

# **Antibody prevalence for SARS-CoV-2 following the peak of the pandemic in England: REACT2 study in 100,000 adults**

Ward H<sup>1,2,6</sup>, Atchison C<sup>1,2</sup>, Whitaker M<sup>1</sup>, Ainslie KEC<sup>1,3</sup>, Elliott J<sup>1</sup>, Okell L<sup>1,3</sup>, Redd R<sup>1</sup>, Ashby D<sup>1</sup>, Donnelly CA<sup>1,3,4</sup>, Barclay W<sup>2,5</sup>, Darzi A<sup>7</sup>, Cooke G<sup>2,5,6</sup>, Riley S<sup>1,3</sup>, Elliott P<sup>1,2,6,8</sup>

<sup>1</sup> School of Public Health, Imperial College London

<sup>2</sup> Imperial College Healthcare NHS Trust

<sup>3</sup> MRC Centre for Global infectious Disease Analysis, School of Public Health, Imperial College London

<sup>4</sup> Department of Statistics, University of Oxford

<sup>5</sup> Department of Infectious Disease, Imperial College London

<sup>6</sup> National Institute for Health Research Imperial Biomedical Research Centre

<sup>7</sup> Institute of Global Health Innovation at Imperial College London

<sup>8</sup> MRC Centre for Environment and Health, School of Public Health, Imperial College London

Corresponding authors

Helen Ward [h.ward@imperial.ac.uk](mailto:h.ward@imperial.ac.uk)

Paul Elliott [p.elliott@imperial.ac.uk](mailto:p.elliott@imperial.ac.uk)

## **Abstract**

### **Background**

England, UK has experienced a large outbreak of SARS-CoV-2 infection. As in USA and elsewhere, disadvantaged communities have been disproportionately affected.

### **Methods**

National REal-time Assessment of Community Transmission-2 (REACT-2) seroprevalence study using self-administered lateral flow immunoassay (LFIA) test for IgG among a random population sample of 100,000 adults over 18 years in England, 20 June to 13 July 2020.

### **Results**

Completed questionnaires were available for 109,076 participants, yielding 5,544 IgG positive results and adjusted (for test performance), re-weighted (for sampling) prevalence of 6.0% (95% CI: 5.8, 6.1). Highest prevalence was in London (13.0% [12.3, 13.6]), among people of Black or Asian (mainly South Asian) ethnicity (17.3% [15.8, 19.1] and 11.9% [11.0, 12.8] respectively) and those aged 18-24 years (7.9% [7.3, 8.5]). Care home workers with client-facing roles had adjusted odds ratio of 3.1 (2.5, 3.8) compared with non-essential workers. One third (32.2%, [31.0-33.4]) of antibody positive individuals reported no symptoms. Among symptomatic cases, the majority (78.8%) reported symptoms during the peak of the epidemic in England in March (31.3%) and April (47.5%) 2020. We estimate that 3.36 million (3.21, 3.51) people have been infected with SARS-CoV-2 in England to end June 2020, with an overall infection fatality ratio of 0.90% (0.86, 0.94).

### **Conclusion**

The pandemic of SARS-CoV-2 infection in England disproportionately affected ethnic minority groups and health and care home workers. The higher risk of infection in these groups may explain, at least in part, their increased risk of hospitalisation and mortality from COVID-19.

## Introduction

England has experienced a large outbreak of SARS-CoV-2 infection leading to the highest excess mortality in Europe by June 2020. (1) The first COVID-19 death occurred on 28 February, with in-hospital deaths peaking at 800 per day within 6 weeks. (2) Hospital admission and mortality data show an asymmetrical burden of COVID-19 in England, with high rates in older people including those living in long-term care, and in people of minority ethnic groups, particularly Black and Asian (mainly South Asian) individuals. (3-6) It is unclear how much of this excess is due to differences in exposure to the virus, e.g. related to workplace exposures and structural inequality, and how much is due to differences in outcome, including access to health care. (7,8)

Antibody data provide a long-lasting measure of SARS-CoV-2 exposure, enabling analyses of the recent epidemic. Most infected people mount an IgG antibody response detectable after 14-21 days although levels may start to wane after ~90 days. (9,10) Uncertain validity of the antibody tests used, variation in sampling, limited numbers and use of selected groups have made many studies difficult to interpret (11), although different criteria may apply for community-based studies where population-wide rather than individual results is the focus. (10-15). Self-administered lateral flow immunoassay (LFIA) tests done at home offer a method for obtaining community-wide seroprevalence estimates rapidly and at scale, at reasonable cost. While there have been questions about their use for individual care, (16-18) reliable population prevalence estimates can be obtained by adjusting for known test performance.(19)

We aimed here to i) estimate the cumulative community seroprevalence of IgG antibodies for SARS-CoV-2 and ii) identify those at most risk of infection, from a large representative sample in England up to early July 2020. We use these data to iii) estimate the total number of infected individuals in England and the infection fatality ratio (IFR).

## Methods

The REal-time Assessment of Community Transmission-2 (REACT-2) programme is evaluating community seroprevalence of SARS-CoV-2 infection in England. (20) We obtained a random population sample of adults in England, using the National Health Service (NHS) patient list, which includes name, address, age and sex of everyone registered with a general practitioner (almost the entire population). Personalized invitations were sent to 315,000 individuals aged 18 years and above to achieve similar numbers in each of 315 lower-tier local authority areas. Participants registered via an online portal or by telephone with registration closed after ~120,000 people had signed up.

