searching health care database		
Miller et al	25	2021	USA	QUANT descriptive	May 2020- August 2020	Orchard and warehouse employees (n = 3,739, including 3,013 orchard employees with a valid SARS-CoV-2 test result or information on COVID-19–like symptoms in the absence of a test was available, and 726 warehouse employees who had a valid test result; n = 3,013 orchard employees	A fruit grower in Washington, USA (4,955 employees including 3,708 orchard employees and 1,247 warehouse employees)	COVID-19 infection	Company surveillance/screening using antigen test and identify employees with symptoms compatible with COVID-19 during work site symptom screening who declined tests.	Employee records	****
Murti et al (a)	26	2021	Canada	QUANT descriptive	Jan 2020- July 2020	Various workplace settings	Various sectors	COVID-19 infection, hospitalization and mortality. Outcomes:	Data were obtained from the integrated Public Health Information System, the Toronto Public Health Coronavirus Rapid Entry System, the Ottawa Public Health COVID-19 Ottawa Database, the Middlesex-London COVID-19 Case and Contact Management tool and Ontario Case and Contact	NR	*****

									Management database, collectively known as CCM Plus		
Murti et al (b)	27	2021	Canada	cross-sectional	Mar 2020-Apr 2020	Residents, staff, and close contacts of residents (visitors) of long-term care homes (NA; NR; n = 34 workers. This includes 33 confirmed and 1 probable case.	LTCF (Total number of staff = 93 (67 original and 26 additional staff)	COVID-19 infection, hospitalisation and mortality	Public Health Information System	NR	****
Noel et al	28	2021	France	QUANT descriptive	17th Mar 2020 - 20th Apr 2020	HCWs	Hospital setting (5,704 workers)	COVID-19 infection	Screening by RT-PCR for SARS-CoV-2	NR	*****
Park et al	29	2020	South Korea	QUANT descriptive	March 2020	People living, working, and visiting in building "X" that houses commercial offices as well as residential living spaces (NA; n = 922; call centre n = 95; other commercial offices n = 2)	Call centre. Total number of employees at company is not available but potentially exposed population are as follows: 1st-6th floor commercial offices = 84; call centre (7, 8, 9, and 11th floor) = 811; 10th floor commercial office = 27	COVID-19 infection	Face-to-face interviews using standardized epidemiologic investigation forms	Face-to-face interviews using standardized epidemiologic investigation forms	*****
Pokora et al	30	2021	Germany	QUANT non-randomised	late June-early Sep 2020	Workers from meat and poultry plants (n = 19072 employees from 22 participating plants; NA; n = 880)	Meat and poultry processing plants in Germany (NA). Seven plants with many infected workers (prevalence of 10.98%), 5 plants had fewer than 10 infected (prevalence of 0.6%) and 10 plants had none, in the period from the end of June	COVID-19 infection, having a positive COVID-19 test	Self-administered questionnaire	A self-administered questionnaire and measurements of ventilation	****

							to the beginning of September 2020				
Porter et al	31	2021	USA	QUANT descriptive	Summer and early fall 2020	Seafood processing industry workers in the state of Alaska (NA; NA; n = 677)	13 different COVID-19 outbreaks in seafood processing facilities in Alaska	COVID-19 infection, having a positive COVID-19 test	Public health records on COVID-19 notifications and outbreak investigations	Public health records on COVID-19 notifications and outbreak investigations	****
Poupin et al	32	2021	France	QUAL, cross-sectional	Apr 2020	Nursing home staff (n = NA; NR; n = 6)	100-resident nursing home (60 workers)	COVID-19 outbreak management and prevention	Meetings between nursing home staff and mobile multidisciplinary team	Meetings between nursing home staff and mobile multidisciplinary team	*
Rovers et al	33	2020	Netherlands	QUANT descriptive	13th Mar 2020 - 14th Apr 2020	HCWs (NA; NR; 12 confirmed, 18 suspected)	480-bed acute care hospital, outbreak was limited to 18-bedded psychiatric ward (70 workers)	COVID-19 infection	Whole genome sequencing, spanning tree	Survey, interview, employees' working schedules and patients' medical records	****
Sami et al	34	2021	USA	QUANT descriptive	23rd Apr 2020 - 29th Apr 2020	Federal Emergency Management Agency (FEMA) staff (n = 466; NR; n = 15)	Open office space building (NR)	COVID-19 infection	Antibody test (ELISA)	Survey	****
Sarti et al	35	2021	Italy	QUAL case study	20th Nov 2020-7th Dec 2020	Office workers (n = 6; NR; n = 5)	Office (NR)	COVID-19 infection	Phone interview	Phone interview	*****
Schneider et al	36	2020	Germany	QUANT descriptive	1st Mar 2020-30th Apr 2020	HCWs (NA; NR; n = 23 HCWs and n = 1 patient	Hospital setting (NR)	COVID-19 infection	Lab specimen, surveillance data	Company surveillance	***
Steinberg et al	37	2020	USA	QUANT descriptive	Mar-Apr 2020	Employees of a meat processing plant and their contacts (NA; n = 3,635, n = 929)	A meat processing facility in South Dakota, USA (3,645 employees)	COVID-19 infection, having a positive COVID-19 test	Public health records, company records workforce testing and survey	Public health records on COVID-19 notifications and outbreak investigations	*****

