PEROSH Project "Lessons learned for OSH from the COVID-19 pandemic"

Country report for England

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Workplace Health and Safety Lessons from the COVID-19 Pandemic: Insights from Investigating Workplace Outbreaks in England

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Executive Summary

This report presents a detailed review of how COVID-19 affected occupational safety and health (OSH) in England and outlines key lessons for future pandemic preparedness. It draws on workplace outbreak investigations, scientific studies, and workplace assessments to inform future planning and resilience.

COVID-19, caused by the highly transmissible SARS-CoV-2 virus, led to major health, social, and economic challenges worldwide. By June 2023, the UK had recorded an estimated 225,000 excess deaths. A judge-led COVID-19 Inquiry in the UK has examined the pandemic's impact and identified lessons to improve future preparedness, recognising that future pandemics are likely.

Unlike SARS-CoV-1, which was mostly limited to healthcare settings, SARS-CoV-2 spread rapidly across many types of workplaces. This highlighted the need for infection-resilient work environments to protect workers' health and ensure business continuity.

Workplaces could be key sites of virus transmission, especially in sectors where remote work was not possible. High-risk jobs included healthcare, social care, education, transport, manufacturing, and public services. The COVID-OUT study, part of the UK's PROTECT National Core Study, investigated 20 workplace outbreaks across diverse sectors. It found that close contact, poor ventilation, and lack of financial support for self-isolation were important transmission risk factors. Although many control measures, such as face coverings, testing, and cleaning were used, their effectiveness varied due to workplace conditions and human behaviour. Surface sampling showed low risk from contaminated surfaces, while ventilation and administrative controls were found to be crucial but often poorly understood or applied.

The report emphasises the need for a layered, risk-based approach to reduce transmission risks, guided by the Hierarchy of Controls. It recommends better ventilation standards, fair sick pay policies, and workplace-specific risk assessments. It also highlights the importance of strong occupational data systems to support real-time monitoring and targeted responses. Linking public health and workplace data was key to identifying outbreak patterns and informing policy.

To prepare for future pandemics, a joined-up approach is needed, one that integrates OSH into wider public health planning. This includes having pre-approved emergency research protocols, collecting occupational data routinely, investing in behavioural science to support long-term safety practices, and strengthening international cooperation. The report calls for a coordinated, system-wide response to future health emergencies to protect both workers and the wider community.

1. Introduction

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is a highly transmissible virus that caused widespread coronavirus disease (COVID-19) and a global pandemic. SARS-CoV-2 virus spreads both directly and indirectly from person to person primarily through respiratory droplets and aerosols, and can be transmitted by individuals who are asymptomatic, pre-symptomatic and symptomatic (1). By June 2023, the pandemic had resulted in an estimated 225,000 excess deaths in the United Kingdom (UK) alone.

In the UK, a judge-led COVID-19 Inquiry, composed of 10 modules, was established to investigate the pandemic's impact and lessons for the future. The first report, Module 1, focused on the UK's resilience and preparedness and was published in July 2024 (2), while the inquiry in other modules continues. The report showed that before the COVID-19 pandemic, the UK has already faced significant social inequalities and economic challenges. Public services, particularly health and social care, were operating at or beyond capacity even in normal times, which increased the country's vulnerability to the disruptive impact of the COVID-19 pandemic. The report concluded that the country's preparedness and resilience were inadequate for a pandemic of this magnitude. It also found a failure to learn fully the lessons from previous civil emergency exercises and infectious disease outbreaks.

The UK's first confirmed COVID-19 cases were identified on 29 January 2020. The first national lockdown was announced on 23 March 2020, with closures of non-essential businesses and schools forming part of the strict measures.

The UK government, led by the Prime Minister, coordinated the national pandemic response across government departments and agencies. Scientific advisory groups, such as Scientific Advisory Group for Emergencies (SAGE) and New and Emerging Respiratory Virus Threats Advisory Group (NERVTAG), and the Environmental and Modelling Group (EMG) provided expert input to inform national policy decisions and operational planning.

The overall response was predominantly top-down, with decisions made nationally and implemented locally. This approach often led to siloed operations, with limited coordination across national, regional and local levels. Mandatory measures included lockdowns, stay-at-home orders, social distancing, and quarantine requirements, all of which were legally enforced. Voluntary measures included hand hygiene and vaccination. While care home staff were briefly required to be vaccinated, this policy was later reversed. Mask-wearing evolved from being recommended to mandatory in some contexts.

Local authorities, including Local Resilience Forums and Directors of Public Health, were key players in implementing public health measures. However, their roles were not always well-integrated into the national response. This lack of coordination sometimes hindered the effectiveness of local interventions.

In England, multiple organisations were responsible for the workplace pandemic response. Public Health England (PHE), now succeeded by the UK Health Security Agency (UKHSA), led on public health advice and infection prevention and control for all settings including workplaces. The Department for Business, Energy & Industrial Strategy (BEIS), with input from local authorities, provided sector-specific guidance to support the workplace COVID-19 pandemic response. As Great Britain's national regulator for workplace health and safety, the Health and Safety Executive (HSE) had primary technical and administrative responsibility for the workplace COVID-19 response, including inspections and other measures to ensure compliance with safety requirements such as social distancing, ventilation, and use of personal protective equipment (PPE).

Public Health England (PHE) and local Directors of Public Health were primarily responsible for managing workplace COVID-19 outbreaks through contact tracing, risk assessments, and public health interventions. They collaborated with local authorities to implement control measures. HSE was brought in when workplace conditions contributed significantly to outbreaks, ensuring compliance with health and safety regulations, and enforcing corrective actions where necessary. Local authorities also played a key role in enforcement and response coordination, particularly in sectors such as hospitality and retail.

During the COVID-19 pandemic, workplaces in England implemented a range of occupational safety and health (OSH) measures. These included both technical controls and administrative strategies, which were adopted at different times and varied by sector. Ideally, these measures were based on appropriate risk assessments tailored to specific workplace environments and were part of a multi-layered approach to reduce transmission risks and ensure business continuity while protecting worker health. In practice, compliance varied across sectors, influenced by factors such as the nature of work, organizational resources, and workforce attitudes and behaviours. For instance, office-based businesses adapted more easily to remote work, whereas industries like construction and manufacturing faced difficulties in maintaining physical distancing and hygiene. Smaller businesses often lacked the resources and infrastructure to implement safety measures as effectively as large organisations with dedicated health and safety teams. Moreover, frequently changing government guidance, often reactive and inconsistently applied, led to confusion. Regular updates on mask mandates, social distancing rules, remote work policies, and sector-specific restrictions posed ongoing challenges for consistent compliance across workplaces. Careful review of workplace responses to COVID-19 can highlight broader systemic challenges in public health infrastructure, inter-agency coordination, and policy implementation, which will in turn inform future pandemic planning.

The UK Covid-19 Inquiry Module 1 report highlighted compelling evidence that another pandemic—potentially more transmissible and lethal than COVID-19—is likely in the near to medium future. It stressed that, unless lessons from COVID-19 are learned, and fundamental changes are implemented, the efforts and costs endured thus far will be in vain in the face of the next pandemic. The report recommended that responsibility for a whole system civil emergency preparedness and resilience in the UK be assigned to the relevant government leader.

Learning from COVID-19 is essential for preparing for future pandemics, which could arise unexpectedly from infectious pathogens different from SARS-CoV-2. A lack of infection resilience incurs substantial social and economic costs. Lessons from the workplace health and safety perspective are crucial for protecting workers' health, safety, and well-being and for strengthening businesses' resilience against future threats. These lessons can also foster a more adaptable, resilient, and supportive work environment.

This report is intended as an initial assessment, not an exhaustive one. It begins by examining the impact of the COVID-19 pandemic on workers and workplaces, followed by an analysis of insights from workplace outbreak investigations in England as well as broader UK-based scientific literature. Synthesising evidence from relevant scientific studies, this report seeks to shed light on the complexities of SARS-CoV-2 transmission within workplaces and its impact on workers' health. Each included study has limitations and potential biases. Most of the evidence gathered provides associative rather than causal insights.

The key lessons learned are summarised in three areas: mitigating SARS-CoV-2 transmission risks in the workplace, accelerating evidence-gathering to support pandemic response and the need for better occupational data, and fostering a systematic approach to pandemic preparedness and resilience.

2. Part 1: Impact of COVID-19 Pandemic on Workplaces

Unlike SARS-CoV-1, which was largely confined to healthcare settings, SARS-CoV-2 spread rapidly throughout the broader community, affecting diverse workplace environments. The case fatality rate for SARS-CoV-1 was around 10%, while SARS-CoV-2's case fatality rate is estimated to be between 0.5% and 1%(3). SARS-CoV-1 generally led to severe symptoms, enabling early detection, isolation, and hospitalisation, which limited its spread largely to healthcare workers. SARS-CoV-2, however, frequently caused mild or no symptoms, complicating early detection and isolation efforts. Significant asymptomatic and pre-symptomatic transmission increased its ability to spread wider and faster, reaching across both communities and workplaces.

From the pandemic's onset, workplaces were recognised as potential sites for transmission. Employees were initially advised to work from home if possible, and those who couldn't were guided to maintain physical distancing and practice frequent cleaning. As understanding of virus transmission evolved, additional protective measures were introduced, including screening tests, face coverings, ventilation, and other interventions as they became available.

Lockdowns, which included travel restrictions, closures of non-essential settings, and stay-at-home orders, were among the most intensive yet effective measures for curbing the spread of SARS-CoV-2 in the community. However, they also had broad and significant negative impacts on mental and physical health, education, society, and the economy (4). Despite lockdowns, many businesses continued to operate, and employees in essential sectors were required to commute to their workplaces. The impact of this continued operation on infection spread and workers' health risk proved challenging to measure.

According to the 2021 UK census, 26 million (55.7%) of the 46 million residents aged 16 and over in England were in employment, excluding full-time students(5). There were 2.4 million businesses in England, majority of these were micro businesses with fewer than 10 employees, and only 45,590 (1.9%) enterprises employed over 50 people **(Table 1)**. Approximately 30% of adult workers continued to commute to work during the first lockdown in May 2020, a figure that rose to 50% by May 2021(6) **(Figure 1 & Figure 2)**.