Those registered were sent a test kit, including a self-administered point-of-care LFIA test and instructions by post, with link to an on-line video. The LFIA (Fortress Diagnostics, Northern Ireland) was selected following evaluation of performance characteristics (sensitivity and specificity) against pre-defined criteria for detection of IgG, (21) and extensive public involvement and user testing. (22) Compared to results from at least one of two in house ELISAs, sensitivity and specificity of finger-prick blood (self-read) were 84.4% (70.5, 93.5) in PCR confirmed cases and 98.6% (97.1, 99.4) in 500 pre-pandemic sera. (21) Participants completed a short registration questionnaire (online/telephone) and a further survey upon completion of their self-test. This included information on demographics, household composition, recent symptoms and a photo of the result. A validation study using photographs showed substantial concordance between participant- and clinician-interpreted results in over 500 tests (kappa: 0.89, 95% CI: 0.88-0.92) (22).

Seroprevalence was calculated as the proportion of individuals with a positive IgG result, adjusted for test performance using:

$$p = (q + \text{specificity} - 1) / (\text{sensitivity} + \text{specificity} - 1)$$

where  $p$  = adjusted proportion positive,  $q$  = observed proportion positive. (19) In addition, prevalence estimates at national level were weighted for age, sex, region, ethnicity and deprivation to account for differential sampling (geographic) and for variation in response rate so as to be representative of the population (18+ years) of England. Logistic regression models were adjusted for age, sex and region, and additionally for ethnicity, deprivation, household size and occupation. We used complete case analysis without imputation.

We estimated total number of SARS-CoV-2 infections since start of the epidemic until 17 July 2020 by multiplying the antibody prevalence, adjusted for test characteristics and re-weighted for sampling, by mid year population size at ages 18+ years in England (23). To correct for survival bias we further added to the seropositive population the deaths that mentioned COVID-19 on the death certificate during this period. We then estimated the IFR, dividing the total number of COVID-19 deaths excluding care home residents.(14) We obtained an overall IFR estimate and estimates stratified by age and gender.(24) Confidence bounds were obtained by using the Delta method. As a sensitivity analysis we calculated IFR and total infections including care home residents and with all-cause excess deaths (for data sources see supplementary table 2).

We obtained research ethics approval from the South Central-Berkshire B Research Ethics Committee (IRAS ID: 283787), and received MHRA approval for use of the LFIA for research purposes only.

Data were analysed using the statistical package R version 4.0.0. (25)

## Results

Of the 121,976 people who were sent LFIA test kits, 109,076 (89.4%) completed the questionnaire of whom 105,651 also completed the test; 5,743 (5.4%) reported an invalid or unreadable result leaving 99,908 (94.6%) individuals, 5,544 IgG positive and 94,364 IgG negative, giving a crude prevalence of 5.6% (95% CI 5.4-5.7). After adjusting for the performance characteristics of the test and re-weighting, overall prevalence for England was 6.0% (95% CI: 5.8-6.1) during the period 20 June to 13 July 2020. This equates to 3.36 (3.22, 3.51) million adults in England who had been infected with SARS-CoV-2 in England to end June 2020.

Prevalence was highest for ages 18-24 years and in London (Table 1). Highest prevalence by ethnic group was found in people of Black (includes Black Caribbean, African and Black British) (17.3%, 95% CI 15.8, 19.1) and Asian (mainly South Asian) ethnicities (11.9%, 95% CI 11.0, 12.8), compared to 5.0% (4.8, 5.2) in people of white ethnicity. (Table 1). The association of seroprevalence with non-white ethnicities was partially but not fully explained by the covariates. For example, in the unadjusted model, compared to white ethnicity, Black ethnicity was associated with a three-fold increase in odds of being antibody positive (OR 3.2, 95%CI 2.7, 3.9) which reduced to OR 2.0 (1.6, 2.4) after adjustment for age, sex, ethnicity, region, deprivation, household size and employment (Figure 1, Table S1). Essential workers, particularly those with public-facing roles, also had increased seroprevalence. Those working in residential care facilities (care homes) with client-facing roles had a prevalence of 16.5% (95% CI 13.7, 19.8) and health care workers with patient contact a prevalence of 11.7% (95% CI 10.5-13.1), with 3-fold (3.09; 2.51,3.80) and 2-fold (2.09; 1.86,2.35) odds of infection respectively compared with non-essential workers (Table 2, Figure 1). Those in the more deprived areas or living in larger households had higher prevalence than those in more affluent areas or who lived alone, although these gradients were partially attenuated in the adjusted models (Figure 1, Table S2). People who currently smoked had a lower prevalence (3.2%, 2.8, 3.7) than those who did not (5.2%, 5.0, 5.4), OR 0.64 [0.58,0.71].

Figure 2 shows how the epidemic evolved between January and June 2020, generating an epidemic curve based on data from the present study, based on those with antibodies who reported suspected or confirmed COVID-19 and provided a date (n=3,493). The top left plot (A) shows this

alongside national mortality for England by date of death which tracks 2–3 weeks behind our epidemic curve, which peaked in the first week of April. The other panels show the proportionate distribution of cases from our data by (B) region, (C) ethnicity and (D) work type. The epidemic was widely distributed across regions; as the epidemic grew there was a shift during lockdown towards a greater proportion of cases in minority ethnic groups, and in essential workers, particularly those in people-facing roles in care homes and health care. These data exclude asymptomatic individuals and symptomatic people whose date of infection was unknown.

