Investigating the effects of population density of residence and rural/urban classification on rate of influenza-like illness symptoms in England and Wales

Louis Tunnicliffe | Charlotte Warren-Gash

Abstract

Background: Better understanding of risk factors for influenza could help improve seasonal and pandemic planning. There is a dearth of literature on area-level risk factors such as population density and rural/urban living.

Methods: We used data from Flusurvey, an online community-based cohort that records influenza events. The study outcome was symptoms of influenza-like illness (ILI). Multivariable Poisson regression analysis was used to explore associations of both population density and rural/urban status with rate of ILI symptoms and whether these effects differed by vaccination status.

Results: Of the 6177 study participants, the median age was 45 (IQR 32–57), 65.73% were female, and 66% reported at least one episode of ILI symptoms between 2011 and 2016. We found no evidence to suggest that the rate of ILI symptoms was higher in the medium [RR 1.02 (95% CI 0.95–1.09)] or high [RR 1.02 (95% CI 0.96–1.09)] population density group versus the low population density group. This was the same for the effect of urban living [RR 0.96 (95% CI 0.90–1.03)] versus rural living on symptom rate. There was weak evidence to suggest that the ILI symptom rate was lower in urban areas compared with rural areas among unvaccinated individuals only [RR 0.90 (95% CI 0.83–0.99)], whereas no difference was seen among vaccinated individuals [1.04 (95% CI 0.94–1.16)].

Conclusions: Although neither population density nor rural/urban status was associated with ILI symptom rate in this community cohort, future research that incorporates activity and contact patterns will help to elucidate this relationship further.

KEYWORDS
influenza, online community-based cohort, population density, rural/urban living
1 | INTRODUCTION

Influenza virus results in a major healthcare and economic burden within the United Kingdom. In England alone, it was estimated to be responsible for 26,408 deaths during the 2017–2018 influenza season.\(^1\) Influenza is also frequently responsible workplace absenteeism,\(^8\) showed opposite results. One study found that more densely populated US cities or areas (by ZIP code) had higher influenza-like illness (ILI) cases than less densely populated cities. However, this study only included cases from hospital visits and hence may have only included more severe cases because it required the individual to seek healthcare. A retrospective ecological analysis of the relationship between mortality and population density in the United States undertaken during the 1918 influenza pandemic\(^6\) also showed a positive association between mortality and increasing levels of population density. However, two other ecological studies\(^5,6\) showed opposite results. One study found that mortality was higher in rural areas with lower population density during the 1918 pandemic in England and Wales.\(^5\) Another study conducted on the 1918 found no link between mortality and population density in Japan.\(^6\)

The only previous individual level study was a cross-sectional Taiwanese study conducted during the 2009–2010 H1N1 pandemic.\(^7\) It found that more densely populated areas of Taiwan were associated with extended epidemics.

There is a clear need for individual-level research with objective case determination among not just hospital admissions but across entire communities. Evidence of a relationship could allow influenza control measures to be targeted to specific high-risk areas to help to address health inequalities in respiratory-transmitted infectious disease burden. Knowledge about the spread of influenza in relation to population density could be useful when predicting the progress of epidemics.

The aim of the present study was to investigate the effect of population density of residence and rural/urban categorisation on the incidence of influenza-like illness symptoms.

2 | METHODS

2.1 | Study design and data collection

This study is a prospective online community cohort study that utilised data obtained from Flusurvey. Flusurvey is based in nine different countries and involves participants submitting weekly forms for active surveillance of the presence and absence of ILI symptoms.\(^8\) The present study used data from the UK’s influenza survey database. Flusurvey was advertised on various media platforms,\(^8\) and anyone could sign up to participate. At enrolment, participants’ baseline characteristics (which can be seen in Table 1) were surveyed; they were then given weekly email prompts to complete a symptoms questionnaire.\(^8,9\)

2.2 | Study population and follow-up

The present study restricted its analysis to participants who had completed at least two surveys, resided within England or Wales and provided a valid postcode that could be linked to census data to calculate household density and rural/urban status.

The present study’s follow-up period typically started each year on the 1st of November and lasted to 1st April, that is, participants were followed up over each winter period, which incorporated times of influenza virus circulation. We followed participants over a total of six winter periods from 2011 to 2017.

2.3 | Outcome and exposure definitions

The outcome of interest was whether an individual had symptoms of ILI. An ILI event was determined by whether participants met the European Centre for Disease Prevention and Control (ECDC) ILI definition ‘the sudden onset of symptoms and at least one of following four systemic symptoms: fever or feverishness, malaise, headache, and myalgia, and at least one of the following three respiratory symptoms: cough, sore throat, and shortness of breath’,\(^10\) with the exception that participants were not required to specify whether the symptoms were of sudden onset or not. Participants that experienced ILI symptoms were then asked to record the start and end date of their symptoms. Participants could record multiple episodes of ILI symptoms.

