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Original research

Potential contribution of vaccination uptake to occupational differences in risk of SARS-CoV-2: analysis of the ONS COVID-19 Infection Survey

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ABSTRACT

Objectives To assess variation in vaccination uptake across occupational groups as a potential explanation for variation in risk of SARS-CoV-2 infection.

Design We analysed data from the UK Office of National Statistics COVID-19 Infection Survey linked to vaccination data from the National Immunisation Management System in England from 1 December 2020 to 11 May 2022. We analysed vaccination uptake and SARS-CoV-2 infection risk by occupational group and assessed whether adjustment for vaccination reduced the variation in risk between occupational groups.

Results Estimated rates of triple vaccination were high across all occupational groups (80% or above), but were lowest for food processing (80%), personal care (82%), hospitality (83%), manual occupations (84%) and retail (85%). High rates were observed for individuals working in health (95% for office based, 92% for those in patient-facing roles) and education (91%) and office-based workers not included in other categories (90%). The impact of adjusting for vaccination when estimating relative risks of infection was generally modest (ratio of hazard ratios across all occupational groups reduced from 1.37 to 1.32), but was consistent with the hypothesis that low vaccination rates contribute to elevated risk in some groups.

Conclusions Variation in vaccination coverage might account for a modest proportion of occupational differences in infection risk. Vaccination rates were uniformly very high in this cohort, which may suggest that the participants are not representative of the general population. Accordingly, these results should be considered tentative pending the accumulation of additional evidence.

BACKGROUND

SARS-CoV-2 infection and COVID-19 mortality risks in the UK have been reported to differ across occupational groups, with variation seen over time.^{1–5} Some of this variation appears to be driven by workplace factors, such as the number of people in the workplace, ability to socially distance from others and whether the work is located in an indoor or outdoor environment.^{6–8} However, uncertainty remains regarding the extent to which occupational

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ There is variation in risk of SARS-CoV-2 infection across occupational groups, but the contribution of variation in vaccine uptake is unclear.

WHAT THIS STUDY ADDS

⇒ This study confirms that there is considerable variation in vaccine uptake across occupational groups. This may make a modest contribution to variation in risk of infection.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These results highlight occupational groups where vaccination uptake is low, while also suggesting a need for additional workplace interventions to mitigate risk. However, due to methodological limitations, the results should be considered tentative pending the accumulation of further evidence.

differences are driven by these characteristics compared with non-workplace factors.

One plausible contributor to the observed variation in risk may be occupational differences in rates of vaccination uptake against COVID-19. The primary function of vaccines is not so much to prevent SARS-CoV-2 infections, as it is to protect against associated morbidity and mortality. Nevertheless, vaccination appears to reduce the risk of SARS-CoV-2 infection as well as associated morbidity and mortality,^{9 10} although effects appear to strongly depend on the time since last vaccination.¹¹ In the UK, vaccine delivery was not mandated but was initially prioritised for certain high-risk occupational groups, such as healthcare workers. Identifying groups with low vaccination is important for informing future vaccine delivery strategy, as it may be necessary to offer specific, targeted encouragement to improve uptake. This would be particularly important if there are groups where low vaccination rates contribute to a higher risk of SARS-CoV-2 transmission in the workplace. Recent studies have highlighted considerable

variation in vaccine uptake across occupations,^{12–14} with low levels observed in people working in elementary trades. However, different data sources have different limitations, such as the possibility of non-random missing data.¹⁴ It is therefore crucial to investigate the replicability of findings relating to vaccination uptake across a variety of data sources, to permit triangulation of results.¹⁵ Moreover, estimating the variation in risk of SARS-CoV-2 infection across occupations with and without adjustment for vaccination status might indicate whether vaccination uptake is an important factor explaining these occupational differences. We therefore analysed data from the Office for National Statistics (ONS) Coronavirus Infection Survey (CIS) to characterise vaccine uptake across occupational groups and to examine vaccination uptake as a possible explanation for occupational variations in SARS-CoV-2 infection.

