



OPEN ACCESS

Original research

# Risk factors for SARS-CoV-2 infection at a UK electricity-generating company: a test-negative design case-control study

Charlotte E Rutter ,<sup>1</sup> Martie van Tongeren ,<sup>2,3</sup> Tony Fletcher,<sup>1</sup> Sarah Rhodes ,<sup>2</sup> Yiqun Chen ,<sup>4</sup> Ian Hall,<sup>2,5</sup> Nicholas Warren,<sup>6</sup> Neil Pearce <sup>1</sup>

► Additional supplemental material is published online only. To view, please visit the journal online (<https://doi.org/10.1136/oemed-2023-109184>).

<sup>1</sup>Faculty of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, UK

<sup>2</sup>Division of Population Health, Health Services Research & Primary Care, School of Health Sciences, The University of Manchester, Manchester, UK

<sup>3</sup>Manchester Academic Health Science Centre, The University of Manchester, Manchester, UK

<sup>4</sup>Science Division, Health and Safety Executive, Buxton, UK

<sup>5</sup>Public Health, Advice, Guidance and Expertise, UK Health Security Agency, London, UK

<sup>6</sup>Science Division, Health and Safety Executive, Bootle, UK

## Correspondence to

Dr Charlotte E Rutter, Faculty of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, WC1E 7HT, UK; [charlotte.rutter1@lshtm.ac.uk](mailto:charlotte.rutter1@lshtm.ac.uk)

Received 29 August 2023  
Accepted 11 February 2024  
Published Online First  
20 March 2024

## ABSTRACT

**Objectives** Identify workplace risk factors for SARS-CoV-2 infection, using data collected by a UK electricity-generating company.

**Methods** Using a test-negative design case-control study, we estimated the OR of infection by job category, site, test reason, sex, vaccination status, vulnerability, site outage and site COVID-19 weekly risk rating, adjusting for age, test date and test type.

**Results** From an original 80 077 COVID-19 tests, there were 70 646 included in the final analysis. Most exclusions were due to being visitor tests (5030) or tests after an individual first tested positive (2968). Women were less likely to test positive than men (OR=0.71; 95% CI 0.58 to 0.86). Test reason was strongly associated with positivity and although not a cause of infection itself, due to differing test regimes by area, it was a strong confounder for other variables. Compared with routine tests, tests due to symptoms were highest risk (94.99; 78.29 to 115.24), followed by close contact (16.73; 13.80 to 20.29) and broader-defined work contact 2.66 (1.99 to 3.56). After adjustment, we found little difference in risk by job category, but some differences by site with three sites showing substantially lower risks, and one site showing higher risks in the final model.

**Conclusions** In general, infection risk was not associated with job category. Vulnerable individuals were at slightly lower risk, tests during outages were higher risk, vaccination showed no evidence of an effect on testing positive, and site COVID-19 risk rating did not show an ordered trend in positivity rates.

## INTRODUCTION

From the outset of the COVID-19 pandemic, there was considerable debate as to the role of occupational exposures in the transmission of infections, and the subsequent morbidity and mortality. Most deaths occurred in those over age 65 years, that is, in those above the usual working age. However, there was still a substantial number of infections, hospital admissions, and deaths in those of working age.<sup>1</sup>

Thus, 1 year into the pandemic, Burdorf *et al*<sup>2</sup> commented that ‘there is scattered evidence that an individual’s type of job may contribute to the risk of becoming infected and, hence, to the mortality pattern in society’. Three years into the pandemic, Michaels *et al*<sup>3</sup> drew stronger conclusions, arguing

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ In the United Kingdom, there is now a considerable body of evidence showing occupational differences in COVID-19 infection and severity, but with understandable focus on high-risk industries like healthcare.
- ⇒ Less is known about differences in risk of COVID-19 infection in other industries that do not involve directly working with the general public, in particular, there is relatively little evidence on the risks of transmission in the electricity-generating industry.

## WHAT THIS STUDY ADDS

- ⇒ At this company, infection risk was not associated with job category after adjusting for test reason; however, women were less likely to test positive than men and the risk was higher when there was a power outage, requiring more staff to visit the site in person.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ The site risk rating showed a modest dose-response with infection risk at higher levels, indicating that such risk ratings may be useful for identifying ‘high risk’ sites.
- ⇒ This analysis demonstrates the importance of adjusting for both date of and reason for test, when prevalence and testing protocols differ over time.

that ‘COVID-19 is an occupational disease that sickened and killed countless workers’ but noted that COVID-19 has rarely been treated or tracked as an occupational disease by public health agencies, particularly in non-healthcare workplaces. They also noted that most white-collar workers could work from home, and that perhaps greater priority might have been placed on making workplaces safe if this had not been the case.