Table 1: Business Counts – enterprises by industry and employment size band in England, 2021

Industry	Micro (0 to 9)		Small (10 to 49)		Medium-sized (50 to 249)		Large (250+)		Total enterprises
	Number	%	Number	%	Number	%	Number	%	Number
1 : Agriculture, forestry & fishing (A)	88,285	96.07%	3,140	3.42%	405	0.44%	70	0.08%	91,900.00
2 : Mining, quarrying & utilities (B,D and E)	10,245	82.62%	1,680	13.55%	345	2.78%	130	1.05%	12,400.00
3 : Manufacturing (C)	95,425	79.52%	18,410	15.34%	5,160	4.30%	1,010	0.84%	120,005.00
4 : Construction (F)	298,060	94.93%	14,025	4.47%	1,645	0.52%	255	0.08%	313,985.00
5 : Motor trades (Part G)	62,165	91.86%	4,690	6.93%	630	0.93%	190	0.28%	67,675.00
6 : Wholesale (Part G)	79,020	83.09%	13,235	13.92%	2,410	2.53%	440	0.46%	95,105.00
7 : Retail (Part G)	176,500	91.51%	14,575	7.56%	1,370	0.71%	420	0.22%	192,865.00
8 : Transport & storage (inc postal) (H)	114,375	93.17%	6,705	5.46%	1,325	1.08%	350	0.29%	122,755.00
9 : Accommodation & food services (I)	108,130	77.71%	27,895	20.05%	2,550	1.83%	570	0.41%	139,145.00
10 : Information & communication (J)	185,015	93.93%	9,580	4.86%	1,985	1.01%	400	0.20%	196,980.00
11 : Financial & insurance (K)	50,560	91.74%	3,245	5.89%	940	1.71%	370	0.67%	55,115.00
12 : Property (L)	88,255	93.88%	5,065	5.39%	485	0.52%	205	0.22%	94,010.00
13 : Professional, scientific & technical (M)	381,480	93.89%	20,580	5.07%	3,515	0.87%	710	0.17%	406,285.00
14 : Business administration & support services (N)	185,820	90.19%	15,520	7.53%	3,685	1.79%	1,010	0.49%	206,035.00
15 : Public administration & defence (O)	6,265	88.80%	305	4.32%	145	2.06%	340	4.82%	7,055.00
16 : Education (P)	30,435	73.52%	6,220	15.03%	3,320	8.02%	1,420	3.43%	41,395.00
17 : Health (Q)	63,575	69.95%	21,690	23.87%	4,600	5.06%	1,020	1.12%	90,885.00
18 : Arts, entertainment, recreation & other services (R,S,T and U)	137,435	90.20%	12,775	8.38%	1,765	1.16%	390	0.26%	152,365.00
Total	**2,161,050**	**89.82%**	**199,325**	**8.28%**	**36,285**	**1.51%**	**9,305**	**0.39%**	**2,405,965.00**
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Figure 1: The proportion of working adults reporting working from home or travelled to work.
Source: Office for National Statistics (ONS) – Opinions and Lifestyle Survey
(https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/businessandindividualattitudestowardsthefutureofhomeworkinguk/apriltomay2021)

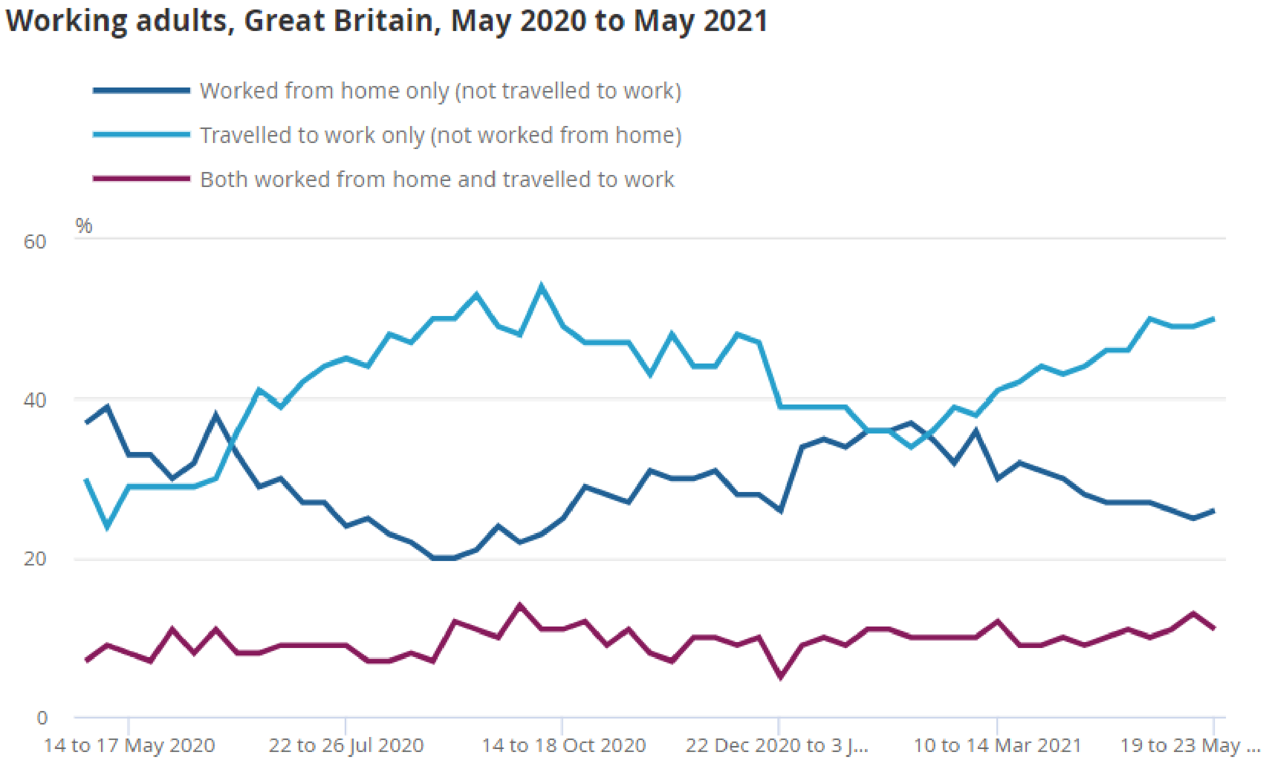
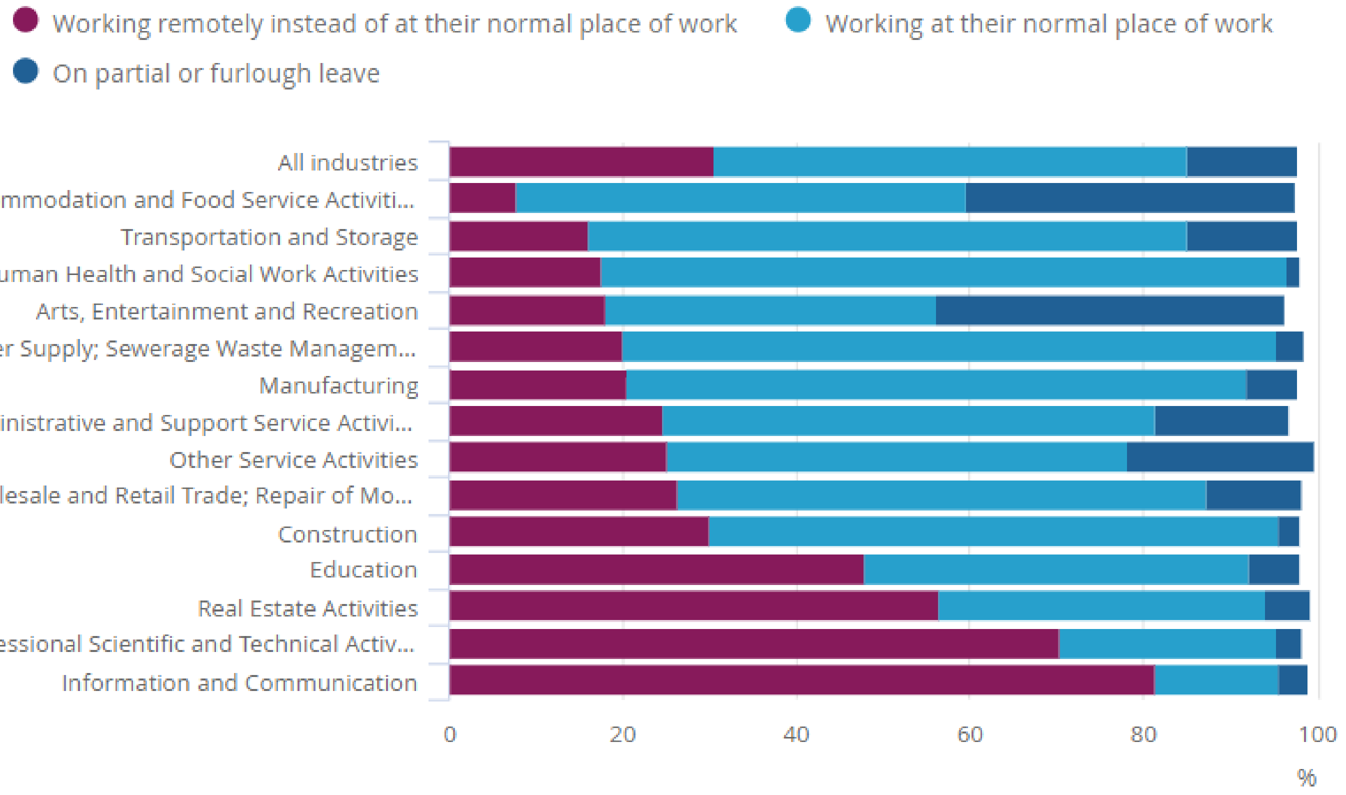


Figure 2: The proportion of working adults reporting working from home or travelled to work by industry sector, April 2021
Source: Office for National Statistics (ONS) – Opinions and Lifestyle Survey (https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/businessandindividualattitudestowardsthefutureofhomeworkinguk/apriltomay2021)



2.1. Occupations with Increased risk of COVID-19

Early in the COVID-19 pandemic, scientific evidence suggested that occupational exposure could play a significant role in SARS-CoV-2 infection risk, particularly for workers in close-contact roles who could not work remotely (7, 8). Those in essential jobs, particularly where physical proximity to others was necessary, faced elevated risks. Key workers, including healthcare and social care personnel, were found to have greater exposure and increased risk of COVID-19 infection (9).

One study of excess mortality (10) analysed the data from the Office for National Statistics (ONS) to assess all-cause mortality among adults, aged 20-64 years at the time of deaths, in England and Wales between 2015 and 2020, focusing on the impacts during the pandemic's peak in 2020. This study highlighted essential workers consistently experienced higher excess mortality, especially healthcare workers. Particularly, medical support staff had the highest excess mortality (22.3%), followed by workers in transport (9.2%), social care (7.7%) and education (3.4%). These findings underscored the need for enhanced protective measures and targeted interventions for high-risk occupational groups.

Further analysis of ONS COVID-19 infection survey data (11), covering 312,304 working-age adults from April 2020 to November 2021, identified elevated infection risks in specific occupations, including police, bus drivers, education workers, and social care workers. Healthcare workers faced high infection risk initially, but these risks decreased over time, likely due to vaccinations and improved protection measures. However, education and social care workers continued to face high infection risks, indicating a need for additional mitigations like enhanced ventilation and distancing measures in these sectors. The study recommended workplace polices should be responsive to evolving pandemic risks.

The Virus Watch prospective cohort study (12), following over 15,000 participants in England and Wales up to April 2022, observed increased infection risk in nurses, doctors, carers, primary and secondary school teachers, and teaching support workers, with risks diminishing in later stages of the pandemic except in education roles where risk remained high. The study emphasised the importance of tailored interventions, such as better ventilation in schools, to address occupational risks that persisted despite other controls.

The UK Industrial Injuries Advisory Council (IIAC) reviewed the evidence in 2021(13), recognising certain high-risk occupations, especially in healthcare, social care, and transport(e.g. bus and taxi drivers), facing increased COVID-19 infection and mortality risks during the first wave of the pandemic. An updated 2022 review(14) reaffirmed that health and social care workers continued to experience elevated risks of infection, subsequent illness and death, but data were inconsistent for other sectors like transport, while education and retail lacked sufficient evidence, suggesting that complete prevention in workplaces was challenging due to asymptomatic spread and multiple transmission routes. The council stressed continuous monitoring and adaptation of preventative measures based on emerging evidence.

In a study analysing the impact of vaccination rates on differences in infection risks between occupational groups(15), variations in COVID-19 risk were linked to differences in vaccination coverage across occupational groups. Lower vaccination rates in food processing, personal care, and hospitality sectors corresponded with higher infection risks, while education and social care workers faced continued risks even with high vaccination coverage. These findings suggested that while vaccines were critical, workplace conditions and practices also significantly influenced transmission.