The main exposure in the present study was population density of area of residence. The secondary exposure was type of area of residence, that is, urban or rural. On enrolment participants were asked to provide their postcode with their baseline data. Linkage with 2011 Office for National Statistics (ONS) population density by postcode district census data\(^11\) enabled generation of population density values for Flusurvey participants. Participants were grouped into three categories of increasing population density: low [0–2.7 persons per hectare (pph)], medium (2.7–18.7pph) and high (18.7– maximum pph). Cut-offs for these groups were determined based on tertiles of postcode district population density within England and Wales obtained from the 2011 Census.\(^11\) The ONS also has 2011 census data that mapped postcode district to rural/urban classification; hence, each individual in the present study could be classified as rural/urban based on their postcode.\(^11\)
| Variable | Category (England + Wales percentage distribution) | 2011/2012 | 2012/2013 | 2013/2014 | 2014/2015 | 2015/2016 | 2016/2017 |
|----------|---------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Number of individuals | Overall, n = 6177 | 1403 | 2650 | 2581 | 2794 | 2016 | 2024 |
| Risk factors collected at the individual level | n (% of individuals) | 853 (60.8) | 1672 (63.1) | 1683 (65.2) | 1837 (65.8) | 1310 (65.0) | 1284 (63.4) |
| Sex | Female (50.8) | 550 (39.2) | 978 (36.9) | 898 (34.8) | 957 (34.3) | 706 (35.0) | 740 (36.6) |
| | Male (49.2) | 79 (5.6) | 137 (5.2) | 214 (8.3) | 162 (5.8) | 95 (4.7) | 85 (4.2) |
| Age group (years) | 0–16 (20.2) | 84 (6.0) | 143 (5.4) | 148 (5.7) | 104 (3.7) | 58 (2.9) | 45 (2.2) |
| | 17–25 (10.8) | 540 (38.5) | 949 (35.8) | 866 (33.6) | 889 (31.8) | 585 (29.0) | 538 (26.6) |
| | 26–44 (24.8) | 522 (37.2) | 1040 (39.3) | 973 (37.7) | 1158 (41.5) | 893 (44.3) | 915 (45.2) |
| | 45–64 (25.6) | 173 (12.3) | 374 (14.1) | 378 (14.7) | 471 (16.9) | 381 (18.9) | 431 (21.3) |
| | 65+ (18.5) | 856 (61.0) | 1731 (65.3) | 1620 (62.8) | 1713 (61.3) | 1173 (58.2) | 1077 (53.2) |
| | Vaccinated | 547 (38.9) | 919 (34.7) | 961 (37.2) | 1081 (38.7) | 843 (41.8) | 947 (46.8) |
| | Vaccinated | 1177 (83.9) | 2179 (82.2) | 2140 (82.9) | 2277 (81.5) | 1624 (80.6) | 1612 (79.6) |
| | Vaccinated | 226 (16.1) | 471 (17.8) | 441 (17.1) | 517 (18.5) | 392 (19.4) | 412 (20.4) |
| | Vaccinated | 1270 (90.5) | 2421 (91.4) | 2409 (93.3) | 2409 (93.3) | 1902 (94.0) | 1902 (94.0) |
| | Vaccinated | 132 (9.4) | 229 (8.6) | 172 (6.7) | 191 (6.8) | 144 (7.1) | 122 (6.0) |
| | Vaccinated | 1 (0.1) | 0 (0.0) | 0 (0.0) | 5 (0.2) | 0 (0.0) | 0 (0.0) |
| | Vaccinated | 45 (3.2) | 120 (4.5) | 85 (3.3) | 106 (3.8) | 78 (3.9) | 75 (3.7) |
| | Vaccinated | 13 (0.9) | 44 (1.7) | 28 (1.1) | 34 (1.2) | 21 (1.0) | 34 (1.7) |
| | Vaccinated | 27 (1.9) | 51 (1.9) | 54 (2.1) | 40 (1.4) | 27 (1.3) | 32 (1.6) |
| | Vaccinated | 669 (47.7) | 1216 (45.9) | 1146 (44.4) | 1207 (43.2) | 873 (43.3) | 849 (42.0) |
| | Vaccinated | 145 (10.3) | 307 (11.6) | 314 (12.2) | 356 (12.7) | 243 (12.1) | 255 (12.6) |
| | Vaccinated | 227 (16.2) | 464 (17.5) | 460 (17.8) | 570 (20.4) | 455 (22.6) | 490 (24.2) |
| | Vaccinated | 163 (11.6) | 245 (9.3) | 326 (12.6) | 243 (8.7) | 141 (7.0) | 118 (5.8) |
| | Vaccinated | 93 (6.6) | 169 (6.4) | 139 (5.4) | 208 (7.4) | 157 (7.8) | 156 (7.7) |
| | Vaccinated | 21 (1.5) | 34 (1.3) | 29 (1.1) | 30 (1.1) | 21 (1.0) | 15 (0.7) |
| | Vaccinated | 590 (42.1) | 970 (36.6) | 982 (38.1) | 1031 (36.9) | 750 (37.2) | 765 (37.8) |
| | Vaccinated | 151 (10.8) | 315 (11.9) | 274 (10.6) | 293 (10.5) | 202 (10.0) | 199 (9.8) |
| | Vaccinated | 45 (3.2) | 105 (4.0) | 96 (3.7) | 112 (4.0) | 87 (4.3) | 85 (4.2) |
| | Vaccinated | 597 (42.6) | 1192 (45.0) | 1178 (45.6) | 1281 (45.9) | 922 (45.7) | 941 (46.5) |
| | Vaccinated | 20 (1.4) | 68 (2.6) | 51 (2.0) | 77 (2.8) | 55 (2.7) | 34 (1.7) |
| | Vaccinated | 40 (2.9) | 67 (2.5) | 60 (2.3) | 74 (2.7) | 49 (2.4) | 47 (2.3) |
| | Vaccinated | 97 (6.9) | 159 (6.0) | 207 (8.0) | 145 (5.2) | 81 (4.0) | 64 (3.2) |
| | Vaccinated | 80 (5.7) | 229 (8.6) | 192 (7.4) | 227 (8.1) | 157 (7.8) | 140 (6.9) |
| | Vaccinated | 152 (10.8) | 360 (13.6) | 318 (12.3) | 375 (13.4) | 269 (13.3) | 274 (13.5) |
| | Vaccinated | 343 (24.5) | 646 (24.4) | 652 (25.3) | 734 (26.3) | 552 (27.4) | 555 (27.4) |
| | Vaccinated | 683 (48.7) | 1113 (42.0) | 1126 (43.6) | 1218 (43.6) | 898 (44.5) | 921 (45.5) |
| | Vaccinated | 8 (0.6) | 76 (2.9) | 26 (1.0) | 21 (0.8) | 10 (0.5) | 23 (1.1) |