In the United Kingdom (UK), there is now a considerable body of evidence showing occupational differences in COVID-19 infection,<sup>4-6</sup> severity,<sup>7</sup> vaccination availability and uptake,<sup>8,9</sup> mortality<sup>1,10-12</sup> and mitigation strategies.<sup>6,13</sup>

However, these studies have mostly considered all occupations together in agnostic analyses, with



© Author(s) (or their employer(s)) 2024. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

**To cite:** Rutter CE, van Tongeren M, Fletcher T, *et al.* *Occup Environ Med* 2024;**81**:184–190.

considerable breadth, but little depth. More in-depth analyses have generally focused on known 'high-risk' industries such as healthcare, social care and other 'essential occupations' involving regular contact with the general public.<sup>14 15</sup>

There have been more in-depth investigations in a plastics manufacturing plant<sup>16</sup> and an automotive manufacturing site,<sup>17</sup> but these have been largely descriptive and have involved only a small number of COVID-19 cases.

To our knowledge, there has not previously been a specific study of electricity-generation workers. This industry is of considerable interest, since working from home is not a possibility for almost all operational staff, and there is little or no contact with the general public during working hours. Therefore, it provides an opportunity to investigate factors affecting workplace transmission in this specific environment.

In July 2020, government scientific advisers and key funders identified where the UK must increase research to respond to near-term strategic, policy and operational needs, and ultimately improve resilience against COVID-19 through 2021 and beyond. Six COVID-19 National Core Studies (NCS) have been established to meet these needs, including the NCS project on transmission of the SARS-CoV-2,<sup>18</sup> led by the UK's Health and Safety Executive. This project is known as 'PROTECT': The Partnership for Research into Occupational, Transport and Environmental Covid NCS, which brings together more than 70 researchers from 16 different institutions.

One of the six key themes of the 'PROTECT' project is to collect data from outbreak investigations in a range of workplaces to understand SARS-CoV-2 transmission risk factors, potential causes for COVID-19 outbreaks and the effectiveness of a range of measures to control and prevent these outbreaks. In addition to specific outbreak investigations conducted as part of PROTECT, some companies have been identified, which succeeded in assembling some detailed data on testing in their workforces, including relevant data on outbreaks they have experienced. One of these is a large electricity-generating company. We here report the findings of a test-negative design (TND) case-control study conducted using the data collected by this company. The main aim of these analyses was to investigate contextual-level, workplace subgroups and individual-level risk factors for SARS-CoV-2 infections.

## METHODS

The large electricity-generating company, which is the subject of this report, tested staff frequently on site throughout the course of the pandemic. The testing strategy and method varied over time and by facility. During some time periods, all staff were tested routinely, whereas in other time periods, most workers were only tested because they had symptoms or were identified as a contact of a positive case. These practices also varied across sites, so that at any given time, some sites may have been testing routinely, while others were only doing symptomatic and contact testing. Reason for test was collected and categorised into four groups: testing due to symptoms (using a lower threshold than government recommendations), testing for close contacts (using government defined criteria), testing for broader-defined work contacts (as per company protocols) and routine testing.

Tests with a missing or inconclusive result were excluded, along with those from visitors (single tests), and any person with missing job type. We also excluded tests that were missing one of the following a priori confounders: age, sex, site, test date or test type.

We included a maximum of one test per day for each person. Where there were multiple tests in a day with different outcomes or reasons (only a small number were identified), we prioritised positive results over negative (as false positives are less common than false negatives) and test reason in order of strength of reason (ie, symptoms, close contact, broader-defined work contact, screening and then missing). For each person, we used tests only up to and including their first positive result. Thus, the analyses presented here relate to the risks of a first infection, and subsequent infections were not considered.

We used a TND, in which positive tests (cases) were compared with negative tests (controls) during each quarter (3-month period). This approach is intended to control for factors that affect the propensity to be tested at different time points (eg, changing testing protocols and recognition of symptoms). It also has the advantage of being feasible, since we only had access to the test data, and not to data on individuals who were not tested. It has been widely used for assessing vaccine effectiveness, both for COVID-19<sup>19</sup> and for other infection.<sup>20</sup> More recently, it has been used for assessing risk factors for COVID-19 infection.<sup>21 22</sup> Site risk rating was assessed by the Outbreak Management Team consisting of the company doctors, occupational health advisors and site representatives for each power station, approximately once a week, based on the background prevalence of disease and the number of cases on site. The risk rating from 0 to 5 determined the COVID-19 mitigation requirements (eg, cleaning, personal protective equipment, testing, social distancing). At the higher risk ratings, more than half the permanent workforce of the power stations were working remotely, face coverings were mandatory at all times inside, enhanced contact tracing and isolation used a broader definition of a contact than in the national regulations. If there was no available risk rating for a particular week, then the rating for the closest previous date was chosen. For sites with no risk rating assigned, then the average risk rating across all sites was used.