Another comprehensive review (16) synthesised data from European population cohorts to analyse risks of SARS-CoV-2 infection, COVID-19 hospitalisation and mortality by occupation across different pandemic waves. The review found that healthcare, social care, education, transport, and food production sectors saw elevated risks, particularly during early pandemic waves. Healthcare workers initially experienced the highest risks, which declined with the introduction of PPE and vaccines. Education sector risks persisted, but severe outcomes did not increase. Social care workers, especially nursing aides, showed higher infection and severe disease rates. Transport and food production workers had elevated early risks, but these did not persist. The study findings suggest that the role of occupation in transmission rates diminished as non-workplace mixing increased and highlight the importance of targeted prevention strategies, such as robust PPE and early vaccination, not only for healthcare workers but also for other high-risk occupations like those in education, social care, and transport sectors.

2.1.1. Impact of COVID-19 on high-risk occupations

The above studies consistently show that healthcare, social care, and education workers experienced elevated COVID-19 infection risks, especially in the early waves of the pandemic. Among healthcare workers, infection rates declined in later waves due to early access to vaccines and the use of PPE, affirming these as critical control measures. In contrast, education and social care workers continued to face sustained infection risks, underlining the need for additional protective measures, such as improved ventilation and tailored protocols.
The studies also highlight some inconsistencies. Despite high vaccination coverage in many sectors, infection rates varied, suggesting that mitigation measures (like PPE and ventilation) played a critical role but were inconsistently effective across different occupational settings. These findings underscore the complex relationship between occupation, workplace conditions, and pandemic control measures, emphasising the need for adaptable, targeted interventions to protect high-risk occupational groups effectively.

The pandemic’s impact was particularly severe on occupations that required physical presence in the workplace, involving higher physical proximity over extended periods. Workers in roles with limited remote work options, such as healthcare, retail, and logistics, faced higher risks of infection, hospitalisation, and premature mortality. Requiring more workers to physically attend workplaces raised transmission risks, especially when those who were unwell continued working due to limited sick leave options or lack of financial compensation. Socioeconomic factors outside the workplace, such as household size, socioeconomic inequalities, and financial barriers to isolation, compounded these risks.

The pandemic also significantly impacted workers' mental health and well-being, particularly for those in high-stress roles. This highlights the need for robust mental health support systems and resilience training tailored for essential and frontline workers. Establishing psychological support for workers in high-stress environments is crucial to prepare for future emergencies effectively. These disparities also highlight the importance of addressing health inequalities in future pandemic planning to quickly identify and protect high-risk occupational groups.

2.2. COVID-19 Outbreaks in Workplace Settings

Workplaces emerged as key sites for COVID-19 transmission during the pandemic. In October 2020, Public Health England (PHE), now the UK Health Security Agency (UKHSA), reported 503 outbreaks in workplaces over four weeks, compared to 720 in care homes, 853 in education, and 89 in hospitals. A study by the European Centre for Disease Prevention and Control (ECDC) reported 1,377 COVID-19 clusters in workplaces across 13 EU/EEA countries and the UK from March to July 2020, with the majority in long-term care facilities

(591 clusters) and hospitals (241), followed by food processing (153), non-food manufacturing (77), and office environments (65)(17).

However, the total number of settings and the number of people exposed within these settings could vary significantly. Without these denominator data it was challenging to assess which workplace types were most at risk. This gap limited early insights into transmission risks and the effectiveness of workplace-specific mitigation measures, particularly in non-healthcare settings. Recognising this limitation, Theme 1 of the UK PROTECT COVID-19 National Core Study(18) fostered a collaboration between PHE and the Health and Safety Executive (HSE) in July 2020, linking the workplace outbreak database with the UK business register. This linkage provided essential denominator data, enabling a detailed analysis of outbreak rates in non-healthcare sectors by industry, region, and enterprise size(19).

The findings highlighted that, while retailers had the highest number of outbreaks (219), food manufacturers had the highest outbreak rate after factoring in denominator data: 1,672 outbreaks per 100,000 workplaces **(Table 2)**. Warehousing and non-food manufacturing followed with rates of 385 and 308 per 100,000, respectively. This pattern was consistent across multiple regions in England and underscored sectors with high production demands and limited remote work options faced elevated transmission risks. These insights underscored the need for targeted investigation into high-risk workplaces to inform better management and outbreak prevention strategies.

Table 2: Number and rate of workplace outbreaks by sector in England, May-Oct 2020

Sector	Number of Outbreaks	Number of Workplaces	Outbreak Rate (per 100,000)
Manufacturers and packers of food	117	6,998	1,672
Warehouses	58	15,058	385
Manufacturers and packers of non-food	195	63,312	308
Retailers	219	195,025	112
First responders/Military sites	57	67,257	85
Distributors and transporters	84	125,414	67
Restaurants and caterers	53	117,836	45
Offices	193	721,351	27
Close contact services	13	52,866	25
No setting type assigned	54	511,071	11
Primary producers	8	93,086	9
Other	266	-	-
Total	1,317	1,969,274	67

The innovative approach of linking national data systems enabled a novel assessment of outbreak rates by industry and geography. This data linkage approach subsequently gained broader adoption by UKHSA to support pandemic response efforts. However, the study also noted limitations, including potential underreporting of outbreaks in smaller enterprises, operational changes affecting data collection and lack of standardised industry grouping system to facilitate data linkages. These findings highlight the importance of robust, consistent data collection to enable accurate outbreak assessments across diverse workplace settings.

Ongoing collaboration between HSE and UKHSA facilitated further linkages of national contact tracing data with business register data, allowing for the analysis of COVID-19 cluster rates, sizes, durations, and trends over time within various sectors(20). This expanded analysis revealed higher transmission risks in schools, hospitals, public service sectors, food manufacturing, and warehousing **(Table 3)**. Additionally, a novel approach was introduced to track infectious case clusters at the individual building level, advancing infectious disease detection beyond COVID-19.

Table 3:
Number and rate of COVID-19 clusters associated with the workplace In England, June 2021 - February 2022

Sector	Sector subgroup	Total workplaces	Total clusters	Cumulative cluster rate/100,000 workplaces
Education		72,998	33,872	46.40
	Secondary education	8,480	12,593	148.50
	Primary education	22,719	17,136	75.43
	Higher education[a]	2,414	1,614	66.86
Human health & social work		158,880	19,852	12.49
	Hospital	5,434	2,423	44.59
	Residential care	30,598	5,383	17.59
	Social work without accommodation	55,382	5,960	10.76
Public services		23,372	4,298	18.39
Manufacturing		146,153	12,710	8.70
	Food & beverage manufacturing	13,185	2,153	16.33
	Non-food manufacturing	132,968	10,565	7.95
Transport, distribution & warehousing		276,373	11,639	4.21
	Warehousing & storage	9,814	1,602	16.32
	Transport (passenger)	17,062	1,243	7.29
	Postal & courier	41,774	2,049	4.90
Services[b]		1,955,835	59,311	3.03
	Accommodation & food services	212,645	16,464	7.74
	Arts & entertainment & recreation	84,682	4,373	5.16
	Retail trade	322,603	15,456	4.79
Waste management & remediation		9,514	518	5.44
Utilities		20,413	897	4.39
All sectors		3,154,847	145,971	4.63

a: May include students as well as staff, aged >18
b: Services sector excludes public service activities, telecom, and distribution & warehousing

2.2.1. Factors associated with COVID-19 workplace outbreaks.

COVID-19 transmission in workplaces results from a complex mix of environmental, human, and socioeconomic factors(21). Workplace transmission risks vary across settings and depend on density, contact duration, interaction dynamics, number of at-risk contacts, and mitigation measures. COVID-19 exposure in workplaces is not isolated but interconnected with broader community transmission.

A study by Rhodes et al.(22) examined job characteristics influencing SARS-CoV-2 infection, applying a COVID-19 job exposure matrix (JEM) to infection data from the Office for National Statistics (ONS) Coronavirus Infection Survey (244,470 participants) and Virus Watch Cohort (16,801 participants) in the UK. This analysis linked certain job characteristics—such as number of workers, nature of contacts, contact via surfaces, indoor or outdoor location, ability to social distance, and use of face covering —that increased risk of infection. Over time, these associations weakened, likely due to evolving workplace policies, enhanced mitigation measures, and rising vaccination rates. The findings emphasised the importance of workplace-specific factors in infection risk and the need for continuous adaptation in exposure assessments and workplace policies to effectively mitigate infection risks.
A systematic review conducted by Clayson(23) identified risk factors reported in studies of workplace COVID-19 outbreaks globally, including those in healthcare, food production, offices, and custodial settings. High-density environments, poor ventilation, shared facilities, low use of face coverings, night shifts, shared accommodations, multi-site roles, and high

community infection rates were among the primary risk factors. The mitigation measures observed across different sectors included testing, physical distancing, ventilation, mandatory face coverings, and staff training. This review stressed the importance of tailored interventions by setting, as well as improved data systems and community prevalence monitoring to inform workplace mitigation measures.

2.2.2. COVID-19 workplace outbreak risk model and analysis

Workplaces were at increased risk of COVID-19 outbreaks because when workers came to work, they brought together the potential for transmission. Workplace outbreaks not only presented risks to individual workers but also amplified community spread. Investigations of COVID-19 outbreaks in high-contact sectors like health and social care, education, transport, and large gatherings were critical in informing protective measures that sustained essential services and safeguarded the economy. In the UK, the PROTECT COVID-19 National Core Study enabled comprehensive research into workplace COVID-19 outbreaks, generating valuable insights into transmission risks and controls across multiple sectors(18).

Leveraging collaborations between the Health and Safety Executive (HSE) and the UK Health Security Agency (UKHSA), researchers from Theme 1 of PROTECT linked diverse datasets—such as NHS contact tracing, vaccination, and census data—to analyse outbreak risks across industries. These linkages provided standardised classifications for job roles and economic activities, essential for evaluating workplace transmission risks. Using the national linked data sets, research by Overton et al. (24) found that physical proximity in the workplace was a primary factor for outbreaks in most industries, while increased vaccination was associated with reduced risk. However, in the education sector, vaccination was associated with increased risk during the Delta period, likely due to the lack of vaccination among students. The findings suggested that reducing physical proximity in the workplace can significantly lower the risk of workplace outbreaks, supporting the need for effective social distancing measures. In addition, increasing vaccination rates among employees can contribute to reducing the risk of workplace outbreaks, although the impact may vary by industry and demographic factors. Despite primarily protecting against severe disease rather than infection, vaccination has been shown to reduce the length of the infectious period in infected individuals(25), which could reduce the length of time workers are exposed to infectious individuals, thus reducing the chance of infection.

The study highlighted that a higher proportion of employees of Black, African, or Caribbean descent or those living in deprived areas correlated with increased outbreak risks in most industries. In contrast, older workers, particularly those aged 60-64, appeared at a lower risk, potentially due to targeted public health messaging for vulnerable populations. These demographic findings align with other studies and underscore the need to address age, ethnicity, and socioeconomic disparities in workplace protection strategies.

Employee commuting patterns also impacted workplace outbreak risks. High use of taxis, a term used in the database to describe travel as passenger in a private car, or other forms of transport correlated with higher risks, while train travel and single-occupancy vehicles posed lower risks, potentially due to enforced distancing measures on trains or a higher immunity rate among public transport users. These findings suggest that promoting safe commuting, such as discouraging car sharing, could reduce workplace transmission risks.