METHODS

Datasets

The CIS has been described elsewhere.^{2 16} It is a randomly sampled panel survey of households, including participants aged 2 years and older, that aims to be representative of the UK population. It began recruitment in April 2020 and has added new participants monthly until January 2022.¹⁷ Participants were visited weekly for the 5 weeks following their recruitment, and monthly thereafter. Survey responses were collected at in-person visits until April 2022, with each visit incorporating a PCR test for SARS-CoV-2, to enable estimation of prevalence. From April 2022 onwards, the CIS phased out in-person visits and started using a more flexible data collection approach using online, telephone and postal methods. Recruitment rates were initially high (51%) but eventually dropped to around 12%.¹⁸ The rate of attrition was very low (less than 1% in 2021¹⁸).

For participants in England, vaccination information (doses received, dates received, vaccine type) is available from the National Immunisation Management System (NIMS).¹⁹ ONS supplied a dataset containing NIMS data, which was bolstered using self-report data from CIS. Because NIMS does not cover Scotland, Wales and Northern Ireland, only self-report data are available for these countries. This represented a fundamental difference in measurement of vaccination in England compared with the other countries, as any vaccinations taking place after an individual's most recent CIS response could be accounted for in England, but not for the other countries. This would lead to considerable undercounting outside of England. We therefore restricted analyses to participants resident in England. We used data (from CIS and NIMS) from 1 December 2020, roughly coinciding with the start of the vaccination programme in the UK, and included all survey visits up to 11th May 2022, which was the most recent available data at the time of the analysis. The study included 256 598 working age adults.

Inclusion criteria

Analyses were conducted on working-age participants in England, which we defined as being aged 20–64 years at their first CIS visit. The definition was selected to allow direct comparison with previous studies.²

Classification of occupation

We developed our own bespoke set of occupational categories derived from four-digit SOCs. Categories used by Nafilyan *et al*⁴ and Mutambudzi *et al*³ were used as a starting point but then categories were merged and disaggregated as appropriate to derive a set of categories that avoided statistical disclosure for

this dataset and allowed assessment of categories perceived to be 'high risk' at some point during the pandemic—for example educators, and public facing transport workers. A job exposure matrix⁶ was used to check that occupations within the same exposure group had broadly similar occupational exposures. The recategorisation was performed by the study team and verified by external exposure experts. (online supplemental table 1). We defined the following occupational categories: education; food processing; healthcare (office based); healthcare (patient contact); hospitality; manual; other workers (non-office based); other workers (office based); personal care; police and protective services; retail; sanitation services; social care; transport (non-public facing); transport (public facing); not working/student. Rather than exclude individuals with missing occupation data, we created a 'missing' category, distinct from 'not employed'. The classification scheme is presented in online supplemental table 1.

Outcome definition

The outcome variable was SARS-CoV-2 infection, defined as a positive PCR test obtained from a CIS visit. Individuals infected with SARS-CoV-2 may test positive on PCR for an extended duration, including on consecutive CIS visits. This makes it difficult to distinguish repeated positive tests due to a single infection from repeated infections. We dealt with this issue by sensitivity analysis. Specifically, we conducted the analysis using two different definitions for a repeat infection. In the first, any new positive PCR test was treated as a new infection, provided that there was at least one negative PCR test since the previous positive test. In the second, we required a gap of 6 months between positive PCR tests, with at least one negative PCR test in between, to consider a subsequent positive PCR test to represent a new infection. This latter criterion was in line with UK government guidance concerning immunity following infection.²⁰ If results did not substantially differ between these two scenarios, it would indicate that findings were robust to handling of this issue.

Statistical analysis

We created descriptive summaries of participant characteristics. We summarised vaccination details (number of doses received, type of each dose) by occupation group. We then conducted analyses looking at how risk of SARS-CoV-2 infection varied across occupational groups in the period from 1 December 2020 to 11 May 2022, and how adjustment for vaccination status affected these estimates.