An outage is a statutory shutdown, when a power station is offline, and maintenance can be undertaken. It is often a time with an increased number of external visitors/contractors to the site (sometimes doubling the number of people on site). We have a binary flag determining whether a test was taken during an outage at the relevant site.

Vulnerability status was determined by increased risk of severe disease or death from COVID-19 due to a pre-existing health condition as determined by the literature and was based on an employee's request for assessment. We have a binary flag for identified vulnerable staff members, who followed different protocols for their own protection (such as home working practices).

Vaccination information was captured for most workers on a voluntary basis. Where we had date of vaccine, then we could determine vaccine status at the time of the test, defining vaccine immunity as beginning 10 days after the vaccination date. Partial vaccination was defined as having received one vaccine (10 days or more prior) and full vaccination as two or more. Individuals without vaccination information were assumed unvaccinated as negative information was not captured. The Janssen vaccine which requires only one dose was not widely used in the UK and no single doses of this type were recorded in this study.

There were different types of tests available at different sites at different times and for different reasons. We categorised the tests as PCR LAMP (PCR loop-mediated isothermal amplification), other PCR (PCR), and lateral flow test. For PCR LAMP, all positives and 10% of negatives were then confirmed by PCR.

**Table 1** Test numbers and exclusions

Exclusion reason (in order)	Excluded tests	Remaining tests
Total		80077
Missing/invalid test outcome	200	79877
Missing test date	0	79877
Missing job category	267	79610
Visitor job category	5030	74580
Missing site	0	74580
Missing sex	0	74580
Missing age group	1	74579
Missing test type	601	74579
Multiple tests in single day*	132	74447
Tests after first testing positive	2968	70878

\*Duplicates deleted; 17 people had both negative and positive tests of which one positive test was kept. Of those with matching outcomes, 31 people had different test reasons of which the highest priority one was kept in this order: symptoms, close contact, broader-defined work contact, screening, missing reason.

We fitted logistic regression models comparing tests with positive outcomes to those with negative outcomes adjusting for the time period. There may have been more than one test per person during a time period but unless the tests were very close together there would not be much dependency. In addition to the a priori confounders of age, sex, date of test and test type, we considered the other available information detailed above as potential confounders or other explanatory variables of interest. Some of these factors were related, for example, routine testing was more common during site outages. All potential confounders were included in the final model, provided there were no problems of collinearity or non-convergence of the model. Ordinal variables were tested for linear trend using a likelihood ratio test and included as either categorical or continuous based on the result. The analysis used Stata 17.<sup>23</sup>

**RESULTS**

From an original file of 80 077 tests, there were 70 878 included in the analysis (table 1). Most exclusions were due to being visitor tests (5030) or tests for an individual after they first tested positive (2968, of which 433 (14.6%) were also positive).

Table 2 shows the demographic characteristics of the study participants. Almost 90% of the workers tested were men. There was a wide spread of ages from under 20 to over 70 and the median age group was 41–45. The largest proportion of workers were external contractors (53%), followed by engineering (16%) and operations (13%). Jobs were spread in a variety of locations, most at power stations, and there were many more tests per person at power stations 3, 7 and 8 (around 10 per person on average) than at other sites (between 2 and 5 per person on average).

The number of tests varied hugely by date, reflecting different stages of the pandemic as well as changes in regulations and protocols of testing and the general prevalence of COVID-19 in the UK. Most tests were in the first half of 2021, but most positive tests were in the first half of 2022 (figure 1).

The proportion of positive tests that were identified, according to the reasons for testing, are shown in table 3. Overall, testing those with symptoms identified more than half (54%) of the positive results, whereas testing close contacts picked up 24% and broader-defined work contacts 3%. Nevertheless, a significant minority of cases (16%) were identified by routine screening. The remaining 3% had missing test reason.