Employment contract stability also influenced outbreak risks: permanent contracts generally lowered risk across industries, with an exception in construction, where it correlated with increased risks. This indicates that job stability may be a critical factor in managing workplace transmission risks.

Through partnerships among UKHSA, ONS, the University of Manchester, and HSE, this research applied infectious disease epidemiology principles to explore transmission patterns by tracking where people live, where people work, and work commute methods. The study identified high-risk workplace settings and examined complex social, environmental, and behavioural factors, which may support a broader approach in workplace health research. Such approaches, including data linkages for detailed workforce, geographic, and transmission analysis, provide a model for supporting public health responses to future pandemics. Additionally, this work highlighted the need for robust multidisciplinary teams, timely data access, and the capacity to create heatmaps and cluster analyses to inform effective transmission risk management.

While the national data linkages study was successful in identifying outbreak risk factors, it was limited in evaluating the specific mitigation measures applied across real workplace settings. To address this, the COVID-OUT study, also part of Theme 1 PROTECT COVID-19 National Core Study, was launched to investigate risk factors and control measures through systematic data collection in workplaces actively experiencing outbreaks. This focused approach further refine our understanding of workplace mitigation strategies.

3. Part 2: Mitigating SARS-CoV-2 Transmission Risks in the Workplace - Insights from the COVID-OUT - workplace outbreak investigation field studies

The COVID-OUT (COVID-19 Outbreak Investigation to Understand Transmission) study applied a pre-defined protocol (26) to examine 20 workplace outbreaks across England during 2021, a time of vaccine rollout. Twelve of these sites received in-depth environmental assessments and surface microbial sampling. The study aimed to systematically gather data from various workplace settings with ongoing outbreaks to identify key transmission risks, transmission routes, and mitigation measures in place. The resulting insights are valuable for developing strategies to prevent and control outbreaks, enabling businesses to maintain operations while protecting workers' health, contributing to future pandemic preparedness. Findings of the investigations were published for outbreak sites individually and combined(27, 28), encompassing a range of sectors, including manufacturing(29-31), a large electricity-generating company(32), a public-facing office(33), a public order and safety(34), a storage and distribution centre(35), and a scientific conference(36).

3.1. COVID-OUT studies

3.1.1. Case Study: Investigation of a COVID-19 Outbreak at an Automotive Manufacturing Site(29)

One COVID-OUT investigation was conducted at an automotive manufacturing site in England, where 51 out of 266 workers (a 19.2% attack rate) were infected. The outbreak coincided with England's third lockdown, during which community cases were generally declining.

The highest infection rates were identified in production, assembly, and finishing areas (28%), followed by the office space (21.3%), with no cases detected in the warehouse (0%). Despite preventive measures—face coverings, social distancing, and hand-sanitising stations—lapses in social distancing and inconsistent hand hygiene were observed. Remote work was offered to office workers three days a week. After an initial one-month site closure after the outbreak, the company phased its reopening, including training on new infection control measures.

In response to the outbreak, the company introduced daily lateral flow device (LFD) testing (later reduced to weekly) and implemented an internal contact tracing system. While office workers received full sick pay, production and warehouse staff were only eligible for statutory sick pay after a three-day waiting period, which may have discouraged adherence to self-isolation guidelines. Daily compliance checks on face covering were implemented. Screens were installed between workstations with workers facing each other but not between those working side by side. "Bubbles" were formed within production teams to limit cross-contact, although office staff—who frequently interacted with production employees—were not included in these bubbles. This may explain the similar infection rates in office and production areas, despite the remote work policy for office workers.

Despite high compliance observed, 42.9% of the 38 workers who took part in the questionnaire survey reported close physical contact with colleagues. Vaccination rates were also notably low, with only 10.5% of workers vaccinated, compared to 43.3% in the surrounding community. Financial concerns posed significant challenges, with 73.7% of workers worried about income loss from isolation and 34.2% concerned about job security.

Lessons learned from the automotive manufacturing outbreak.

The manufacturing sector is especially prone to SARS-CoV-2 outbreaks due to the necessity of on-site work, close worker proximity, and prolonged interactions. These factors contributed to the high attack rates observed in densely populated production areas.

Financial concerns surrounding isolation may lead to presenteeism, where symptomatic employees or close contacts still come to work. Transparent communication on available support and equitable sick pay policies are essential for addressing these concerns. Ongoing training in COVID-19 preventive measures and regular compliance checks are critical to ensure adherence and address lapses swiftly.

The manufacturing sector requires specific support to address its unique challenges, including practical solutions for social distancing, appropriate face coverings usage, and adequate financial support for workers to encourage compliance with health measures.

3.1.2. Case Study: Investigation of a COVID-19 Outbreak at a Plastics Manufacturing Plant(31)

In March 2021, during the UK's third national lockdown, a COVID-19 outbreak with an attack rate of 14.3% (33/231 workers) occurred at a plastics manufacturing plant. The outbreak investigation uncovered several workplace dynamics contributing to virus transmission. Workers often operated in close proximity, with noise levels in the manufacturing area reaching 79dB, making communication at a two-meter distance difficult, especially when workers wore face coverings. Social distancing was inconsistent at high-traffic points, particularly around a drink station where face coverings use was sporadic.

Ventilation at the plant was generally adequate; however, the technical office exceeded the recommended CO_2 levels (1,500 ppm) on 12 occasions over 30 days, with readings peaking at 2,100 ppm during periods of high occupancy—likely contributing to increased transmission risk.

Prior to the outbreak, the plant's infection control measures included weekly LFD testing, hand sanitising stations, social distancing signage, and once-per-shift cleaning. After the outbreak, the company intensified these efforts: LFD testing increased to twice weekly, surgical masks and face shields were distributed, ventilation was improved by opening windows and doors more frequently, and electrostatic sanitising devices were added. The local authority also established a temporary on-site RT-PCR testing facility to help contain the outbreak.

A worker survey, although with a low response rate, revealed key behaviours: 73.1% of respondents reported close contact with colleagues during the outbreak, while 7.5% had social contacts outside of work. Only 20% of respondents reported using surgical masks or FFP2/FFP3 respirators for more than half of their workday. Additionally, vaccination rates were low, with only 12.7% of workers having received one vaccine dose prior to the outbreak. Job security concerns were widespread, with 71% of workers worried about income loss due to self-isolation or a potential plant shutdown, fostering a presenteeism culture where workers might attend work despite symptoms.

Lessons learned from the plastics manufacturing plant outbreak

Manufacturing environments present unique challenges due to limited remote work options and close worker proximity on production lines. During the outbreak, vaccines were not yet widely available for younger workers, requiring the plant to rely heavily on non-pharmaceutical measures to control transmission.

The findings emphasise the need for specific infection prevention guidance tailored to high-occupancy, enclosed manufacturing spaces. This includes multi-layered preventive measures like regular testing, face covering usage, improved ventilation, and air cleaning interventions. Facilities without mechanical systems may benefit from portable air purifiers with HEPA filters or UV systems to reduce airborne virus particles.

In addition, a comprehensive and tailored infection control strategy should consider both workplace conditions and worker concerns, for preventing future outbreaks in manufacturing settings.

3.1.3. Case Study: Investigation of a COVID-19 Outbreak in a Storage and Distribution Centre(35)

Between May and August 2021, a significant COVID-19 outbreak at a large storage and distribution centre in England resulted in an attack rate of 26.5%. The outbreak took place as the UK began exiting its third lockdown, during a period of declining local and national infection rates. Despite this, the centre’s infection rate remained high, suggesting unique workplace risk factors. The facility employed approximately 1,150 workers across different shift patterns, with half being agency staff. Although the site continued operating, some work was transferred to other locations to reduce on-site density.

Survey data, while limited by low participation, indicated that workers generally adhered to infection control measures. However, financial concerns about self-isolation were prevalent, with about a quarter of respondents reporting that they continued working despite known exposure to symptomatic contacts, reflecting a strong culture of presenteeism.

Environmental assessments further revealed that 51.3% of surface samples across the site tested positive for SARS-CoV-2 RNA, the highest contamination rate among the 12 outbreak sites tested. While RNA levels were low, frequent contamination suggested multiple transmission events, consistent with the high number of cases identified through polymerase chain reaction (PCR) and LFD testing at the facility.

The outbreak also highlighted the financial strain faced by warehouse workers. Pay rates, adjusted for inflation, have declined since 1990, and statutory sick pay in the UK—particularly relevant for agency workers—provides minimal support, covering only about 11 hours of work at minimum wage rate per week. With half of the workforce being agency employees, job insecurity and low pay likely contributed to presenteeism.

Lessons Learned from the storage and distribution centre outbreak

This investigation underscores that even when public health measures are robustly implemented, high-contact, high-density workplaces remain susceptible to outbreaks. Workplace risk assessments remain an essential tool for assessing and controlling occupational COVID-19 risks and should be routinely updated to reflect local infection rates and adjust control measures accordingly.

In addition to infection control measures, such as workplace testing programmes, adequate sick pay is essential to encourage self-isolation among workers who may otherwise attend work while potentially infectious, contributing to the spread of the virus. Preventing outbreaks in essential sectors, such as storage and distribution, is not only vital for protecting workers but also for reducing transmission to the wider community.

3.1.4. Case Study: Investigation of a COVID-19 outbreak in a large meat-processing plant(30)

In June 2021, as the Delta variant spread and local COVID-19 cases rose, a large meat-processing plant in England faced a workplace outbreak, with an attack rate of 4.1%. To assess risk factors and control measures, an investigation was conducted from June to July 2021. The plant, employing 1,541 workers across day and night shifts, saw notably higher infection rates on the night shift (11.6%) compared to the day shift (2.4%). There was daily shared transportation for 150 dayshift and 104 nightshift workers.

The plant's production lines, designed for efficiency, required workers to operate in close proximity, while high noise levels ($\geqslant$80 dB(A)) often necessitated loud communication, likely increasing aerosol transmission. Face visors were mandatory, but additional face coverings were not always used, and the facility's refrigeration system continuously recirculated chilled air. Testing revealed 11.7% of surface microbial samples across all areas were positive for SARS-CoV-2 RNA.

Ventilation was poorly understood by the company, and their COVID-19 risk assessments did not address ventilation in the production areas. Ventilation systems were maintained by external contractors, and CO_2 monitors, typically used to estimate ventilation, could not be relied on due to the plant's use of CO_2 in packaging.

The cut-preparation area was identified as having a particularly high aerosol transmission risk, with low temperatures (mean of 4.5°C) and high humidity (mean of 95.9%). The CO_2 readings in this area were over 2,200 ppm, peaking at 5,100 ppm. Emerging evidence later suggested that high CO_2 levels could increase the virus's stability in the air, which elevated transmission risk in this environment. Although workers wore visors and fabric face coverings, these measures were insufficient to counter aerosol risks, particularly given the prolonged work shifts and close contact inherent to production lines.

To control contamination, the plant maintained an extensive fogging program, though no evidence supports fogging's effectiveness against SARS-CoV-2 transmission, but the financial costs and the environmental impact could be substantial.

The outbreak was successfully contained, even as local infection rates continued to climb. Leadership played a critical role in containment efforts, with plant management reevaluating key controls in collaboration with local public health. Strong leadership and diligent compliance monitoring, paired with workplace testing, contact tracing, social distancing, hand hygiene, surface cleaning, and vaccine promotion, were instrumental in mitigating the outbreak.