### *Clinical presentation*

Of the 5,544 IgG positive people, 3,406 (61.4%; 60.1, 62.7) reported one or more typical symptoms (fever, persistent cough, loss of taste or smell), 353 (6.4%; 5.8, 7.0) reported atypical symptoms only, and 1,785 (32.2%; 31.0, 33.4) reported no symptoms. This varied by age, with people over 65 being more likely to report no symptoms (392/801, 48.9%, 45.4, 52.4) than those aged 18-34 (418/1,393, 30.0%, 27.6, 32.4) or 35-64 years (975/3,350, 29.1%, 27.6, 30.6), ( $p < 0.001$ ) (Table S1 and S2); prevalence was higher in those with more severe symptoms, and who had contact with a confirmed or suspected case (Figure 1, Table S2). Those who were overweight or obese had higher prevalence than those with normal weight, and current smokers had a lower prevalence than non-smokers (3.2% vs. 5.2% (OR 0.64 [0.58,0.71])).

### *Infection Fatality Ratio*

The estimated community IFR (excluding care homes) was 0.9% (0.86, 0.94), increasing with age and higher in males (1.07%, 1.00, 1.15) than females (0.71%, 0.67, 0.75) (Table 3). Sensitivity analyses indicate an IFR as high as 1.58% (1.51%, 1.65%) if excess rather than COVID-specific deaths are used and care home deaths are included (Table S2).

## **Discussion**

This is to our knowledge, the largest community-based evaluation of SARS-CoV-2 antibody prevalence, and the only nationwide study based on unsupervised use of LFIA tests at home. It shows an overall prevalence of 6.0% in England, with the epidemic widely dispersed geographically. Overall we estimate that 3.4 million adults had been infected with SARS-CoV-2 virus in England to the end of June 2020, with the majority of people who developed antibodies reporting symptoms during the peak of the epidemic in March and April 2020. This is broadly consistent with other surveillance systems and from a smaller national study of serological surveillance which reported a

26) Our findings are also broadly in line with large prevalence surveys in other countries which have

shown a relatively low overall prevalence, despite apparently large outbreaks, and far below what would be necessary to confer some level of herd immunity. (14,27 )

We have shown that as the epidemic increased in March and April it became more concentrated in specific groups including Black, Asian and other minority ethnic groups, essential workers, particularly those working in long-term residential care and health care workers, those living in larger households and deprived areas. While these associations were partially attenuated in the adjusted analyses, they remained important predictors, and reflect starkly uneven experience of the COVID-19 epidemic across society. This key finding of unequal burden of infection supports evidence emerging from other countries, mostly from hospital-based studies and mortality data. In the USA local and clinical studies indicate a higher rate of infection in Black and Hispanic populations. One clinical study in Louisiana reported a high proportion of cases but no increased mortality in Black non-Hispanic people; a similar pattern was observed in US Veterans and in national estimates of differential mortality. (28-30)

Our study has the advantage of including ethnicity data alongside information about employment, deprivation, household size and other potential confounders. This allows a more nuanced exploration of the underlying mechanisms for the unequal risks (8). We found that while some of the increased risk of infection in minority ethnic groups was explained by these other factors, odds of infection remained two-fold and 1.4-fold higher for people of Black and Asian ethnicities respectively compared with white ethnicity after adjusting for these factors, indicating that higher rates of infection are a component of the higher hospitalisation and mortality rates. However, more research is needed to better understand whether underlying structural inequalities, occupational or other factors may have contributed to this pattern of risks in non-white populations. (31)

In common with some other studies we found that current smokers have a lower prevalence of SARS-CoV-2 infection than non-smokers. (6,32-33) Reasons for this observation are unclear; further research is needed as to whether it reflects unmeasured confounding, differential adoption of preventive behaviours or whether there may be some biological basis (34).

Our estimated IFR of 0.9% is in line with a recent large study in Spain which reported 0.83% to 1.07%, lower than described in Italy at 2%, and higher than the 0.38% reported from a German study. (35-37) The overall IFR is dependent on the age and sex distribution of infection, and stratified estimates maybe more informative. In estimating the IFR, we may have underestimated the number of infected individuals (leading to higher estimates of IFR), as a result of weakened or absent antibody response in some people, and waning antibody over time. (6) Like many countries, England

experienced high numbers of cases and deaths in care home residents which have accounted for just under half of all deaths. (38) While the high rates of infection in care home workers may have spilled over into the community, the care home and community epidemics were somewhat separate. We excluded care home mortality from our estimates of community IFR, especially as only a relatively small number of care home residents were included in our study.

The clinical spectrum of infection is wide, with just under one third (32%) of people with antibodies reporting no symptoms, and this proportion was higher in people over 65 years (49%) as also reported for individuals in long-term care. (40). The national seroprevalence study in Spain reported that 28.5% or 32.7% were asymptomatic depending on the test (14), similar to our findings overall, although a systematic review of 16 clinical studies puts the figure at 40–50% (39).

The high prevalence in individuals with people-facing roles in social and health care suggests that infection control in the early months of the epidemic was inadequate in these settings and likely placed both staff and residents/ patients at risk. Together with our finding that almost 50% of infections in people over 65 were asymptomatic, this emphasises the need for expanded testing in the care home setting in particular among staff and residents.