**Table 2** Demographic characteristics of analysis sample

Variable	Category	Test level		Individual level (at time of first test)	
		Number	%	Number	%
Total		70878		10768	
Sex	Male	63 197	89.2	9571	88.9
	Female	7681	10.8	1197	11.1
Age group	16–20	1012	1.4	189	1.8
	21–25	4950	7.0	760	7.1
	26–30	7692	10.9	1184	11.0
	31–35	8775	12.4	1300	12.1
	36–40	7875	11.1	1237	11.5
	41–45	7037	9.9	1098	10.2
	46–50	7969	11.2	1231	11.4
	51–55	9727	13.7	1480	13.7
	56–60	9352	13.2	1348	12.5
	61–65	5106	7.2	715	6.6
	66–70	1225	1.7	193	1.8
	71+	158	0.2	33	0.3
Job category	Energy operations	9067	12.8	1420	13.2
	Engineering	12 752	18.0	1716	15.9
	External contractors	37 064	52.3	5710	53.0
	HSE and security	2621	3.7	373	3.5
	Nuclear and scientific	3175	4.5	460	4.3
	Office-based	4395	6.2	783	7.3
	Project management	1804	2.6	306	2.8
Job site	Head office	1273	1.8	576	5.4
	Power station 1	2573	3.6	1099	10.2
	Power station 2	5758	8.1	1164	10.8
	Power station 3	5692	8.0	1011	9.4
	Power station 4	15 333	21.6	1494	13.9
	Power station 5	2926	4.1	981	9.1
	Power station 6	2555	3.6	865	8.0
	Power station 7	18 403	26.0	1869	17.4
	Power station 8	15 516	21.9	1357	12.6
	Other	849	1.2	352	3.3
Test date	Q1–3 2020*	304	0.4		
	Q4 2020	2379	3.4		
	Q1 2021	23 516	33.2		
	Q2 2021	27 016	38.1		
	Q3 2021	11 385	16.1		
	Q4 2021	3933	5.6		
	Q1 2022	1786	2.5		
	Q2–3 2022†	559	0.8		
Test type	PCR LAMP	51 935	73.3		
	Other PCR	16 572	23.4		
	Lateral Flow Test	2371	3.4		
Test reason	Symptoms	2773	3.9		
	Close contact	3174	4.5		
	Broader-defined work contact	2666	3.8		
	Routine screening	62 033	87.5		
	Missing‡	232	0.3		
Vaccination status§	Not vaccinated	57 718	81.4		
	Partially vaccinated (1)	5078	7.2		
	Fully vaccinated (2+)	8082	11.4		
Vulnerability status¶	Not vulnerable	65 262	92.1	9819	91.2
	Vulnerable (Cat1-3)	5616	7.9	949	8.8
Outage**	Not during outage	35 580	50.2		
	During outage	35 298	49.8		

continued

Table 2 continued

Variable	Category	Test level		Individual level (at time of first test)	
		Number	%	Number	%
Site risk rating††	0/1‡‡ (lowest risk)	1886	2.7		
	2	15 008	21.2		
	3	47 208	66.6		
	4	6 776	9.6		
	5 (highest risk)	0	0		

\*3 quarters combined due to low volumes (Q1=1, Q2=5, Q3=298).  
†2 quarters combined due to low volumes, especially negative tests (Q2=390, Q3=169).  
‡Kept in sample as not all models use test reason.  
§Based on vaccination date being populated and dated at least 10 days before test.  
¶Assumed to be not vulnerable if no vulnerability assessment took place.  
\*\*Based on statutory outage dates at the relevant site.  
††Based on approximately weekly risk rating given to each site to determine COVID-19 safety protocols. If there was no risk rating for the week, the closest available was used. If site was Other, then average risk rating for the week was used.  
‡‡Categories 0 and 1 were combined as there were only 73 in category 0.  
LAMP, loop-mediated isothermal amplification.

Table 4 shows the findings for the main risk factors under study. Our 'base model' adjusted for test date, age group and test type (results not shown) as well as the other risk factors shown in the table. There was strong evidence against a linear trend for time period ( $p < 0.0001$ ) and weak evidence for age group ( $p = 0.05$ ), so these were both included as categorical.

We found that the reason for testing was a strong confounder; in particular, the OR for 'external' workers (ie, contractors) changed from 0.74 (95% CI 0.61 to 0.89) to 1.14 (0.89 to 1.45) after adjusting for the test reason. Also, women showed lower risks than men, after adjustment for test reason (0.70; 0.58 to 0.86) but not before 1.00 (0.85 to 1.17). As well as being a strong confounder of job type, reason for testing was a very strong factor itself (table 4).

Vulnerability, outages, vaccination status and site risk rating were not identified as confounders (on introduction

to the model, results not shown) but were included in the final model for completeness. There was strong evidence against a linear trend for site risk rating ( $p < 0.0001$ ), so this was included as categorical. There was no evidence against a linear trend for vaccine status ( $p = 0.92$ ), so this was included as continuous.

The final model included job type, age, sex, test date, test type, test reason, job site, vaccination status, vulnerability status, outage and site risk rating. This model showed that there were few differences between job types and likelihood of testing positive after adjusting for all the other included factors. Women were less likely to test positive than men (0.71; 0.58 to 0.86).

The relationship between site and test positivity showed that power station 8 was higher risk (2.05; 1.52 to 2.77) than power station 7, the site with the most tests. Power station 6 was the lowest risk (0.22; 0.16 to 0.29 compared with power station 7). All other sites were estimated to be similar or lower risk than power station 7 but with varying magnitudes and levels of evidence (table 4).