Lessons learned from this large meat-processing plant outbreak

Outbreaks in meat-processing plants are likely driven by a combination of workplace and environmental factors. High worker density and unfavourable conditions, such as poor ventilation, play significant roles in increasing virus transmission risk. Shared transportation, while necessary, may also contribute to outbreaks and is difficult to manage.
The outbreak was controlled through proactive leadership, timely reassessment of control measures, and cooperation with health protection teams. Successful strategies included early case identification, effective testing, strict hygiene practices, and adequate sick pay policies.

As essential infrastructure, meat-processing plants should collaborate with local health teams to develop and rehearse outbreak response plans to control future infectious disease outbreaks and ensure business continuity.

3.1.5. Case Study: Investigation of a COVID-19 Outbreak at a Public Order & Safety Training Facility(34)

In June 2021, amid rising community transmission as the UK reopening from its third national lockdown, a COVID-19 outbreak occurred at a public order and safety (POS) training facility in England. The outbreak, with an attack rate of 39%, affected 9 out of 23 trainees participating in an intensive 18-week training program. This investigation sought to uncover the occupational risk factors driving virus transmission in this high-contact, in-person training environment.

The training program included both classroom-based instruction and practical exercises such as personal safety, first aid, and driving. Close-contact activities like resuscitation and restraint training required trainees to wear surgical masks and gloves. For advanced driver training, which involved close proximity inside vehicles, instructors and trainees used FFP3 respirators and kept windows open for ventilation. However, only contracted driving instructors were required to undergo twice-weekly LFD testing, while regular testing was not mandated for trainees.

Inadequate air circulation was identified in naturally ventilated areas, with carbon dioxide (CO_2) levels in some classrooms exceeding 1,500 ppm. This posed additional risk for virus transmission in these indoor spaces.

Despite a low questionnaire response rate, the investigation found that 30 out of 33 participants sharing the same workplace setting did not become infected, though they reported frequent close physical contact and multiple close interactions with colleagues each day. Detectable SARS-CoV-2 antibodies in all participants suggested either prior infection or vaccination, and the outbreak was effectively contained within the cohort of new recruits, with no spread among other staff. This containment pointed to the effectiveness of the facility’s preventive measures, which included vaccination, use of face coverings, regular cleaning, and full-paid sick leave.

Several site-specific and activity-specific factors likely contributed to the transmission risk. Regular rapid LFD testing was not implemented for all trainees. If implemented, it could have helped detect infections early. While surgical masks were used during training, FFP2 or FFP3 respirators may provide better protection during close contact activities. However, proper use of such masks or respirators requires face-fit testing and user training. Inadequate ventilation in some areas highlighted the need for improved air circulation strategies, such as the use of CO_2 monitors to assess room-specific risks, enhance ventilation, or reduce room occupancy where necessary.

Lessons learned from this public order and safety training facility outbreak

The outbreak at this POS training facility underscored the elevated infection risk faced by public order and safety officers during the pandemic, whose work and training involve close physical contact, exertion, and shouting, all of which can increase transmission risks.
The investigation emphasised the importance of addressing both site-specific and activity-specific factors in assessing and mitigating transmission risks. Future risk assessments for POS training environments should consider these unique factors, implementing interventions such as improved ventilation, consistent testing, and appropriate protective equipment to ensure the continuity of essential training while minimising the spread of infectious diseases.

3.1.6. Case Study: Investigation of a COVID-19 Outbreak in a Public-Facing Office(37)

In August 2021, a COVID-19 outbreak occurred in a public-facing public sector office in England, where 22 of the 40 staff members, or 55%, tested positive for SARS-CoV-2. The outbreak prompted a voluntary two-week closure. Notably, the outbreak occurred as local infection rates were slowly rising, though 78% of the local population aged 12 and older were fully vaccinated, and most government restrictions had been lifted.

The outbreak affected various roles within the office, including 75% of cleaners (3 out of 4), 67% of security staff (4 out of 6), and 50% of general office staff (15 out of 30). Although the attack rate among cleaners and security personnel appeared higher, statistical significance could not be established due to small sample sizes, and the absence of cleaners and security staff in the follow-up survey limited the interpretation of these findings. The security office, a small, shared space of 7.8 square meters used by rotating shifts of security staff, showed the highest viral contamination rate, with 67% of surface samples testing positive for SARS-CoV-2 RNA, suggesting it might have been a hotspot for transmission.

Before the outbreak, the office had implemented several COVID-19 safety measures, including enhanced cleaning protocols, staff training, and commercial hand sanitisers. However, government guidelines at the time did not require face coverings, and none were observed during the study site visit. This was significant given the open-plan nature of the office, where staff engaged in up to 15 face-to-face meetings daily, often in close proximity to the public, despite plastic screens being used as barriers. While plastic screens can block large droplets, they are less effective for aerosol transmission, which was a probable risk given the lack of face coverings, additional ventilation, or air-cleaning devices.

The absence of face coverings raised particular concern given the steady rise in local infection rates. However, recognising that face coverings can hinder verbal communication in public-facing roles, careful risk assessment would have been beneficial in determining alternative control strategies suited to the specific office context. Strategies such as limiting in-person interactions, continuing meetings via phone or internet, requiring viral testing for visitors, enhancing meeting room ventilation, deploying portable air purifiers, and redesigning work practices to minimise close contact could have been considered to better manage transmission risks.

Lessons learned from the public-facing office outbreak

This outbreak underscores the vulnerabilities of public-facing offices to COVID-19 transmission, even amid high vaccination rates. Despite adherence to recommended measures, the high attack rate revealed the need for adaptive, site-specific risk assessments in public settings. At that time, government guidance emphasised ventilation, cleaning, and isolation while discontinuing requirements for face coverings and social distancing. The outbreak highlighted the importance of updating risk assessments in response to changing local infection rates and differentiating risk levels across workspaces, particularly for roles involving high public contact.

For public-facing offices, tailored control measures, including face coverings, social distancing, regular testing, ventilation improvements, air purification, and occupancy limits, should be considered as part of dynamic risk management, especially when local infection rates are rising. This case study illustrates how environmental analyses, such as surface sampling, can help identify infection control gaps and guide timely adjustments to workplace protocols, ensuring the continuity of essential services during health crises.

3.1.7. Surface sampling for SARS-CoV-2 RNA in workplace outbreak settings(27)

The persistence of viral particles on surfaces provides a way to assess potential transmission risks in workplaces by identifying areas of high surface contamination. This can highlight higher-risk zones and offer real-world evidence of potential fomite transmission routes. As part of the COVID-OUT study, a pooled analysis was conducted for the surface microbial samples collected, between March 2021 and March 2022, from 12 UK workplace outbreak sites. This study aimed to understand transmission risks associated with surface contamination, focusing on identifying higher-risk zones and informing local infection control measures. The sampling spanned diverse workplaces, including manufacturing, food production, office environments, distribution, and critical infrastructure, with most sites located in England. For comparative analysis, two critical infrastructure sites without outbreaks were also included.

Each workplace outbreak site had an average of 63.7 samples collected, with a total of 829 samples analysed for SARS-CoV-2 RNA via qPCR. Overall, 7.4% (61 out of 829) of the samples tested positive, though most contained low viral loads. A small portion of the samples (1.8%) showed higher viral loads, while an additional 5.4% were classified as “suspected positive,” indicating trace viral material near the detection threshold. The vast majority, 87.2%, tested negative. The highest positivity rates occurred at a non-food manufacturing site in March (38.9%) and a distribution site in May (32.9%).

Locker rooms consistently emerged as high surface contamination zones, likely due to their confined spaces and less frequent cleaning routines. Toilets, canteens, and general work areas demonstrated lower positivity rates, and high-touch surfaces, which were presumed to be higher risk, showed comparably low contamination. Enhanced cleaning in these high-traffic areas likely contributed to these results.

Positivity rates were notably higher for samples collected from March to early May 2021, followed by a sharp decline after late May. This reduction corresponded with the national COVID-19 vaccination rollout, which may have contributed to decreased viral shedding and environmental contamination in workplaces. Limitations in the study, however, included variations in the timing of outbreak notification and sampling, potential environmental changes before sampling, and sector-specific differences, local infection rates, circulating variants, and vaccination rates, complicating direct site-to-site comparisons.

Lessons learned from surface contamination detected in workplace outbreak settings

The study's findings suggest that the risk of fomite transmission in workplace settings was likely low, particularly with effective cleaning protocols in place. Nevertheless, prompt environmental sampling and real-time data collection proved instrumental in helping workplaces adjust cleaning strategies and infection control practices rapidly, emphasising the potential value of timely interventions in outbreak management.

3.1.8. Managing SARS-CoV-2 transmission risk in workplace COVID-19 outbreaks(28)

The COVID-19 pandemic posed significant challenges for businesses across all sectors, especially in managing workplace outbreaks that threatened both employee health and business operations. Initially, reports of workplace outbreaks were frequent, yet comprehensive field studies on the risk factors and practicalities of implementing control measures were limited. Most existing research focused on individual outbreaks without direct workplace observation or evaluations of control measures(23).

A published study(28) summarises findings from the COVID-OUT study, which performed in-depth environmental assessments across 12 non-healthcare workplaces experiencing COVID-19 outbreaks. These assessments included staff discussions, site visits, and CO_2 measurements to evaluate ventilation. By directly observing workplaces during or shortly after outbreaks, the study provides insights into the control measures employers were willing and able to implement, as well as the obstacles they faced. This investigation sheds light on the effectiveness of physical distancing, testing, surface decontamination, ventilation, and face coverings in real-world settings, offering guidance for workplace strategies to reduce respiratory disease transmission risks.

Physical distancing

A physical distance of more than two meters was generally recommended by the UK government, with remote work encouraged only for office-based employees. However, in manufacturing, food production, and warehousing distribution sectors, physical distancing was difficult to maintain due to space constraints, high noise levels, and fixed production layouts. Shared spaces like changing rooms, toilets, narrow walkways, and canteens were prone to "pinch points," where distancing broke down, particularly around entrances and vending machines. In food production, workers needed hearing protection, which, combined with face coverings, hindered communication, and led to closer proximity during interactions. Some settings, such as a public safety training facility, practical training sessions required close physical contact for activities, such as resuscitation and restraint training, with some necessitating physical exertion, and shouting.

While distancing measures were sometimes supplemented by screens and face coverings, site layouts and the nature of tasks often limited distancing effectiveness. Other control measures, such as staggering shifts and breaks and limiting the number of people in shared areas, proved practical. Where feasible, temporary outdoor facilities were created to improve spacing and ventilation. The assessments underscore the challenges of implementing physical distancing. In workplace settings where distancing isn't feasible, such as in training facilities, manufacturing, and food production, tailored distancing strategies will be needed to reduce close-range droplet transmission.

Testing

Various testing methods were adopted across sites. Five sites used skin surface temperature screening, though this approach was discouraged by the UK's Medicines and Healthcare Products Regulatory Agency due to its unreliability in identifying COVID-19 cases. LFD testing was widely implemented when it became available, with eight sites using it regularly, especially after outbreaks. Some sites increased testing frequency to twice a week or limited it to high-risk individuals. For confirmatory testing, PCR tests were typically administered offsite, with only two sites having access to mobile PCR units provided by local public health. Eleven sites also used contact tracing to minimise spread, employing LFD testing, exclusion protocols, and additional cleaning for those identified as close contacts.

Logistical challenges, particularly during shift changes, complicated mass testing. Although imperfect, onsite testing provided valuable real-time data when combined with illness reporting and internal contact tracing programs, helping to identify and exclude potential exposure sources from the workplace.