										interview to identify contacts	
Tanislav et al	38	2021	Germany	QUANT descriptive	NR	HCWs (NA; n = 102 (n = 74 vaccinated and n = 28 unvaccinated); n = 14)	Hospital, geriatric care unit (NR)	Key factors for outbreak response	Workplace testing	NR	***
Venkatachalam et al	39	2021	Singapore	QUAN, descriptive	6th Jan 2020 - 16th Mar 2020	HCWs (NA; n = 32; n = 5, 2 medical social workers, 1 psychologist, 1 nurse and 1 researcher	Hospital with 1,946 workers	COVID-19 infection	Data collected as part of surveillance and outbreak management	Data collected as part of surveillance and outbreak management	*****
Waltenburg et al	40	2020	USA	QUANT descriptive	April–May 2020	Workers in the meat and poultry processing facilities in the US (112,616 across 239 affected facilities in the USA; NA; A total of 16,233 cases in 239 facilities in 23 states)	239 meat and poultry process facilities with recorded "outbreaks" since the start of the pandemic through to 31 May 2020, in 23 states in the US, were included	COVID-19 infection, COVID-19 related mortality	State surveillance data as well as information from direct observation or from facilities	State surveillance data as well as information from direct observation or from facilities	*****
Wang et al	41	2020	China	QUANT descriptive	25th Dec 2019 - 15th Feb 2020	HCWs (n=118; NR; n=12, 4 doctors and 8 nurses)	Hospital	COVID-19 infection	Lab specimen	Survey	*****
Wee et al	42	2020	Singapore	QUAN, descriptive	1st Jan 2020-22nd April 2020	HCWs (NA; 2,250 (51.0%) were for acute respiratory illness symptoms.2,090 (92.8%) examined and 1,642 (72.9%) tested; n=14, 10 (71.4%) were nonmedical personnel: 2 medical social workers, 1 psychologist, 2 researchers, 1 administrative staff, and 4 cleaners	Largest public tertiary-care hospital in Singapore, with 1,785 beds	COVID-19 infection	Lab specimen	Data collected by the hospital's Infection Prevention and Epidemiology department	*****

Wei, Yuan and Cheng	43	2020	China	QUANT descriptive	NR	HCWs (NR; n=19; n=14)	Hospital	COVID-19 infection	Lab specimen	NR	**
Weissberg et al	44	2020	Switzerland	QUAL, cohort study	NR	Office workers (n=13; n=13; n=11)	700m2 sized open-plan office with personal desk space	COVID-19 infection	Lab specimen	Semi-structured telephone interviews	*****
Yau et al	45	2021	Canada	QUAL, grounded theory	June 2020-July 2020	LTCF staff (n = 23; NR; NR)	LTCF (multiple facilities)	Key factors for outbreak response	Semi-structured interviews	Semi-structured interviews	*****
Zawitz, Chad et al	46	2021	USA	QUANT descriptive	1st Mar 2020 - 30th Apr 2020	Prison staff (also detainees) (NR; not available; n = 279)	Very large prison in Chicago with an average daily number of 5,800 persons, including 2,577 workers (2,370 as of 1st March and 270 more added during outbreak)	COVID-19 infection	Illinois's National Electronic Disease Surveillance System (I-NEDSS)	Documentation of interventions	**
Zollner-Schwetz et. al.	47	2021	Austria	QUANT descriptive	22nd March 2020 - 14th Apr 2020	HCWs (NR; NR; n = 19)	3 LTCFs under Geriatric Health Center of the City of Graz with 283 workers	COVID-19 infection	NR	Structured questionnaire	**

Abbreviations: *ELISA* Enzyme-linked immunosorbent assay, *FQHC* Federally Qualified Health Centre, *HCWs* Healthcare workers, *LTCF* Long-term Care Facility, NA Not applicable, *NR* Not reported, *QUAL* Qualitative, *QUAN* Quantitative

The PROTECT COVID-19 National Core Study on transmission and environment is a UK-wide research programme improving our understanding of how SARS-CoV-2 (the virus that causes COVID-19) is transmitted from person to person, and how this varies in different settings and environments. This improved understanding is enabling more effective measures to reduce transmission – saving lives and getting society back towards 'normal'.

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