There was a large effect of test reason, with those testing due to symptoms having 94.99 (78.29 to 115.24) times the odds of those from routine screening, those testing due to a positive close contact having 16.73 (13.80 to 20.29), and broader-defined work contact 2.66 (1.99 to 3.56) times the odds of those tested in routine screening (table 4).

There was no evidence of a difference in risk for vaccinated workers (0.97 per vaccination; 0.88 to 1.06), but vulnerable workers were at lower risk of testing positive than other workers (0.78; 0.63 to 0.96) and workers testing during an outage were at increased risk (1.35; 1.12 to 1.63). The site risk rating did not have a linear relationship with an individual's risk of testing positive as category 2 was lower risk than category 0/1 (baseline), but the higher categories showed a dose-response with infection risk (table 4).

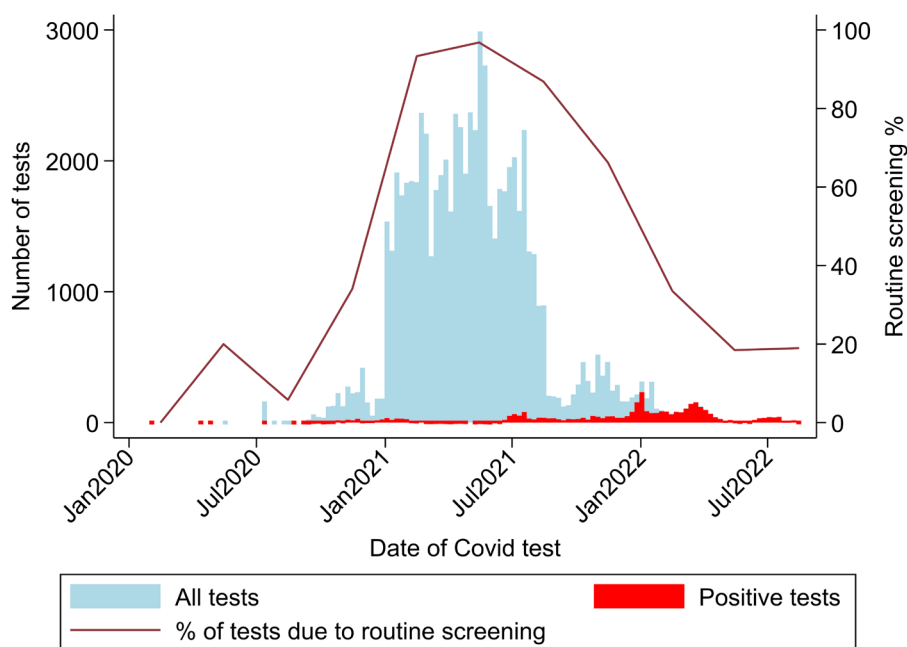


Figure 1 Number of tests, positive tests and percentage due to routine screening, by date.

**Table 3** Proportion of positive tests by test reason in each time period

Date (quarters)	Number of positive tests	Test reason				
		Symptoms (%)	Close contact (%)	Broader-defined work contact (%)	Routine screening (%)	Missing (%)
Q1–3 2020	25	28	44	0	4	24
Q4 2020	183	33	27	11	21	8
Q1 2021	204	48	24	10	18	0
Q2 2021	120	37	35	5	22	2
Q3 2021	492	59	20	2	18	1
Q4 2021	742	54	30	3	12	2
Q1 2022	1324	55	25	2	15	3
Q2–3 2022	552	65	10	0	21	3
Total	3642	54	24	3	16	3

We have also presented findings stratified by reason for testing in online supplemental table S1. In general, the findings are consistent with those of the final model (taking into account the wide confidence intervals for some effect estimates). The exception are the findings for those undergoing routine screening, where, for some variables, the effect estimates were inconsistent with those in the final model. However, once again, the CIs for these effect estimates were

relatively wide, due to data sparsity in some time periods from the changing testing protocols (figure 1).

**DISCUSSION**

As noted in the introduction, there have been relatively few in-depth investigations of work-place risk factors for COVID-19 infection. To our knowledge, no similar study has