We used time-to-event methods, with calendar time as the timescale for analysis. Specifically, we set 1 December 2020 as the time origin, and considered participants to be left censored prior to their first survey visit after this date. We incorporated multiple infections per individual using a Prentice, Williams, Peterson Total Time approach, which estimates HRs with stratification by event number.^{21 22} We included COVID-19 vaccination status as a categorical variable, measuring the number of vaccines received (0, 1, 2, 3). The count of vaccines for each individual was not updated until 14 days after the vaccination date, to allow for a delay in conferred protection from the vaccine. The longitudinal nature of the survey means that repeated measurements are available for participants over time. We allowed all variables to be time-varying in the analysis. These analyses assume that the adjustment set, described below, was sufficient to account for any confounding of the occupational–infection relationship and of the vaccination–infection relationship.

We fitted models sequentially, with the adjustment variables selected using a Directed Acyclic Graph (DAG) (an interactive version is available at <http://dagitty.net/dags.html?id=7XRWnH> based on a previous version presented in Rhodes *et al*²). The DAG was constructed with the aim of identifying short-term effects of attending the workplace, rather than the effects of extended tenure in an occupation. Accordingly, we considered variables relating to health and living conditions to be confounders, rather than mediators, of the occupation effect. We first fitted models with occupation category as the exposure variable, adjusted for age and sex (model 1). We then additionally adjusted for ethnic group, index of multiple deprivation (categorised by quartiles), geographic region, household size, urban or rural location and presence of a health condition (model 2). We then added vaccination status, as described above (model 3). We present HRs (95% CIs) for each adjustment set. We calculated the 'ratio of HRs' as the ratio of the largest to the smallest HR among occupation groups (excluding 'not working' and 'missing' categories). We used 'other office-based workers' as the reference category for the occupation variable, as this was considered to be a large, low-risk group. We also present HRs (95% CIs) corresponding to number of vaccines received.

RESULTS

Our analyses included 256 598 working age adults. The characteristics of the sample are shown in [table 1](#).

Number of vaccines by occupation

[Figure 1](#) shows the proportion of survey participants in each occupation category who had zero, one, two or three (or more) vaccines by 11 May 2022. The overwhelming majority of individuals in all categories had had three vaccines. The proportion of individuals who had three vaccines was lowest for food processing. The results for office-based healthcare workers, personal care workers and public-facing transport workers cannot be fully displayed due to disclosure rules. However, office-based healthcare workers had the highest proportion with triple vaccination (95%). Proportions of individuals who had received three vaccinations were 80% in personal care and 87% in public-facing transport roles.

Online supplemental tables 2–4 show the type of vaccine received for first, second and third doses by occupation group.

Relationship with infection risk

Online supplemental table 5 shows the estimated hazard ratios for number of vaccines received in relation to SARS-CoV-2 infection. Infection risk decreased with increasing numbers of vaccinations. Online supplemental table 6 shows the number of infections by occupational group, although this is heavily redacted due to disclosure rules. [Figure 2](#) shows risk of infection (at least 1) and proportion of individuals with three vaccinations by occupational group. Risk of infection in this period was not highly variable across groups. Individuals working in personal care and food processing had relatively low rates of triple vaccination and relatively high rates of infection. People working in education had the highest risk of infection, and high rates of triple vaccination. People working in healthcare had the highest rates of triple vaccination, whereas risk of infection was not notably elevated compared with other occupational groups, including those who had regular contact with patients.