(Continues)
Other variables and missing data

At the start of each winter period, data were collected on a number of variables including year of study, age, sex, vaccination status, occupation, smoking status, education level, main activity, chronic illness status, frequent contact with children and number of household members. Vaccination status was recorded yearly and was based on whether the individual had been vaccinated that winter. Region was regrouped from 10 categories to increase power.

Some participants had missing data in records for some winter periods, for example, on variables such as age, current smoking status, highest education level and number in household. Omitting all participants with records with missing values would have led to a significant loss of power and potentially introduced selection bias. Hence, values were imputed for the purpose of the analysis. The rules for imputation were as follows:

1. Extrapolate back in time to the last record with non-missing value.
2. Extrapolate forwards in time to the next record with non-missing value (without overruling rule 1).

Descriptive analysis

All analyses were conducted using STATA 16.1 software.

The baseline characteristics (count and percentage distribution of each variable category) of the cohort at the beginning of each winter period were summarised. If the data were available, England and Wales distributions from census data of each variable were displayed to allow comparison of the cohort to the rest of the general population. Data that had been imputed from ‘missing’ were displayed, and the number and proportion of missing values for each variable were also presented.

Multivariable analysis

A multivariable Poisson regression analysis with random effects was conducted using a forward modelling approach to investigate associations between the exposures and self-reported ILI symptoms. Year of study, age, sex and occupation were selected as a priori confounders. Occupation was considered to be a proxy measure of socio-economic
status (SES), an important potential confounder that Flusurvey did not directly measure. The highest education level was not selected for this purpose because the ‘still in education’ category would have encompassed both current university students and children at school, hence meaning potential misclassification in terms of SES. Variables such as transport that were thought to be on the causal pathway (urban areas have more public transport, which is likely to lead people to having more ILI symptoms due to increased contact with people), were ruled out from being potential confounders. Models containing the exposure and outcome with a priori confounders were run. Subsequently, other potential confounders were added one at a time to the models, and if they caused the effect estimate to change by >10%, then they were included in the final model. Whether there was any introduction of collinearity due to the addition of variables into the model was also assessed by comparing the standard errors of the log rate ratios of the crude versus adjusted models.

2.7 | Effect modification

We first stratified by vaccination status and then ran Poisson regression analysis allowing for interaction between vaccination status and the exposure variables that was also conducted to explore this possibility of effect modification; this interaction was assessed using likelihood ratio tests.

2.8 | Sensitivity analysis

The imputation of missing values as described in Section 2.4 has the potential to introduce bias. Hence, a sensitivity analysis was conducted excluding participants with any missing data. Results between the two analyses were compared for consistency.