**Table 4** ORs and 95% CIs for risk of testing positive on COVID-19 test

Exposure	Category	Crude job type association (n=70 878)	Base model* (n=70 878)	Base model*+test reason (n=70 646)	Final model† (n=70 646)
Job category	Energy operations	0.98 (0.86 to 1.12)	1.22 (0.99 to 1.51)	0.91 (0.70 to 1.19)	0.91 (0.70 to 1.20)
	Engineering	0.78 (0.68 to 0.88)	0.99 (0.81 to 1.21)	0.90 (0.69 to 1.16)	0.90 (0.70 to 1.17)
	External	0.36 (0.32 to 0.40)	0.74 (0.61 to 0.89)	1.14 (0.89 to 1.45)	1.05 (0.82 to 1.36)
	HSE and security	0.92 (0.76 to 1.10)	1.16 (0.87 to 1.54)	1.10 (0.77 to 1.57)	1.12 (0.78 to 1.62)
	Nuclear and scientific	0.85 (0.71 to 1.01)	1.09 (0.84 to 1.43)	0.92 (0.66 to 1.29)	0.96 (0.68 to 1.35)
	Office-based	1.00 (baseline)	1.00 (baseline)	1.00 (baseline)	1.00 (baseline)
	Project management	0.92 (0.75 to 1.13)	1.22 (0.89 to 1.68)	1.01 (0.66 to 1.53)	1.00 (0.66 to 1.51)
Sex	Female		1.00 (0.85 to 1.17)	0.70 (0.58 to 0.86)	0.71 (0.58 to 0.86)
Job site	Head office		0.74 (0.55 to 0.99)	0.67 (0.46 to 0.97)	0.70 (0.48 to 1.03)
	Power station 1		1.38 (1.10 to 1.72)	0.61 (0.47 to 0.80)	0.58 (0.43 to 0.77)
	Power station 2		0.40 (0.33 to 0.48)	0.44 (0.34 to 0.56)	0.38 (0.29 to 0.49)
	Power station 3		2.54 (2.04 to 3.16)	1.12 (0.85 to 1.47)	0.90 (0.67 to 1.20)
	Power station 4		0.74 (0.61 to 0.90)	0.57 (0.45 to 0.73)	0.42 (0.32 to 0.55)
	Power station 5		1.34 (1.04 to 1.71)	0.93 (0.69 to 1.27)	0.97 (0.70 to 1.33)
	Power station 6		0.39 (0.31 to 0.49)	0.26 (0.20 to 0.34)	0.22 (0.16 to 0.29)
	Power station 7		1.00 (baseline)	1.00 (baseline)	1.00 (baseline)
	Power station 8		4.16 (3.26 to 5.31)	2.41 (1.79 to 3.24)	2.05 (1.52 to 2.77)
	Other		0.93 (0.69 to 1.25)	0.34 (0.24 to 0.48)	0.31 (0.21 to 0.44)
Test reason	Symptoms			85.70 (71.37 to 102.91)	94.99 (78.29 to 115.24)
	Close contact			15.32 (12.75 to 18.40)	16.73 (13.80 to 20.29)
	Broader-defined work contact			2.51 (1.89 to 3.33)	2.66 (1.99 to 3.56)
	Routine screening			1.00 (baseline)	1.00 (baseline)
Vaccination status	Per vaccination‡				0.97 (0.88 to 1.06)
Vulnerability status	Vulnerable				0.78 (0.63 to 0.96)
Outage	During outage				1.35 (1.12 to 1.63)
Site risk rating	0/1 (lowest risk)				1.00 (baseline)
	2				0.64 (0.50 to 0.82)
	3				1.30 (1.00 to 1.69)
	4				1.60 (1.11 to 2.31)

\*Adjusted for job category, sex and site in the table, and also test date, test type and age group (results not shown).

†Adjusted for all variables in the table plus test date, test type and age group (results not shown).

‡Up to fully vaccinated (two or more vaccinations).

been completed in the electricity-generating industry, so our analyses were largely exploratory, with the aim of assessing a number of potential risk factors for infection in this context. This industry is of particular interest, since working from home is difficult and unusual, and there is relatively little contact with the general public during working hours. It, thus provides an opportunity to study workplace risk factors for transmission in this environment.

In this TND study, based on data from a UK electricity-generating company, we estimated the ORs for infection by job category, site, reason for testing, vulnerability, sex, reason for testing and the COVID-19 weekly risk rating for each site, adjusting for age and test date.

With regards to ‘reason for testing’, it is partly because of this variable that we used the TND. For example, if one particular job primarily involves routine testing, whereas another job primarily involves testing only when symptoms occur, we would expect to find differences between these two jobs in the rate of positive tests. One of the coauthors (NP) has written on precisely this problem in a follow-up<sup>21</sup> to a paper on the use of the TND for analysing COVID-19 test results,<sup>24</sup> stating: ‘For the application of the TND to study risk factors in situations where testing includes symptomatic as well as non-symptomatic persons, the reason for testing is important to record and account for in analysis and inference... increasingly people are being tested for a variety of reasons, and it is therefore necessary to control for ‘reason for testing’ in the analysis’.