Estimated HRs (95% CIs) from PWP models are shown in [figure 3](#) and online supplemental table 7. Risk of infection during this period remained relatively high for education workers,

Table 1 Characteristics of the sample

Characteristic	Summary (n=256 598)
Age (years)	45.3 (12.3)
Sex, male	115 904 (45)
Ethnicity	
White	231 868 (90)
Asian	13 973 (5)
Black	3465 (1)
Mixed	4298 (2)
Other	2982 (1)
Missing	12 (0)
Occupation	
Education	12 131 (5)
Food processing	1080 (0)
Healthcare—office based	777 (0)
Healthcare—patient contact	10 970 (4)
Hospitality	2462 (1)
Manual	10 387 (4)
Other workers—non-office based	11 351 (4)
Other workers—office based	70 210 (27)
Personal care	732 (0)
Police and protective services	3076 (1)
Retail	5875 (2)
Sanitation services	1610 (1)
Social care	6533 (3)
Transport—non-public facing	2990 (1)
Transport—public facing	1088 (0)
Student/not working	65 236 (25)
Missing/incomplete	50 090 (20)
Index of multiple deprivation	
1	40 810 (16)
2	62 239 (24)
3	73 118 (29)
4	80 431 (31)
Urban–rural	
Major urban	106 046 (41)
Urban city town	105 716 (41)
Rural town	23 318 (9)
Rural village	21 518 (8)
Household size	
1	34 764 (14)
2	97 856 (38)
3	52 013 (20)
4	50 666 (20)
5+	21 299 (8)
Health conditions	
Yes	44 599 (17)
Missing	3084 (1)
Mean (SD) or n (%).	

people working in hospitality, personal care, police and protective services, social care and potentially public-facing transport roles, compared with other office-based workers. Adjustment for non-vaccine covariates had little impact on estimates. The impact of adjustment for number of vaccines received was negligible for some groups, such as education, social care and police and protective services. It was more pronounced for others; estimates for individuals employed in food processing, hospitality, manual professions, personal care, retail, sanitation services and

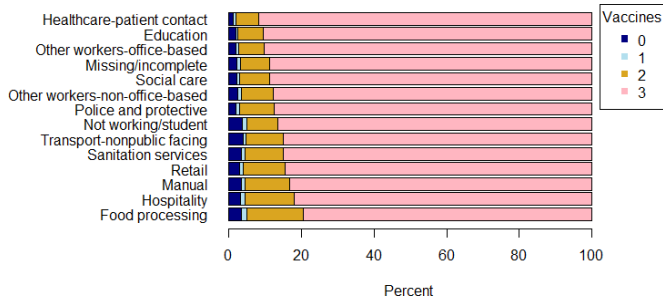


Figure 1 Percentage of individuals receiving 0, 1, 2, 3 COVID-19 vaccines in England by occupation group by 11 May 2022. Note that disclosure rules mean that results for office-based healthcare workers, personal care workers and public-facing transport workers cannot be displayed.

non-public facing transport roles were all noticeably reduced after adjustment for vaccination due to low uptake in these groups, although with considerable imprecision in estimates. Adjusting for vaccination substantially increased the estimate for healthcare roles with patient contact, and to a lesser extent office-based healthcare workers, due to high uptake in these groups. The ratio of hazard ratios reduced from 1.37 prior to adjustment for vaccination (model 2) to 1.32 following adjustment (model 3).

Results from the sensitivity analysis where a 6-month gap between positive PCR tests was required to register a new infection demonstrated a negligible difference in results (online supplemental figure 1 and online supplemental table 8).

DISCUSSION

The current results suggest that variation in vaccine uptake explains some of the differences in risk of SARS-CoV-2 infection between occupational groups. While the overwhelming majority of individuals in all groups had received three vaccines by 11 May 2022, there was substantial variation in the number of vaccines received between occupations. The variation in absolute risk of infection between occupational groups during the study period was not large.