Surface decontamination

Surface decontamination was a key element of COVID-19 risk assessments across all sites, especially in food production, where stringent hygiene practices were already in place. Enhanced cleaning targeted high-touch surfaces like door handles, and anti-viral fogging was employed at nine sites, some integrating it into daily cleaning routines. While fogging was not officially recommended for non-healthcare settings, it was widely used as both a preventive and remedial measure, despite questions around its cost effectiveness and potential health risks for workers.

Surface sampling showed that few samples tested positive for SARS-CoV-2 RNA, and those that did contained low viral loads, indicating limited environmental viability of the virus(27). As scientific understanding evolved, the emphasis shifted toward airborne rather than droplet transmission(38), underscoring that surface decontamination alone is insufficient without complementary measures like distancing and ventilation.

Ventilation

Implementing effective ventilation improvements varied significantly. Seven sites implemented ventilation actions before outbreaks, typically by opening windows and doors to enhance natural airflow. Only three sites had mechanical ventilation systems, which were primarily designed for thermal regulation rather than infection control. CO_2 monitoring highlighted poorly ventilated areas, with CO_2 levels often surpassing 1,500 ppm in spaces such as canteens and training rooms, signalling inadequate ventilation.

Ventilation involves bringing clean outdoor air into a building and effectively distributing it to replace indoor air. This process helps provide clean, breathable air by removing and diluting contaminants. It is a key strategy for reducing the transmission risk of respiratory pathogens(39). Despite evidence supporting airborne transmission, understanding of ventilation's role developed slowly, and many non-specialists remained unclear on the difference between air movement and effective ventilation. Upgrading ventilation systems to mitigate viral transmission was logistically challenging for most companies due to high costs and complexity. Simple solutions, such as guidance to open windows, were beneficial but limited by workers' compliance, thermal comfort concerns, and energy costs.

Measurement of CO_2

CO_2 measurements offered a practical way to monitor ventilation in occupied spaces. Levels above 1,500 ppm indicated inadequate ventilation(40), highlighting areas where virus transmission risk might increase. In certain work environments, continuous monitoring with audible alarms encouraged timely action. However, CO_2 levels need careful interpretation; low levels in large spaces do not always confirm sufficient ventilation, and CO_2 used in processes like meat packing may cause elevated readings unrelated to human respiration.

Face coverings

Face coverings or visors were mandated at all sites except one, with some sites requiring them only in specific areas. Compliance was high across the sites, with disposable face coverings and visors widely used, especially in high-risk areas like food production and training facilities. Reusable face coverings offered a more sustainable option, while face coverings effectively reduced droplet and aerosol transmission, although they did not fully protect against inhaling fine particles. In production environments, where noise impeded communication, workers sometimes broke distancing to converse, indicating the practical limitations of face coverings alone. Disposable half-mask respiratory protective equipment (RPE) was only observed at the training facility during shared car driver training, making it the sole site to use RPE as a control measure across the 12 outbreak sites investigated.

Lessons learned from analysis of mitigation measures across workplace outbreak sites

The COVID-19 pandemic posed significant challenges for businesses, especially in managing workplace outbreaks that threatened both employee health and business continuity. In response, companies adopted a range of control measures to mitigate SARS-CoV-2 transmission risks. The evaluation of implementing these measures revealed key insights into effective strategies for outbreak management, underscoring the complexities involved in safeguarding workplaces during a pandemic.

Effective risk mitigation required a combination of strategies: working from home, face coverings, hand hygiene, and regular testing. Although physical distancing and ventilation improvements were critical components, they proved particularly difficult to implement in production environments. Factory layouts, essential tasks, and the close proximity needed for communication often made distancing unfeasible. To compensate, companies employed alternative measures like screens and face coverings, though their effectiveness against airborne transmission could be limited.

Ventilation presented another challenge for many workplaces. Even as awareness of airborne transmission grew, many employers struggled to implement adequate ventilation solutions. CO_2 monitoring in occupied workspaces emerged as a simple and cost-effective method to identify poorly ventilated areas, highlighting the value of real-time air quality assessments. However, upgrading mechanical ventilation systems often required specialised expertise and came at significant expense—making it impractical for many businesses to overhaul systems mid-pandemic. Ideally, ventilation should be integrated as a design priority in workplaces to better manage infection risks.

Complete prevention of disease transmission proved nearly impossible under prolonged pandemic conditions. Even with rigorous control measures, fostering a culture that encourages early symptom reporting and self-isolation remains essential. Risk assessments must include response plans for individual cases or clusters to minimise the potential for widespread outbreaks.

Site investigations underscored the crucial role of administrative controls in managing workplace outbreaks, especially those relying on human behaviour. These controls, heavily dependent on communication, training, and strong supervision, proved effective only when backed by clear leadership and ongoing support. This highlights the need for continuous assessment of human behavioural factors, which play a central role in effective outbreak management.

Ultimately, control measures must be tailored to each workplace through thorough risk assessments specific to tasks and environments. The traditional hierarchy of controls remains foundational to managing respiratory disease outbreaks, but a layered approach—combining multiple control strategies—is essential, particularly in production settings where physical distancing is challenging.

Summary of COVID-OUT findings on mitigating transmission in the workplace

The COVID-OUT studies have investigated many workplace outbreaks across different high-risk sectors in England throughout 2021. These studies identified key transmission risk factors and mitigation measures, offering valuable insight for future pandemic preparedness. In various workplace settings, close worker proximity, inadequate ventilation, and high noise levels contributed significantly to COVID-19 transmission risks, particularly in environments like plastics manufacturing, warehousing and distribution centres, meat-processing plants, training facilities, and public-facing offices. Enhanced infection control measures—such as improved ventilation, regular testing, the use of face coverings, and targeted protective equipment—were essential across these sites to manage outbreaks. Financial concerns affecting self-isolation, such as inadequate sick pay, exacerbated infection rates in some locations, highlighting the need for policies that encourage potential infectious workers to self-isolate. Surface sampling generally showed low fomite transmission risk with effective cleaning, but prompt environmental assessments enabled dynamic adjustments to cleaning protocols and overall infection control.

Overall, tailored risk assessments and a layered approach combining multiple control strategies were crucial for managing respiratory disease outbreaks in diverse workplace settings. Continuous assessment of human behavioural factors and strong leadership were essential for effective outbreak management.

3.2. Other studies on non-pharmaceutical interventions (NPIs) relevant to workplaces

Non-pharmaceutical interventions (NPIs) aimed at reducing SARS-CoV-2 transmission played a crucial role in public health, both in workplace and community settings, alongside formal treatment, and vaccination efforts. These NPIs—ranging from asymptomatic testing, physical distancing, and face coverings to venue closures—were critical in the early phases of the pandemic before effective treatments and vaccines became widely available, though they remained relevant throughout. Unlike pharmaceutical interventions, real-world evidence on the effectiveness of NPIs to reduce COVID-19 transmission is limited(41).

A Cochrane review (42) assessed NPIs in long-term care facilities (LTCFs), where 22 studies (11 observational and 11 modelling) evaluated measures to prevent transmission among residents, staff, and visitors. Although the evidence was of low certainty due to potential bias in observational studies and concerns with the quality of modelling, the findings highlighted the importance of frequent, sensitive testing with rapid turnaround times, as well as isolation and cohorting of infected individuals. Combining these with the use of personal protective equipment (PPE) and visitor restrictions proved effective in managing outbreaks and reducing mortality. The review also emphasised that proactive, multi-faceted approaches are essential to protect vulnerable populations in LTCFs, particularly when community transmission is high.

In England, a study (43) on ventilation within two residential care homes demonstrated the significance of adequate ventilation for reducing airborne infection risks. Using remote sensors to monitor CO_2 levels, the study found that while ventilation was generally sufficient, additional measures—such as using air cleaners, increasing window openings, and encouraging wearing face coverings during outbreaks—were beneficial. The presence of visible CO_2 monitors was shown to encourage positive ventilation practices, further underscoring ventilation as a fundamental factor in infection control within indoor spaces.

A comprehensive review and meta-analysis (44) examined infection prevention and control (IPC) measures in various workplace settings, covering approximately 280,000 employees across healthcare, nursing homes, manufacturing, and office environments. The findings highlighted that combined IPC measures significantly reduced COVID-19 cases, with lower positive rates (0.2%) compared to single interventions such as asymptomatic PCR testing (1.7%) or universal masking alone (24%). Key strategies, including timely contact tracing, isolation, PPE use, and smaller cohorts, were effective in mitigating workplace transmission. Combined IPC measures, particularly when implemented early, were supported by modelling studies, which underscored the importance of a multi-layered approach in safeguarding workplaces.

In educational settings, a systematic review(45) explored COVID-19 mitigation strategies in schools, incorporating 33 studies primarily from North America and Europe. The evidence suggested that measures to reduce transmission, such as remote teaching, mask mandates, and improved ventilation, had generally positive effects on health and attendance outcomes. However, remote learning often had negative impacts on students and staff, while physical distancing had mixed outcomes, sometimes lowered student infections but increased transmission among staff. Surveillance measures, including daily testing as an alternative to quarantine, reduced school days lost to isolation. Nonetheless, the review stressed the need for high-quality, empirical studies to better understand both the benefits and unintended consequences of NPIs within diverse school contexts.

A retrospective cohort study conducted in Italy to investigate the impact of mechanical ventilation system (MVSs) on reducing SARS-CoV-2 airborne transmission in 1, 419 schools, with 316 classrooms equipped with MVSs and 10,125 relying on natural ventilation(46). The study found that classrooms with MVSs had significantly lower infection rates compared to those relying on natural ventilation, with increased ventilation rates correlating with up to an 80% reduction in relative infection risk. This study advocates for stronger ventilation standards in schools to mitigate airborne transmission. The study concludes that mechanical ventilation is a crucial strategy for mitigating airborne transmission of COVID-19 in schools and suggests that higher ventilation rates should be adopted for better protection. The findings support the need for improved ventilation standards in indoor environments to control respiratory infections.

In December 2021, a survey conducted in English schools—following the installation of 386,000 CO_2 monitors across state-funded educational settings—found that 12% of schools using CO_2 monitors reported identification of spaces with sustained high CO_2 readings (1500ppm and above) and the majority of these were able to remedy this through quick fixes, e.g. opening windows, but 3% of schools were unable to remedy through quick fixes or remedial building works(47). This underscored the utility of CO_2 monitors in identifying areas with inadequate ventilation, prompting improvements in air quality through straightforward adjustments.

A large-scale survey(48) from the Virus Watch cohort, with over 6,000 participants, examined the varied approaches to COVID-19 mitigation across sectors. Healthcare workers consistently reported higher adherence to hygiene measures, whereas sectors with fewer restrictions showed varied practices, particularly in times of national relaxation. Key practices such as ventilation, consistent hygiene, and PPE use were essential across industries. The study emphasised the importance of clear communication and targeted support, especially in sectors with low compliance, to strengthen workplace preparedness for future public health crises.

A Cochrane review(49) of 78 studies on physical interventions (screening, isolation, physical distancing, hand hygiene, and face coverings) highlighted limited evidence of efficacy for certain measures, particularly face coverings, where results were highly uncertain. The review noted that effectiveness often depended on adherence, suggesting a need for further robust, well-designed studies.

Another rapid mapping review in the UK(41) analysed 151 studies from community settings, found that NPIs focused primarily on identifying and isolating infectious individuals, with less evidence on individual-level measures like hand hygiene and ventilation. The study pointed to a significant gap in evaluation, advocating for better integration of evaluation methods into public health interventions. The review found that despite the large number of studies published, there is still a lack of robust evaluations of the COVID-19 NPIs implemented in the UK and emphasised the need to build evaluation into the design and implementation of public health interventions and policies from the start of any future pandemic or other public health emergency.