Our study has a number of limitations. As in almost all population surveys, our study showed unequal participation, with lower response from ethnic minority groups and people in more deprived areas. We re-weighted the sample to account for differential response, although this may not have overcome unknown participation biases. An important limitation was the exclusion of children for regulatory reasons as the tests were approved for research use in adults only. We used self-administered home LFIA tests as opposed to “gold standard” laboratory tests based on a blood draw. However, we carried out extensive evaluation of the selected LFIA which showed it to have acceptable performance in terms of both sensitivity and specificity in comparison with the confirmatory laboratory tests (21). We also took steps to measure and improve usability, including ability to perform and read an LFIA test, through public involvement and evaluation in a national study of 14,000 people. (22).

Use of the LFIA enabled us to obtain antibody tests on large numbers, without the need for laboratory or health care personnel, over an 18-day period. Antibodies were strongly associated with clinical history of confirmed or suspected COVID-19, providing face validity; although there was a theoretical potential for reporting bias as respondents were not blinded to their test results, there was high concordance of self-reported with clinician-read results from the uploaded photos. Our results closely tracked other indicators of the epidemic curve and we believe that use of home-based



self-tests is a sustainable model for community-based seroprevalence studies in other populations – to provide reliable estimates of the timing, extent and at risk groups of the epidemic, avoiding the biases of studies carried out in e.g. health care or work settings.

In conclusion, our finding of substantial inequalities in SARS-CoV-2 prevalence by ethnicity and social deprivation shows the underlying importance of excess risk of exposure in these groups, and counters suggestions that the excess risk is due predominantly to comorbidities or other biological factors. The higher risk of infection in these groups may explain, at least in part, their increased risk of hospitalisation and mortality from COVID-19.

### **Contributions**

HW, CA, PE designed the study and drafted the manuscript

MW, KECA, JE, LO, RR conducted the analyses

HW, CA, GC, DA, CAD, WB, AD, GC, SR, PE, provided study oversight

AD and PE obtained funding

All authors have reviewed and approved the final manuscript

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**Table 1: Prevalence of SARS-CoV-2 IgG antibodies: crude, adjusted for test performance, and weighted to the population (18+ years) of England, by sociodemographic characteristics**