These results are consistent with the findings from the Virus Watch cohort which found that individuals working in transport, trade, service and sales had the lowest uptake,¹² and also with an analysis based on 2021 Census data which suggested high uptake among office-based and professional workers and low uptake among people working in elementary occupations.¹⁴

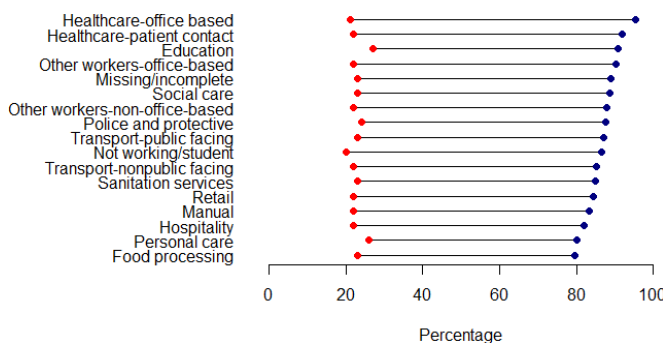


Figure 2 Rates of SARS-CoV-2 infection (at least one, red) and triple vaccination (blue) by occupation, between 1 December 2020 and 11 May 2022.

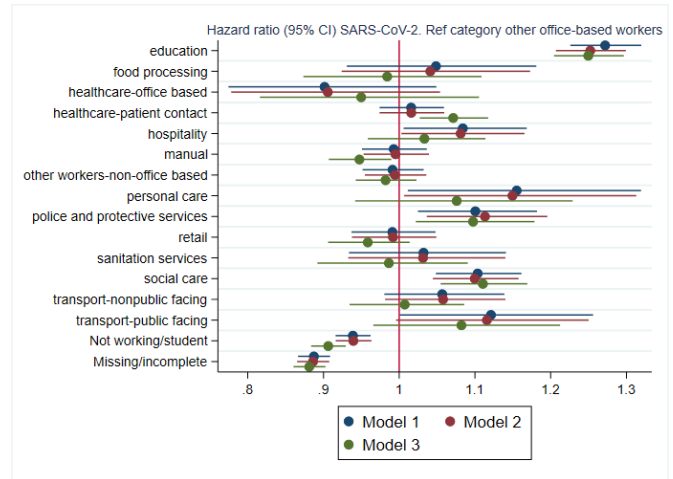


Figure 3 HR (95% CIs) corresponding to occupational group in relation to infection with SARS-CoV-2. Based on n=256 598 individuals. Model 1: adjusted for age and sex. Model 2: additionally adjusted for ethnicity, deprivation, region, urban or rural area, household size and presence of pre-existing health conditions. Model 3: additionally adjusted for number of vaccines received. The reference category was ‘other office-based workers’.

The estimates of relative infection risk for occupational groups with the lowest rates of triple vaccination (food processing, hospitality, manual, personal care, retail and sanitation services) were all reduced after adjusting for vaccination, which might suggest that relatively low vaccination rates account for some of the risk in these groups. Conversely, relative risk estimates for the occupational groups with the highest rates of triple vaccination were increased after adjustment for vaccination, suggesting that high vaccination coverage in healthcare workers may have conferred notable protection in this (high risk) group during the study period. However, there were also occupational groups with high vaccination coverage for which relative risk estimates were essentially unaffected after adjusting for vaccination (education, social care). Relative risk of infection remained high for these groups despite vaccination (although for social care, overall rates of triple vaccination in the period were below that observed for the reference group, other office-based workers). The estimated relative risk for police and protective services remained similar after adjustment for vaccination, and was elevated. Again, vaccination rates in this group were lower than for the reference group.

This is the first study to attempt to reconcile the effect of COVID-19 vaccination on the occupational risk of SARS-CoV-2 infection. There are a number of important limitations to consider in interpreting the results. Our analyses assume that we have sufficiently controlled for confounding between occupation and infection and between vaccination and infection. If the latter condition was not met, adjusting for vaccination as a purported mediator of the occupation-infection relationship could induce collider stratification bias. One probable source of unmeasured confounding in the current study relates to individual behaviour, such as socialising and shopping. However, previous analyses suggest that while occupational differentials in SARS-CoV-2 infection risk vary over time, they are relatively robust to adjustment for sociodemographic, health-related and non-workplace activity-related potential confounders.^{2 5} While data on behaviour is captured within the CIS, it is self-reported and subject to substantial rates of missingness. Further investigation of this dataset using methods for time-varying

confounding^{23 24} could prove worthwhile. It would also be useful to compare estimates across models after translating to a common, marginal scale, noting that there are challenges in implementing this with time-varying variables. We were unable to undertake advanced analyses due to practical restrictions on data access, which required attendance at a physical location by appointment, with no ability to browse the internet. We did not have access to data on working hours and so were unable to account for this in the analysis.