A Cochrane review of evidence has looked at workplace interventions to reduce the risk of SARS-CoV-2 infection outside of healthcare settings(50). Of two studies included, one found that “test-based attendance” (testing daily with negative results) among school staff in England did not significantly impact symptomatic infection rates or absenteeism compared to standard 10-day isolation. This highlighted the need for high-quality studies focused on diverse interventions such as ventilation, administrative adjustments, and PPE.

Asymptomatic SARS-CoV-2 testing, using LFD tests, for healthcare workers (HCWs) in England began in November 2020 and was withdrawn in August 2022. A study using computational modelling (51) examined asymptomatic SARS-CoV-2 testing for healthcare workers (HCWs) and found that twice-weekly testing during an Omicron-like period reduced infections by 1–4.4%. However, this required substantial resources, suggesting that targeted testing of symptomatic individuals or new patients on admission might be more efficient. The analysis pointed to the need for balanced, cost-effective testing policies that maximise workplace protection with efficient resource allocation.

LFD testing, which enabled rapid self-read and self-report capabilities, emerged as a valuable tool during the pandemic, enhancing personal risk management and large-scale surveillance. Effective communication surrounding testing strategies and evolving guidelines played a vital role in public and professional compliance, further underscoring the importance of clear, adaptable communication in implementing NPIs during health crises(52).

Summary of findings from other studies on mitigating transmission in the workplace

Despite the limited real-world evidence on the effectiveness of non-pharmaceutical interventions (NPIs), several studies provide limited but valuable insights into their impact and implementation aimed at mitigating SARS-CoV-2 transmission across different settings. The studies highlight that NPIs like frequent testing, adequate ventilation, PPE, physical distancing, and multicomponent approaches were effective in reducing SARS-CoV-2 transmission in some settings, though with varying degrees of certainty. Higher certainty evidence indicated the importance of combined, layered measures—especially in high-risk environments like healthcare, long-term care facilities, schools, and high-occupancy workplaces—where single measures (e.g., masking alone) often proved insufficient.

Ventilation emerged as a potentially effective intervention, with improvements in airflow significantly reducing infection risks. The studies also identified gaps in the quality and consistency of evidence for some NPIs, pointing to a need for more robust, controlled studies and real-time evaluations in future health emergencies. In addition, the success of NPIs often hinged on adherence, clear communication, and contextual tailoring of interventions, emphasising that timely, flexible, and well-communicated strategies are crucial for effective pandemic response across different settings.

3.3. Applying the Hierarchy of Controls for improving mitigation measures

Employers have a duty of care to protect the health and safety of their employees, contractors, and visitors to their premises. Many studies, including those from our COVID-OUT research, highlight the needs for multi-layered mitigation strategies. However, some measures could be more effective than others according to the Hierarchy of Controls(53). This hierarchy provides a structured approach to risk reduction, supported by appropriate risk assessment, to reduce SARS-CoV-2 transmission risks in the workplace to the lowest reasonably practicable level(54).

The Hierarchy of Controls is designed and widely used to reduce exposure risk to workplace generated hazards, whether physical, chemical, or biological. It categorises control measures from most to least effective:
1) **Elimination** - Physically removing the hazard.
2) **Substitution** - Replacing the hazard with something less dangerous.
3) **Engineering Controls** - Isolating people from the hazard.
4) **Administrative Controls** - Changing work practices and procedures.
5) **Personal Protective Equipment (PPE)** - Protecting the individual.
Controls higher in the hierarchy are, in theory, more effective. For example, eliminating or substituting a hazard is more protective than engineering controls, which, in turn, are more effective than PPE.

COVID-19 presented unique challenges that required adapting traditional control strategies. Community transmission introduces SARS-CoV-2 into workplaces, and preferred methods like hazard elimination are often impractical. Therefore, multiple controls are needed, especially where options such as working from home, physical distancing, or upgrading mechanical ventilation system are infeasible(55). Decision-making during the pandemic required flexibility due to uncertainties, such as limited data on control effectiveness and feasibility (air cleaning devices) or limited availability of control options (diagnostic testing). However, a comprehensive workplace risk assessment that considering all sources of exposure is essential to support decision on appropriate controls.

Prior to COVID-19, control banding was proposed to systematically assess and prioritise controls for aerosol-transmissible diseases, such as influenza, in broader settings beyond healthcare(56). Control banding involves categorising job tasks by exposure risk, toxicity, and pathogen transmissibility, implementing control measures in a hierarchical order—from source control to pathway control, and finally receptor control (PPE). This approach reduces reliance on PPE, especially during shortages, by emphasising sustainable and adaptable measures based on evolving knowledge of the pathogen. While this method was initially limited to aerosol transmission, it has since proven valuable for COVID-19 risk assessment. Further work applied control banding to COVID-19, using several case examples, considering every worker could be a potential infection source due to the rapid and broad spread of SARS-CoV-2 in the community(57). The model emphasises source controls (e.g., eliminating in-person interactions, testing, health screening), pathway controls (e.g., barriers, ventilation), and receptor controls (PPE), providing a structured, multilayered approach to reduce viral spread in non-healthcare settings, especially when accurate exposure measurements are unavailable.

In the context of controlling SARS-CoV-2 transmission in the workplace, the Hierarchy of Controls can be applied as follows(21, 50, 54):

- **Elimination**: Removing the hazard is the most effective control but is often impractical in a pandemic. Measures may include encouraging remote work to reduce on-site personnel. Temporary workplace closures are effective but costly, and rarely feasible across all settings.

- **Engineering Controls**: These controls isolate people from hazards, such as through barriers or enhanced ventilation. Examples include using high-efficiency air filters, sneeze guards, and in healthcare settings, specialised ventilation for aerosol-generating procedures. However, installing or upgrading systems during a health emergency may be challenging.

- **Administrative Controls**: Changing how people work can reduce hazards, although these controls depend on consistent human adherence. Examples include:
    - Implementing flexible work arrangements (e.g., remote work, teleconferencing).
    - Regularly updating workplace risk assessments and continuity plans.
    - "COVID-19-secure" adaptations, including physical distancing, staggered hours, and shift work.
    - Testing, contact tracing, and enforcing self-isolation policies.
    - Enforcing handwashing, cleaning, and ventilation protocols.
    - Developing communication plans that clarify risks, employer responsibilities, and support strategies.
    - Supervising compliance to ensure adherence to controls.

- **Personal Protective Equipment (PPE)**: PPE is a final line of defence, providing protection where higher controls are impractical. During an outbreak, PPE guidance may change based on availability and updated research. Training workers on PPE's proper usage and limitations is essential for effectiveness.

Effective COVID-19 control requires a mix of physical, behavioural, and policy interventions. Combining strategies ensures that multiple lines of defence work together to reduce transmission risk. For instance, Control of Substances Hazardous to Health (COSHH) regulations in Great Britain (GB) requires a risk assessment process and the Hierarchy of Control. The Health and Safety at Work Act mandates a balance between risk level and control effort, ensuring reasonably practicable measures protect worker health. The Hierarchy of Controls provides a structured, effective approach to managing COVID-19 risks and other workplace hazards. It will be a useful tool in the pandemic preparedness framework.

3.4. Lessons learned on improving mitigation measures for future preparedness

During the COVID-19 pandemic, the approach to managing respiratory infectious diseases experienced a significant shift, revealing both the limitations of early responses and the urgency for more comprehensive, science-informed strategies. Initially, the World Health Organisation (WHO) underestimated the importance of airborne transmission, which led to delays in promoting critical measures, like improved ventilation and air filtration, to reduce indoor spread(58). This underscored that effective infection control needs to address all potential transmission routes in all settings.

Early workplace risk assessments emphasised contact-based transmission routes—such as droplets and fomites—over aerosol transmission, which, while critical for SARS-CoV-2, was both less understood and more challenging to control. Increasing evidence emerged in 2020 highlighted the essential role of ventilation—whether natural or mechanical—in reducing airborne transmission, especially in indoor spaces where people gather, such as workplaces(38). Observational studies from workplace outbreak investigations have shown that many workplaces struggled with implementing and maintaining effective ventilation systems, pointing to the need for enhanced communication, training, and support in this area(59). Though upgrading mechanical ventilation can be costly or impractical, incorporating ventilation considerations into initial building designs could create infection-resilient spaces that promote healthier indoor environments. Investments in building design, improved ventilation, and air filtration will contribute to long-term infection resilience and to combat future respiratory pathogen pandemic threats(60).

The rapid transmission of SARS-CoV-2 in workplaces accentuated the necessity of swift and adaptable mitigation strategies. Organisations adopted a hierarchy of controls approach to risk assessment, implementing various control measures based on evolving epidemiological insights, though evidence of effectiveness was mostly uncertain, as the review for preparing this document has shown. Frequent updates to guidelines occasionally led to confusion, highlighting the importance of clear, timely communication of research findings and public health guidance to ensure that workers stay informed and prepared to implement appropriate precautions.

The pandemic also demonstrated the feasibility and necessity of remote work in certain circumstances to reduce population and workplace transmission risks. Workplace practices to managing transmission risks need to be adaptable, including remote work backed by digital infrastructure, infection prevention protocols, and enhanced cleaning. Furthermore, specific support for high-risk occupations—like priority testing, vaccination, and access protective equipment—was essential for reducing transmission risks in the workplace(52).

To further mitigate workplace transmission risks, it is crucial to create supportive environments that prioritise employee health(58). Economic and social support, such as financial assistance for workers needing to self-isolate, is key to preventing hardship and encouraging compliance. COVID-19 workplace outbreak risk model analyses illuminated the complex social, environmental, and behavioural factors influencing workplace transmission risks(24). Workplace outbreak investigation site visits also revealed that lower-level control measures—administrative strategies and personal protective equipment (PPE)—were necessary and played vital roles in managing transmission but relied heavily on consistent human compliance(28). Achieving sustained behavioural change is challenging; however, research suggests that multi-faceted, coordinated, and sustained interventions that enhance motivation, capabilities, and opportunities for change are the most effective in the long term(61).

Embedding infection control behaviours into daily routines has been a key strategy for minimising COVID-19 transmission over time. Staying “Covid-safe” emphasises a risk management approach that incorporates individuals’ understanding of risk and their responses to it(61). Sustainable behavioural change will require strengthening financial, social, and physical infrastructures and ensuring people have the necessary education, regulatory support, communication, and resources to develop the capabilities, opportunities, and motivation to maintain these behaviours. A collaborative approach among all stakeholders is necessary to prioritise and implement locally adapted, epidemiologically informed measures that have the most impact.

Looking forward, future research in the behavioural and social sciences should focus on promoting prosocial behaviours, such as wearing face coverings and vaccination adherence, to reinforce pandemic preparedness(58). Developing robust health communication strategies and effective surveillance systems will be essential to enable rapid responses to workplace outbreaks and foster compliance with health protocols, ensuring that future workplaces are better prepared and resilient to similar challenges.

4. Part 3: Accelerating evidence-gathering to support pandemic response and occupational data.

4.1. Meeting the urgent evidence needs

At the pandemic's outset, there was an urgency to generate rapid evidence about SARS-CoV-2 to support immediate policy and operational decisions. Research efforts followed a precautionary approach, setting clear questions to address evidence needs, considering all potential transmission routes of the virus.