	<i>Total antibody positive</i>	<i>Total tests (with valid results)</i>	<i>Crude prevalence % [95% confidence intervals]</i>	<i>Prevalence % adjusted for test [95% confidence intervals]</i>	<i>Weighted<sup>1</sup> prevalence % [95% confidence intervals]</i>
<i>England</i>	5544	99908	5.6 [5.4-5.7]	5.0 [4.8-5.2]	6.0 [5.8-6.1]
<b>Sex</b>					
<i>Male</i>	2405	43825	5.5 [5.3-5.7]	4.9 [4.7-5.2]	6.2 [5.9-6.4]
<i>Female</i>	3139	56083	5.6 [5.4-5.8]	5.1 [4.8-5.3]	5.8 [5.5-6.0]
<b>Age</b>					
18-24	463	6499	7.1 [6.5-7.8]	6.9 [6.2-7.7]	7.9 [7.3-8.5]
25-34	930	13366	7.0 [6.5-7.4]	6.7 [6.2-7.2]	7.8 [7.4-8.3]
35-44	964	17052	5.7 [5.3-6.0]	5.1 [4.7-5.6]	6.1 [5.7-6.6]
45-54	1255	20634	6.1 [5.8-6.4]	5.6 [5.3-6.0]	6.4 [6.0-6.9]
55-64	1131	20404	5.5 [5.2-5.9]	5.0 [4.6-5.4]	5.9 [5.5-6.4]
65-74	568	15543	3.7 [3.4-4.0]	2.7 [2.4-3.1]	3.2 [2.8-3.6]
75+	233	6410	3.6 [3.2-4.1]	2.7 [2.2-3.3]	3.3 [2.9-3.8]
<b>Ethnicity</b>					
<i>White</i>	4827	92737	5.2 [5.1-5.3]	4.6 [4.4-4.8]	5.0 [4.8-5.2]
<i>Mixed</i>	106	1347	7.9 [6.5-9.4]	7.8 [6.2-9.7]	8.9 [7.1-11.1]
<i>Asian<sup>2</sup></i>	369	3658	10.1 [9.2-11.1]	10.5 [9.3-11.7]	11.9 [11.0-12.8]
<i>Black<sup>3</sup></i>	135	900	15.0 [12.8-17.5]	16.4 [13.8-19.4]	17.3 [15.8-19.0]
<i>Other</i>	79	762	10.4 [8.4-12.7]	10.8 [8.4-13.7]	12.3 [10.2-14.7]
<b>Deprivation Quintile<sup>4</sup></b>					
1 most deprived	682	10082	6.8 [6.3-7.3]	6.5 [5.9-7.1]	7.3 [6.8-7.7]
2	947	16015	5.9 [5.6-6.3]	5.4 [5.0-5.9]	6.4 [6.0-6.8]
3	1196	21474	5.6 [5.3-5.9]	5.0 [4.7-5.4]	5.9 [5.5-6.3]
4	1287	24840	5.2 [4.9-5.5]	4.6 [4.2-4.9]	5.2 [4.8-5.6]
5 least deprived	1432	27497	5.2 [5.0-5.5]	4.6 [4.3-4.9]	5.0 [4.6-5.4]
<b>Household size</b>					
1	720	15052	4.8 [4.5-5.1]	4.1 [3.7-4.5]	4.7 [4.3-5.1]
2	1784	36413	4.9 [4.7-5.1]	4.2 [4.0-4.5]	5.0 [4.7-5.3]
3	1158	19734	5.9 [5.5-6.2]	5.4 [5.0-5.8]	6.5 [6.0-6.9]
4	1204	19611	6.1 [5.8-6.5]	5.7 [5.3-6.1]	6.4 [6.0-6.8]
5	447	6403	7.0 [6.4-7.6]	6.7 [6.0-7.5]	7.7 [7.0-8.5]
6	152	1848	8.2 [7.1-9.6]	8.2 [6.8-9.8]	12.3 [10.8-14.0]
7+	79	827	9.6 [7.7-11.7]	9.8 [7.6-12.5]	13.0 [11.0-15.3]
<b>Region</b>					
<i>North East</i>	196	3574	5.5 [4.8-6.3]	4.9 [4.1-5.9]	5.0 [4.3-5.9]
<i>North West</i>	714	11996	6.0 [5.5-6.4]	5.5 [5.0-6.0]	6.6 [6.1-7.2]
<i>Yorkshire</i>	284	6519	4.4 [3.9-4.9]	3.6 [3.0-4.2]	3.9 [3.5-4.5]
<i>East Midlands</i>	601	12684	4.7 [4.4-5.1]	4.0 [3.6-4.5]	4.2 [3.7-4.8]
<i>West Midlands</i>	547	9620	5.7 [5.2-6.2]	5.2 [4.6-5.7]	5.8 [5.3-6.4]
<i>East of England</i>	805	14433	5.6 [5.2-6.0]	5.0 [4.6-5.5]	5.1 [4.6-5.6]
<i>London</i>	1045	9547	10.9 [10.3-11.6]	11.5 [10.8-12.3]	13.0 [12.3-13.6]
<i>South East</i>	995	21979	4.5 [4.3-4.8]	3.8 [3.4-4.1]	3.9 [3.5-4.3]
<i>South West</i>	357	9556	3.7 [3.4-4.1]	2.8 [2.4-3.3]	2.8 [2.4-3.3]