Another limitation of the dataset is that the relative timing of vaccination and infection is not always clear. If a participant obtains a positive PCR test at a survey visit, we can say that they became infected sometime since the previous visit, but whether this occurred prior to or following vaccination cannot be discerned, since we cannot know the actual date of infection. Another potential source of bias relates to the representativeness of the CIS. Estimated vaccine uptake reported here is similar to that observed in the Virus Watch cohort¹² but is considerably higher compared with some administrative databases, potentially indicating that response rate might be higher in vaccinated individuals. For example, we estimated the proportion of manual workers who had received three vaccinations to be over 80% by 11 May 2022. By contrast, an analysis based on 2021 Census data estimated the proportion of workers in elementary and related occupations to be just 58% by 28 February 2022.¹⁴ It is unclear however if the observed differences are due to lack of representativeness in the CIS, due to biases in the Census-based study arising from missing data or due to other methodological differences, such as the discrepancy in study periods. Overall, 88% of the CIS cohort had received three vaccinations by 11 May 2022. For comparison, we estimate that approximately 64% of 18–64 year olds in England had had three vaccinations by this date using publically available NIMS²⁵ and Census 2011²⁶ data. Noting the slight difference in age bandings, it does therefore appear that vaccination rates may be higher in the CIS cohort. It may be, for example, that participation in the study increases the likelihood of vaccination. If vaccination rates are consistently overestimated in the CIS data, this could cause us to understate the role of vaccination in explaining differential risk between occupations and could plausibly mean that overall variation in risk between occupations is understated. Consequently, triangulation of the results relating to vaccination effects will be important, using data sources with different biases, although at present there is no comparable analysis examining the role of vaccination in explaining differences in infection risk. These results should be considered preliminary pending the accrual of further relevant data. We did find that vaccination rates were lowest among several occupational groups involving substantial public contact, in line with recent work.¹⁴

We have categorised individuals based on task, but in future research it may be useful to consider alternative categorisation schemes based on occupational qualification or socioeconomic status. This would allow exploration of the question of whether differences in vaccine uptake could account for social inequalities in occupational infection risks.

CONCLUSIONS

The present results suggest that differences in vaccination uptake between occupations contribute to some of the difference in infection risk. However, it is not sufficient to explain all of the variation in risk, and important differences remain. These could be related to workplace factors, work activities or behaviours outside the workplace. Complementary approaches

are therefore likely to remain necessary, particularly for high-risk occupations.

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Contributors SR is principal investigator and is responsible for the overall content as the guarantor. All authors (SR, ED, JW, MC, RE, MG, SVK, TK, WM, NP, MvT) contributed to the design of the research proposal and study, including the statistical analysis plan. JW conducted analyses and wrote the first draft of the manuscript. All authors (SR, ED, JW, MC, RE, MG, SVK, TK, WM, NP, MvT) contributed to the interpretation of the results, critically revised the paper and agreed on the final version for submission.

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Competing interests SVK was cochair of the Scottish Government's Expert Reference Group on Ethnicity and COVID-19 and a member of the UK Scientific Advisory Group on Emergencies subgroup on ethnicity.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The COVID-19 Infection Survey received ethical approval from the South-Central Berkshire B Research Ethics Committee (20/SC/0195). All participants provided informed consent. For use of this data for this project statistics authority self-assessment classified the study as low risk. This assessment was approved by the Office for National Statistics Research Accreditation Panel. Participants gave informed consent to participate in the study before taking part.

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