There was little difference in risk by job category after adjusting for other factors. There were large differences in risk between job sites, which could be for a variety of reasons including localised community infection rates (partially adjusted for by site risk rating), whether the site was always operational (some were not), and differences in workplace culture. In general, the electricity-generating sites included in this study were high hazard, critical national infrastructure, highly regulated and with a strong safety culture. Women were less likely to be infected than men (OR=0.71). The strongest predictor of a positive test in our data was the reason for testing. For example, someone who was tested because of symptoms had 95 times the odds of testing positive compared with someone who was routinely screened. Those who were tested because of close contact with a case, had 17 times the odds of testing positive, and those with broader-defined work contact had 2.7 times the odds. This is consistent with the COVID-19 literature, unsurprisingly those with symptoms are much more likely to have an infection than randomly selected people without symptoms. Thus, this is not an original finding, but it does reinforce the importance of adjusting for reason for testing in the analyses. Reason for testing was also a strong confounder for job category, sex and job site (table 4).

It is also notable that despite these strong associations with symptomatic and contact testing, across the pandemic, 16% of cases were identified by routine testing. Thus, routine testing may have played an important role in identifying a large minority of cases, and thereby also reducing the spread of infection to contacts.

One limitation of this study is that we have included multiple tests on the same person in each time period (online supplemental table 2). If the tests are well spaced, then they should still be independent. However, tests close together on the same person will be more likely to have the same result as each other. One option is to shorten each time period and remove multiple

tests, but if the time periods are very short, then there are problems of sparse data due to the large number of parameters in the model. In addition, although most individuals had up to four tests in a time period, there were some with substantially more. These could bias results towards the null as there is a maximum of one positive result per person and so the multiple negative tests would outweigh the positive one when estimating the effects.

Overall, these findings showed little difference in positivity rates by job category once the analyses were adjusted for test reason. There were some differences by site, with four sites showing substantially lower risks, and one site showing higher risks in the final model. Vulnerable individuals showed slightly lower risks, possibly due to those individuals taking more care. Positivity rates were slightly higher during outages when there could be a lot more people on site. Vaccination did not show a protective effect on testing positive, which is perhaps surprising, and also in contrast with results from Rhodes *et al*, which showed that number of vaccines was inversely related to infection risk in working age people taking part in the COVID-19 infection survey in the UK.<sup>25</sup> Only about a fifth of tests in the present study related to a worker that was vaccinated at the time of testing, as vaccines for the majority of workers were not introduced until the middle of 2021.

The site risk rating showed a modest dose-response with infection risk at higher levels, indicating that such risk ratings may be useful for identifying ‘high-risk’ sites. It could be argued that the site risk rating depends on the number of cases, so it may not be appropriate to always adjust for it. However, inclusion of this variable made little difference to the main effect of job category (table 4) and the relationship between site risk rating and the odds of testing positive is of interest in itself.

X Martie van Tongeren @martievt

**Acknowledgements** We would like to thank the energy company for supplying the data and thank the employees for agreeing to take part in the study.

**Contributors** Conception or design of the work: NP, MvT. Data collection: data supplied by the company. Data checking and management: CER. Data analysis and interpretation: CER. Drafting the article: CER. Critical revision of the article: CER, MvT, TF, SR, YC, IH, NW and NP. Final approval of the version to be published: CER, MvT, TF, SR, YC, IH, NW and NP. Guarantor: CER.

**Funding** This work was supported by the PROTECT (Partnership for Research in Occupational, Transport and Environmental COVID Transmission) COVID-19 National Core Study on Transmission and Environment and managed by the Health and Safety Executive on behalf of HM Government (grant number 1.11.4.3941).

**Disclaimer** The contents of this paper, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect Health and Safety Executive policy.

**Competing interests** None declared.

**Patient consent for publication** Not applicable.

**Ethics approval** The Observational Research Committee of the London School of Hygiene and Tropical Medicine gave ethical approval for this work (ref 28125).

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data may be obtained from a third party and are not publicly available. The data are owned by the electricity-generating company.

**Supplemental material** This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and

is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

**Open access** This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

#### ORCID iDs

Charlotte E Rutter <http://orcid.org/0000-0002-9823-7932>  
 Martie van Tongeren <http://orcid.org/0000-0002-1205-1898>  
 Sarah Rhodes <http://orcid.org/0000-0002-5837-801X>  
 Yiqun Chen <http://orcid.org/0000-0003-4218-084X>  
 Neil Pearce <http://orcid.org/0000-0002-9938-7852>