**Legend** <sup>1</sup>All estimates of prevalence adjusted for imperfect test sensitivity and specificity (see text for details). Responses have been re-weighted to account for differential sampling (geographic) and for variation in response rate (age, gender, ethnicity and deprivation) in final column to be representative of the England population (18+); <sup>2</sup> Asian / Asian British; <sup>3</sup> Black / African / Caribbean / Black British; <sup>4</sup> Based on Index of Multiple Deprivation (2019) at lower super output area.

**Table 2: Prevalence of SARS-CoV-2 IgG antibodies: crude and adjusted for test performance, for individual and clinical characteristics**

	<b>Total antibody positive</b>	<b>Total tests (with valid results)</b>	<b>Crude prevalence % (95% CI)</b>	<b>Prevalence % adjusted for test</b>
<b>Employment</b>				
<i>Health care (patient-facing)</i>	379	3402	11.1 [10.1-12.2]	11.7 [10.5-13.1]
<i>Health care (other)</i>	73	1151	6.3 [5.1-7.9]	6.0 [4.4-7.8]
<i>Care home (client-facing)</i>	115	761	15.1 [12.7-17.8]	16.5 [13.7-19.8]
<i>Care home (other)</i>	12	146	8.2 [4.8-13.8]	8.2 [4.1-15.0]
<i>Other essential worker<sup>1</sup></i>	1209	19927	6.1 [5.7-6.4]	5.6 [5.2-6.0]
<i>Other worker</i>	2189	37855	5.8 [5.6-6.0]	5.3 [5.0-5.6]
<i>Not in employment</i>	1516	35737	4.2 [4.0-4.5]	3.4 [3.2-3.7]
<b>History of COVID-19</b>				
<i>Positive PCR test</i>	277	341	81.2 [76.7-85.0]	96.2 [90.8-100.0]
<i>Suspected by doctor</i>	353	1144	30.9 [28.2-33.6]	35.5 [32.3-38.8]
<i>Suspected by respondent</i>	3118	17893	17.4 [16.9-18.0]	19.3 [18.6-20.0]
<i>No</i>	1698	80390	2.1 [2.0-2.2]	0.9 [0.7-1.0]
<b>Symptoms</b>				
<i>Appetite loss</i>	1504	5895	25.5 [24.4-26.6]	29.1 [27.7-30.4]
<i>Nausea/vomiting</i>	516	2286	22.6 [20.9-24.3]	25.5 [23.5-27.6]
<i>Diarrhoea</i>	744	3048	24.4 [22.9-26.0]	27.7 [25.9-29.6]
<i>Abdominal pain</i>	452	2230	20.3 [18.7-22.0]	22.7 [20.8-24.8]
<i>Runny nose</i>	732	4327	16.9 [15.8-18.1]	18.7 [17.4-20.1]
<i>Sneezing</i>	550	3293	16.7 [15.5-18.0]	18.4 [16.9-20.0]
<i>Blocked nose</i>	743	4217	17.6 [16.5-18.8]	19.5 [18.2-21.0]
<i>Sore eyes</i>	610	2945	20.7 [19.3-22.2]	23.3 [21.6-25.1]
<i>Loss of sense of smell</i>	2159	4714	45.8 [44.4-47.2]	53.5 [51.8-55.2]
<i>Loss of sense of taste</i>	2212	5247	42.2 [40.8-43.5]	49.1 [47.5-50.7]
<i>Sore throat</i>	1336	8994	14.9 [14.1-15.6]	16.2 [15.3-17.1]
<i>Hoarse voice</i>	502	3376	14.9 [13.7-16.1]	16.2 [14.8-17.7]
<i>Headache</i>	2128	10374	20.5 [19.7-21.3]	23.0 [22.1-24.0]
<i>Dizziness</i>	824	3956	20.8 [19.6-22.1]	23.4 [21.9-25.0]
<i>Shortness of breath</i>	1259	6899	18.2 [17.4-19.2]	20.3 [19.2-21.4]
<i>New persistent cough</i>	1537	9746	15.8 [15.1-16.5]	17.3 [16.5-18.2]
<i>Tight chest</i>	1228	6931	17.7 [16.8-18.6]	19.7 [18.6-20.8]
<i>Chest pain</i>	590	3408	17.3 [16.1-18.6]	19.2 [17.7-20.7]
<i>Fever</i>	1906	9128	20.9 [20.1-21.7]	23.5 [22.5-24.5]
<i>Chills</i>	1233	5329	23.1 [22.0-24.3]	26.2 [24.8-27.6]
<i>Difficulty sleeping</i>	930	5366	17.3 [16.3-18.4]	19.2 [18.0-20.4]
<i>Tiredness</i>	2626	12246	21.4 [20.7-22.2]	24.1 [23.3-25.0]
<i>Severe fatigue</i>	1256	5089	24.7 [23.5-25.9]	28.0 [26.6-29.5]
<i>Numbness/tingling</i>	358	1446	24.8 [22.6-27.0]	28.1 [25.5-30.9]
<i>Heavy arms/legs</i>	1173	5196	22.6 [21.5-23.7]	25.5 [24.2-26.9]
<i>Muscle aches</i>	2236	10205	21.9 [21.1-22.7]	24.7 [23.8-25.7]
<i>None of these symptoms</i>	6	74	8.1 [3.8-16.6]	8.1 [2.9-18.3]
<b>Symptom severity</b>				
<i>None</i>	87	683	12.7 [10.4-15.4]	13.7 [10.9-16.9]
<i>Mild symptoms</i>	1025	6071	16.9 [16.0-17.8]	18.7 [17.5-19.8]
<i>Moderate symptoms</i>	1850	9261	20.0 [19.2-20.8]	22.4 [21.4-23.4]
<i>Severe symptoms</i>	884	3501	25.2 [23.8-26.7]	28.7 [27.0-30.5]
<b>Contact with case</b>				
<i>Yes, with confirmed case</i>	742	3946	18.8 [17.6-20.1]	21.0 [19.5-22.5]
<i>Yes, with suspected case</i>	896	5307	16.9 [15.9-17.9]	18.7 [17.5-19.9]
<i>No</i>	3906	90655	4.3 [4.2-4.4]	3.5 [3.3-3.7]
<b>Number of pre-existing health conditions<sup>2</sup></b>				



	>1	1097	22127	5.0 [4.7-5.3]	4.3 [4.0-4.6]
	1	1558	28308	5.5 [5.2-5.8]	4.9 [4.6-5.3]
	0	2889	49473	5.8 [5.6-6.0]	5.3 [5.1-5.6]
<b>BMI<sup>3</sup></b>					
	<i>Underweight (&lt;18.5)</i>	65	1236	5.3 [4.1-6.6]	4.6 [3.3-6.3]
	<i>Normal (18.5-24.9)</i>	1919	36191	5.3 [5.1-5.5]	4.7 [4.4-5.0]
	<i>Overweight (25-29.9)</i>	1826	31818	5.7 [5.5-6.0]	5.2 [4.9-5.5]
	<i>Obese (&gt;=30)</i>	1161	19855	5.8 [5.5-6.2]	5.4 [5.0-5.8]
<b>Smoking (current)</b>					
	Yes	433	10635	4.1 [3.7-4.5]	3.2 [2.8-3.7]
	No	5059	88290	5.7 [5.6-5.9]	5.2 [5.0-5.4]
<b>Care home resident</b>					
	Yes	6	131	4.6 [2.1-9.6]	3.8 [0.9-9.9]