In October 2022, the UK National Core Studies program, with seven research strands led by GO-Science(62), assembled senior experts to direct research, form integrated teams, and build the infrastructure necessary to answer urgent questions. These ranged from transmission risks in specific settings to broader topics like immunity and long COVID(52). Among the strands was the PROTECT COVID-19 National Core Study on Transmission and Environment(18). PROTECT had six themes, led by HSE Chief Scientific Adviser Professor Andrew Curran. Theme 1 of PROTECT focused on investigating workplace outbreaks(63). From its inception, Theme 1 established key research questions **(Table 4)** and fostered collaboration with other groups, swiftly engaging over 45 scientists from institutions like HSE, UKHSA, LSHTM, University of Manchester, and ONS. Together, they conducted in-depth investigations across 20 workplace outbreaks and analysed national linked datasets to understand workplace COVID-19 outbreaks.

Table 4. PROTECT Theme 1 (Outbreak Investigations) research questions.

Key research questions about "How does transmission occur?"

1. What are the potential transmission routes of SARS-CoV-2 and their relative importance in an occupational setting outbreak?
2. What are the risk factors for SARS-CoV-2 transmission in workers in an outbreak?
3. Are there risk factors in relation to workers, workers' behaviours, the environment, and controls, that could enhance the virus transmission and their relative importance in an outbreak setting?
4. Is there evidence of SARS-CoV-2 environmental contamination (on surfaces and in the air) in an occupational outbreak setting?
5. What is the extent of the contamination and its links to transmission within an occupational outbreak setting?
6. Is there evidence for the efficacy of infection prevention and control mitigations (singly or in bundles) in preventing COVID-19 transmission or outbreak in occupational settings?

Key research questions about "Where does transmission occur?"

1. Where, in which (occupational) settings, SARS-CoV-2 transmission is occurring?
2. How can we measure the relative risk of SARS-CoV-2 transmission by setting type and location, so that we can target areas where risk of transmission and risk of outbreak are high?
3. How can we measure and monitor the transmissibility of SARS-CoV-2 and its new variants in the population in different settings?
4. How can we identify the type of (occupational) settings and their characteristics (occupants, behaviours, environment, and controls) that can be associated with an increased or decreased risk of SARS-CoV-2 transmission?
5. How can we develop a model to predict the risk of COVID-19 outbreaks in certain settings and locations; and how can we validate and improve the predictive ability of the model?

One significant effort within Theme 1 of PROTECT(63) was the COVID-OUT (COVID-19 Outbreak Investigation to Understand Transmission) study, which systematically gathered data from various workplace outbreak settings to better understand SARS-CoV-2 transmission routes, risk factors, and implemented mitigation measures. Using a predefined protocol(26), COVID-OUT collected routine public health outbreak data, and added comprehensive questionnaires, viral and serologic testing, surface sampling, and environmental assessments, covering ventilation and other control measures. This protocol, developed rapidly by adapting WHO's early COVID-19 investigation frameworks, integrating learning from previous investigations of emerging pathogens. As a research initiative, COVID-OUT was distinct from regulatory investigations and required informed consent from participants. Ethical approval, usually a lengthy six-month process through the Integrated Research Application System (IRAS), was fast-tracked to two weeks due to the UK government's prioritisation of SARS-CoV-2 transmission studies. This expedited IRAS approval was published online shortly to prevent duplications of national research efforts(64). Despite the urgency, recruiting participating outbreak sites posed challenges, requiring access to the UKHSA and HSE outbreak line lists and creating daily "Watch Lists" for outreach. Over 150 companies were contacted to participate in COVID-OUT. Site visits for data collection often exceeded 14 days after the outbreaks were declared due to approval requirements, impacting data quality; these issues were later addressed with process improvements to streamline recruitment and site access. As the pandemic progressed, COVID-OUT's methods adapted as well. For instance, with greater testing availability in 2021, weekly PCR tests at workplaces were phased out, replaced by secure data linkages to national testing databases.

The experience of the COVID-OUT study and PROTECT underscored the importance of rapid collaboration and interdisciplinary approaches. Yet they also revealed difficulties in accessing outbreak sites and collecting samples. Future preparedness efforts should include pre-approved emergency research protocols for site access and sample transport, as well as sufficient resources to undertake review and comparison of outbreaks occurring internationally to gain intelligence(52).

To respond effectively in future pandemics, pre-established study protocols need to be deployable and scalable, allowing a rapid investigation of high-risk environments and transmission routes or novel pathogens. This will be a critical need in the early stages of a pandemic of a novel pathogen when non-pharmaceutical interventions (NPIs) are the primary line of defence until vaccines could be developed. Evidence from other pandemics, such as HIV (via sexual and intravenous routes), Ebola (contact transmission), and Zika (vector-borne), has shown the necessity of rapid evidence-based strategies in controlling infectious spread(52).

The ability to conduct high-quality research in response to emerging pandemics also relies on pre-established frameworks and adaptable research projects. For rapid responses, interdisciplinary studies encompassing biomedical sciences, social sciences, economics, and public health are essential. Improved international collaboration is also necessary to assess mitigation measures effectively(2). A global understanding of the pathogen and disease development, particularly at the onset of an outbreak, is crucial. Pre-existing research systems should be able to be adapted quickly, but such efforts require coordinated leadership and adequate resources to scale up efficiently. In peacetime, assembling funders, researchers, and regulator/policymakers can streamline emergency research mobilisation(52).

4.2. Data on occupation, industry, and work locations

The COVID-19 pandemic highlighted the important associations between work environments and health outcomes, underscoring the importance of systematically collecting data on individuals' occupations and workplaces. Standardised classifications for these data should be integrated into national public health systems to support future pandemic preparedness and improve broader health outcomes across the population.

Identifying high-risk settings for transmission is essential to target mitigation efforts effectively. Early in the pandemic, data indicated that workers in frontline care roles and other in-person services, like transport and cleaning, faced disproportionately high exposure and infection risks. While data alone couldn't fully explain these disparities, they were likely due to a combination of workplace and non-work factors(21). Concurrently, hospitalisation data revealed higher rates of severe outcomes among Black and Asian patients compared to White patients. However, ethnic disparities were often complicated by factors such as socioeconomic deprivation and high prevalence living environments. Additionally, overrepresentation of some ethnic minority groups in high-risk occupations linked ethnicity and occupation as key issues when considering transmission risk factors and health impacts. For future responses to health emergencies, healthcare and disease surveillance systems should routinely capture critical demographic details, including occupation and ethnicity. This proactive approach would allow disparities to be assessed early and support targeted interventions. Additionally, formal data-sharing agreements and governance processes must be pre-established to enable timely linkage and analysis of datasets, including occupational data(52).

The pandemic also exposed limitations in the detail, standardisation, and accessibility of national data on occupation and industry, all of which hampered timely assessments of workplace transmission risks. For instance, a study in 2020(19) aimed at analysing COVID-19 outbreak rates across workplaces in England required considerable time and resources to link public health outbreak database with business registries. Challenges with data acquisition and classification persisted, particularly as standard classifications for industry sectors were not implemented within the public health data system at that time. Similarly, in constructing a workplace COVID-19 outbreak risk model in 2022(24), researchers faced challenges linking datasets, including NHS contact tracing data, vaccination records, and census information. The model relied on 2011 census data due to delays in the availability of the 2021 census, potentially affecting the accuracy of the analysis.

Good data are essential for an effective pandemic response(52). Therefore, setting up appropriate data systems and linkages during peacetime is critical. From a workplace health and safety perspective, core data should include standardised classifications for occupation and workplace details, both geographically and by industry. This will facilitate necessary data linkages and support the rapid identification of high-risk settings.

The pandemic also surfaced that many organisations—public health bodies, national health services, government agencies, academic institutions, and private companies—operated separate data platforms, which introduced operational challenges in data sharing, even when agreements were in place. Reliable, up-to-date data systems need to be automated and integrated to offer real-time insights, with consistent standards for data compatibility, secure sharing, and rapid analysis. Establishing these systems in advance will enable faster, more effective responses to future health crises(2).

5. Part 4: Fostering a systematic approach to pandemic preparedness and resilience

The COVID-19 pandemic revealed the interconnected nature of our environments, such as workplaces, homes, communities, and transportation systems all contribute to the risk of virus transmission. Recognizing these links is crucial for identifying infection sources, accurately assessing risks, and implementing effective measures.(65) For example, community infection rates significantly influence workplace mitigation strategies. High prevalence in the community increases the likelihood of employees encountering the virus outside work and potentially bring it into their workplaces. When community transmission is high, standard workplace precautions, such as physical distancing and face coverings, might not be sufficient. In response, employers can implement targeted measures, such as enhanced testing, local workplace contact tracing, and stricter social distancing, to prevent outbreaks(30). Moreover, by monitoring community prevalence, public health agencies, in turn, can more effectively allocate resources such as PPE and mobile testing units more effectively to higher-risk workplace settings, facilitating tailored responses that reflect real-time, localised data.

This interconnected approach enables comprehensive strategies that reduce transmission both in communities and at work. Routine exercises that involve high-risk workplaces and public health teams help all parties prepare for various emergencies, protecting people and operations in times of crisis. Additionally, engaging with specific occupational groups allows for tailored interventions, anticipating challenges in deploying large-scale responses.

The pandemic demonstrated the need for various response components—testing, contact tracing, and non-pharmaceutical measures—to work together effectively. It also exposed societal disparities related to socioeconomic status, occupation, and ethnicity, underscoring the importance of balanced decision-making. Real-time data collection and analysis were vital, enabling an adaptive response as the pandemic evolved. A robust research infrastructure and data systems provided critical insights, while clear communication strategies supported public compliance.

Pandemic impacts also varied across demographics, with differences by age, ethnicity, and occupation. Adopting integrated data collection and analysis that considers the full spectrum of exposure settings helps address these disparities, ensuring interventions are both equitable and inclusive(65). This broad perspective fosters stronger collaboration between occupational health and public health agencies, creating a coordinated public health response that benefits both the workplace and community.

Before the pandemic, most workplaces had policies, practices, risk assessments that did not account for managing infection risks like those posed by COVID-19, leaving many businesses unprepared. During the pandemic, companies often had to adapt their strategies on an ad hoc manner, highlighting the need to systematically incorporate occupational health into pandemic preparedness planning(52).

The pandemic also fostered stronger collaboration between occupational health and public health, highlighting each field's contributions in managing emergencies(66). To strengthen this collaboration, workplaces should regularly conduct preparedness exercises with public health teams equipped for pandemic-scale incidents.

A significant obstacle during the pandemic was public resistance to some of the health measures such as face coverings and vaccinations (58). Securing public acceptance of a range of public health measures will be essential for future pandemic preparedness. Proactive communication and ongoing public education on practices such as respiratory etiquette, self-isolation, vaccination, and improving ventilation can help foster safer, infection-resilient communities and workplaces.

Human behaviour plays a central role in the spread and prevention of infectious diseases. Increasing investment in behavioural and social science research can support the development of more effective interventions, encouraging protective behaviours and building resilience against future pandemics.

The pandemic highlighted how interconnected risks can turn a health crisis into a social and economic crisis(2). Effective pandemic preparedness requires a holistic approach that considers the cascading effects of an emergency across sectors, including workplaces and occupational health.

Building resilience should be a comprehensive, whole-system effort. The UK COVID-19 Inquiry has recommended the establishment of an independent body to coordinate emergency preparedness and resilience, ensuring a unified, strategic response, and this body should integrate workplace and occupational health into its planning, solidifying them as key components of resilience and future pandemic preparedness(2).

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