#### REFERENCES

- Nafilyan V, Pawelek P, Ayoubkhani D, et al. Occupation and COVID-19 mortality in England: a national linked data study of 14.3 million adults. *Occup Environ Med* 2022;79:433–41.
- Burdorf A, Porru F, Rugulies R. The COVID-19 pandemic: one year later - an occupational perspective. *Scand J Work Environ Health* 2021;47:245–7.
- Michaels D, Wagner GR, Ryan L. Lessons from COVID-19 for protecting workers in the next pandemic. *JAMA* 2023;330:23–4.
- Rhodes S, Wilkinson J, Pearce N, et al. Occupational differences in SARS-Cov-2 infection: analysis of the UK ONS COVID-19 infection survey. *J Epidemiol Community Health* 2022;76:841–6.
- Beale S, Hoskins S, Byrne T, et al. Differential risk of SARS-Cov-2 infection by occupation: evidence from the virus watch prospective cohort study in England and Wales. *J Occup Med Toxicol* 2023;18:5.
- Beale S, Hoskins S, Byrne T, et al. Workplace contact patterns in England during the COVID-19 pandemic: analysis of the virus watch prospective cohort study. *Lancet Reg Health Eur* 2022;16:100352.
- Mutambudzi M, Niedzwiedz C, Macdonald EB, et al. Occupation and risk of severe COVID-19: prospective cohort study of 120 075 UK Biobank participants. *Occup Environ Med* 2021;78:307–14.
- Nafilyan V, Dolby T, Finning K, et al. Differences in COVID-19 vaccination coverage by occupation in England: a national linked data study. *Occup Environ Med* 2022;79:758–66.
- Beale S, Burns R, Braithwaite I, et al. Occupation, worker vulnerability, and COVID-19 vaccination uptake: analysis of the virus watch prospective cohort study. *Vaccine* 2022;40:7646–52.
- Cherrie M, Rhodes S, Wilkinson J, et al. Longitudinal changes in proportionate mortality due to COVID-19 by occupation in England and Wales. *Scand J Work Environ Health* 2022;48:611–20.
- Matz M, Allemani C, van Tongeren M, et al. Excess mortality among essential workers in England and Wales during the COVID-19 pandemic. *J Epidemiol Community Health* 2022;76:660–6.
- Matz M, Rhodes S, Tongeren MV, et al. Excess mortality among essential workers in England and Wales during the COVID-19 pandemic: an updated analysis. *J Epidemiol Community Health* 2023;77:481–4.
- Beale S, Yavlinsky A, Hoskins S, et al. Between-occupation differences in work-related COVID-19 mitigation strategies over time: analysis of the virus watch cohort in England and Wales. *Scand J Work Environ Health* 2023;49:350–62.
- Chen Y, Atchison C, Atkinson B, et al. The COVID-OUT study protocol: COVID-19 outbreak investigation to understand workplace SARS-Cov-2 transmission in the United Kingdom [version 1; peer review: awaiting peer review]. *Wellcome Open Res* 2021;6:201.
- Nicholls G, Atkinson B, van Veldhoven K, et al. An outbreak of SARS-Cov-2 in a public-facing office in England. *Occup Med (Lond)* 2023;kqad100.
- Graham A, Raja AI, van Veldhoven K, et al. A SARS-Cov-2 outbreak in a plastics manufacturing plant. *BMC Public Health* 2023;23:1077.
- Raja AI, van Veldhoven K, Ewuzie A, et al. Investigation of a SARS-Cov-2 outbreak at an automotive manufacturing site in England. *Int J Environ Res Public Health* 2022;19:6400.
- University of Manchester. PROTECT COVID-19 national core study. Available: <https://sites.manchester.ac.uk/covid19-national-project/> [Accessed 1 Aug 2023].
- Cerqueira-Silva T, Katikireddi SV, de Araujo Oliveira V, et al. Vaccine effectiveness of heterologous Coronavac plus BNT162b2 in Brazil. *Nat Med* 2022;28:838–43.
- Vandenbroucke JP, Pearce N. Test-negative designs: differences and commonalities with other case-control studies with 'other patient' controls. *Epidemiology* 2019;30:838–44.
- Vandenbroucke JP, Brickley EB, Pearce N, et al. The evolving usefulness of the test-negative design in studying risk factors for COVID-19. *Epidemiology* 2022;33:e7–8.
- Vandenbroucke JP, Brickley EB, Vandenbroucke-Grauls C, et al. The test-negative design with additional population controls: a practical approach to rapidly obtain information on the causes of the SARS-Cov-2 epidemic [in press]. *Epidemiology* 2020.
- StataCorp. *Stata Statistical Software: Release 17*. College Station, TX: StataCorp LLC, 2021.
- Vandenbroucke JP, Brickley EB, Vandenbroucke-Grauls C, et al. A test-negative design with additional population controls can be used to rapidly study causes of the SARS-Cov-2 epidemic. *Epidemiology* 2020;31:836–43.
- Rhodes S, Demou E, Wilkinson J, et al. Potential contribution of vaccination uptake to occupational differences in risk of SARS-Cov-2: analysis of the ONS COVID-19 infection survey. *Occup Environ Med* 2023;81:34–9.