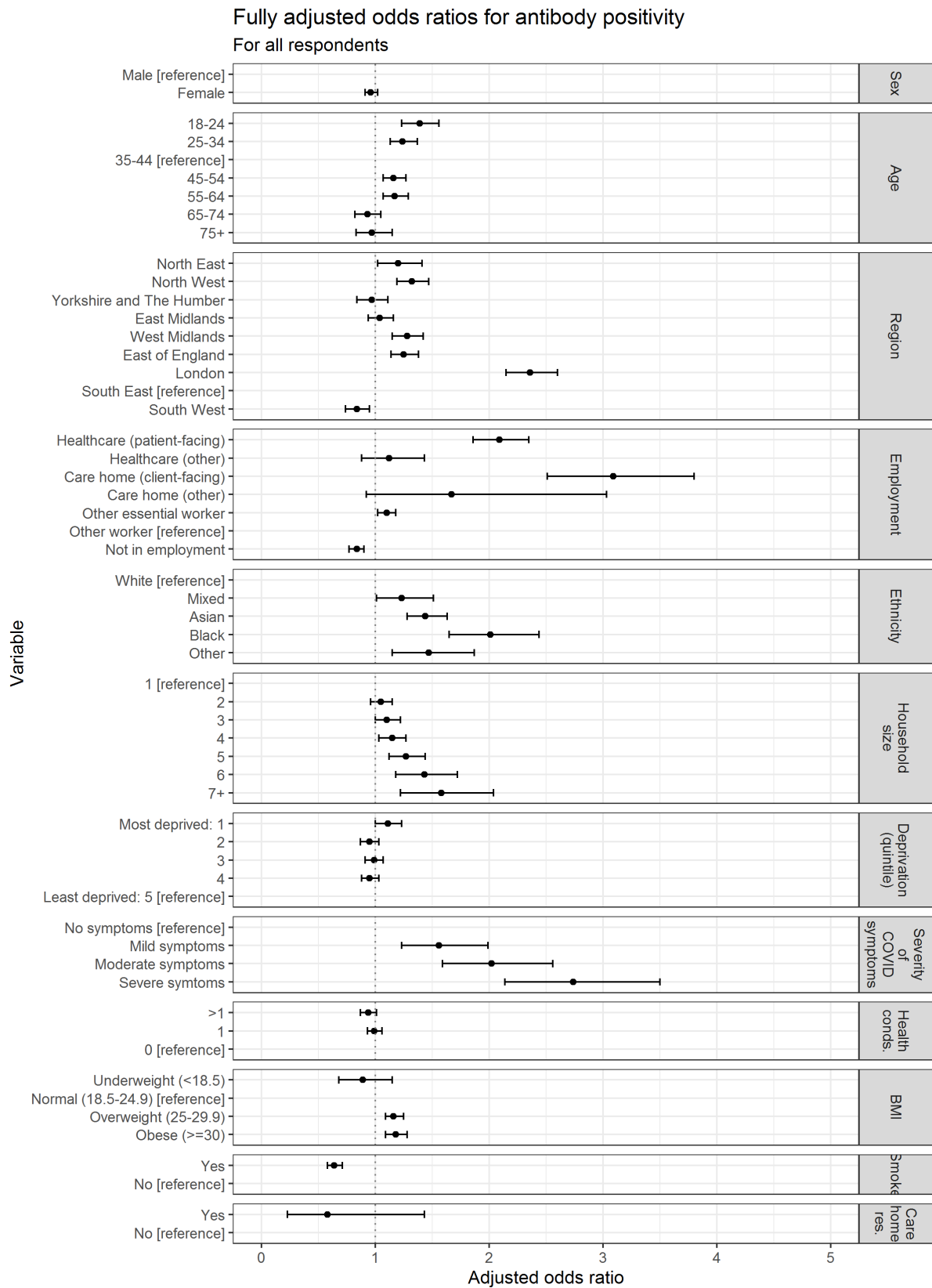
**Legend:** \* All estimates of prevalence adjusted for imperfect test sensitivity and specificity. <sup>1</sup> List of essential workers from government <https://www.gov.uk/guidance/coronavirus-covid-19-getting-tested#essential-workers>. <sup>2</sup>Pre-existing health conditions included: organ transplant recipient, diabetes (type I or II), heart disease or heart problems, hypertension, overweight, stroke, kidney disease, liver disease, anemia, asthma, other lung condition, cancer, condition affecting the brain and nerves, weakened immune system/reduced ability to deal with infections, depression, anxiety, psychiatric disorder, none of these; <sup>3</sup>Body Mass Index (BMI) formula: weight (kg) / [height (m)]<sup>2</sup>.

**Table 3: Infection Fatality Ratio and estimated total numbers of deaths**

<i>Category</i>	<i>Population size</i>	<i>SARS-CoV-2 antibody prevalence% (95% CI)<sup>1</sup></i>	<i>Confirmed COVID-19 deaths*</i>	<i>Infection fatality ratio % (95% CI)<sup>2</sup></i>	<i>Estimated number of infections (95% CI)</i>
<b>Total</b>	56,286,961	6.0 (5.7, 6.8)	30180	0.9 (0.9, 0.9)	3,362,037 (3,216,816; 3,507,258)
<b>Sex</b>					
Male	27,827,831	6.2 (5.8, 6.6)	18575	1.1 (1.0, 1.2)	1,729,675 (1,614,585; 1,844,766)
Female	28,459,130	5.8 (5.4, 6.1)	11600	0.7 (0.7, 0.8)	1,633,785 (1,539,821; 1,727,749)
<b>Age</b>					
15-44	21,335,397	7.2 (6.7, 7.7)	524	0.0 (0.0, 0.0)	1,535,884 (1,436,941; 1,634,826)
45-64	14,405,759	6.2 (5.8, 6.6)	4657	0.5 (0.5, 0.5)	895,238 (837,231; 953,244)
65-74	5,576,066	3.2 (2.7, 3.7)	5663	3.1 (2.6, 3.6)	181,044 (153,426; 208,661)
75+	4,777,650	3.3 (2.5, 4.1)	19330	11.6 (9.2, 14.1)	166,077 (131,059; 200,646)

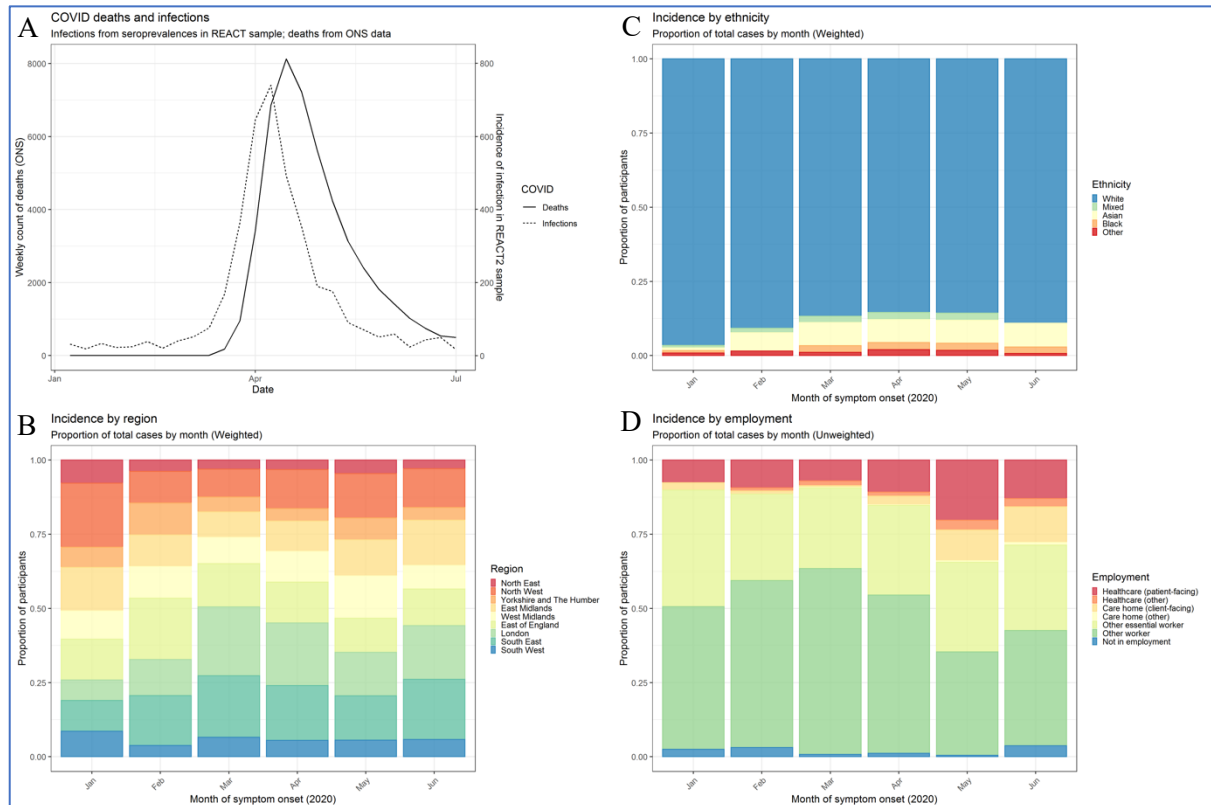
**Legend:** <sup>1</sup>All estimates of prevalence adjusted for imperfect test sensitivity and specificity (see text for details). Responses have been re-weighted to account for differential sampling (geographic) and for variation in response rate (age, gender, ethnicity and deprivation) in final column to be representative of the England population (18+); <sup>2</sup> Infection fatality ratios were calculated excluding care home residents. Confirmed COVID-19 death counts were obtained from <https://fingertips.phe.org.uk/static-reports/mortality-surveillance/excess-mortality-in-england-week-ending-17-Jul-2020.html>. Deaths in care homes by age on 12 June 2020 were obtained from <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/deathsinvolvingcovid19inthecaresectorenglandandwales/deathsoccurringupto12june2020andregisteredupto20june2020provisional>. Total deaths in care home residents up to 17 July 2020 were obtained from <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/numberofdeathsincarehomesnotifiedtothecarequalitycommissionengland>. The age stratified estimates of COVID-19 deaths were then estimated using the total deaths from 17 July and the age distribution from 12 June. We assume the age distribution of deaths did not change between 12 June and 17 July 2020.

**Figure 1: Logistic regression for SARS-CoV-2 antibodies: adjusted Odds Ratios (95% CI) for sociodemographic and clinical covariates**



**Legend** Odds ratios [95% confidence intervals] from univariable logistic regression for the covariate of interest, adjusted odds ratio from multivariable logistic regression for the covariate of interest for age, sex, and region. <sup>1</sup> Jointly adjusted odds ratios were obtained from multivariable logistic regression adjusting for age, sex, ethnicity, region, deprivation, household size and employment status. For data see supplementary table S1.

**Figure 2 COVID-19 epidemic in England, January to June 2020, based on participants with SARS-CoV-2 antibodies by date of confirmed or suspected COVID-19 (A) compared to COVID deaths in England; and showing proportionate distribution of cases over time by (B) ethnicity (C) region (D) employment**



**Legend:** Reported COVID-19 cases by month, based on the date of symptom onset among 3,493 antibody-positive participants who reported symptoms in the REACT2 study. Panel A: Number of symptomatic infections by month (dotted line; right y axis) compared with deaths by month (solid line; left y axis). Data from ONS [ref: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/weeklyprovisionalfiguresondeathsregisteredinenglandandwales>]). Panel B: Weighted proportion of monthly cases by ethnicity. Panel C: Weighted proportion of monthly cases by region. Panel D: Weighted proportion of monthly cases by employment.