2.9 | Ethical considerations

Ethical approval for Flusurvey was granted by the London School of Hygiene & Tropical Medicine (LSHTM) Research Ethics Committee (REC), application number 5530. The LSHTM REC approved secondary use of data from Flusurvey for this analysis (Ethics Reference: 22462).

3 | RESULTS

Results from the descriptive analysis of the cohort can be seen in Table 1. A total of 6177 [65.73% female and median age of 45 with an interquartile range (IQR) of 32–57] individuals participated in the study across six winters, ranging from 1403 in the 2011–2012 winter to 2794 in the 2014–2015 winter. Figure 1 shows the geospatial distribution of participants. The majority of individuals were from southern England with London being the region containing the highest numbers of participants as well as being the area where participants had the highest mean population density of residence.

The results from forward modelling of the relationship between population density group and rural or urban status can be seen in Table 2. The final model consisted only of a priori (year of study, age, sex and occupation) confounders because no addition of other variables led to >10% change in the effect estimate.

![Figure 1](image-url)  
(A) The geospatial distribution of present study participants. (B) Mean population density of residence of study participants by region. Lon, London; pph, persons per hectare; NE/NW, North East/West; SW/SE, South West/East; WM/EM, West/East Midlands; Y&H, Yorkshire and Humber
In the multivariable model for population density, the third group (most densely populated) had a rate 1.02 (95% CI 0.96–1.09) that of the baseline group (least densely populated). For the middle group the rate was 1.02 (0.95–1.10) times that of the baseline group. The likelihood ratio test for association between population density and rate of ILI symptoms gave a P-value of 0.80 indicating a lack of evidence for association between population density of residence and self-reporting ILI.

We found no evidence of association between rural/urban status and ILI symptoms (adjusted RR 0.96, 95% C.I. 0.90–1.03, P = 0.27).

The results of Poisson regression analysis allowing for interaction between vaccination status and each of the exposure variables can be seen in Table 3.

There was no evidence for an interaction between influenza vaccination and population density on the rate of ILI symptoms (P = 0.44).

There was weak evidence (P = 0.04) to indicate that the ILI symptom rate was lower in urban areas compared with rural areas among unvaccinated individuals [RR 0.90 (95% CI 0.83–0.99)], whereas no difference was seen among vaccinated individuals [1.04 (95% CI 0.94–1.16)].

The sensitivity analysis provided no evidence (P = 0.92) to suggest that the rate of ILI symptoms was higher in the medium [RR 0.99 (95% CI 0.91–1.07)] or high [RR 1.00 (95% CI 0.92–1.07)] population density group than in the low population density group after adjusting for year of study, age, sex and occupation among individuals with no missing data. Moreover, no evidence (P = 0.16) was found to suggest that the rate of ILI symptoms in rural areas [RR 0.95 (95% CI 0.88–1.02)] was different to that of urban areas after the same adjustment.

### TABLE 2

Results of multivariable Poisson regression analysis investigating the effect of population density and rural or urban living on rate of ILI symptoms

| Poisson regression model | Population density group | Correlated crude incidence rate per thousand PY (95% CI) | Crude RR (95% CI) | LRT P-value | Adjusted RR* | LRT P-value |
|--------------------------|--------------------------|--------------------------------------------------------|-------------------|-------------|-------------|-------------|
| Population density group | 1 Least dense            | 1045.47 (987.80–1106.51)                                | 1                 | <0.0001     | 1           | 0.8045      |
|                          | 2                        | 1065.34 (1015.08–1118.08)                              | 1.02 (0.95–1.10)  | 1.02 (0.95–1.09) |
|                          | 3 Most dense             | 1199.50 (1152.53–1248.38)                              | 1.15 (1.07–1.23)  | 1.02 (0.96–1.09) |
| Rural/urban group        | Rural                    | 1085.73 (1014.94–1161.48)                              | 1                 | 0.2910      | 1           | 0.2684      |
|                          | Urban                    | 1128.99 (1094.97–1164.07)                              | 1.04 (0.97–1.12)  | 0.96 (0.90–1.03) |

Notes: The LRT test for assessing whether \( \theta = 0 \) in the full models gave a P-value of <0.0001 in all instances. This provides strong evidence for within person clustering of ILI symptom episodes.

Abbreviations: LRT, likelihood ratio test; PY, person-years; RR, rate ratio.

*Adjusted for year of study, age, sex and occupation.

### TABLE 3

ILI symptom rate ratios of population density and rural/urban groups from multivariable Poisson regression analysis of cohort stratified by vaccination group

| Variables in Poisson regression model | Vaccination status | Population density group | Rate ratio (95% CI) | LRT for interaction P-value |
|--------------------------------------|--------------------|--------------------------|---------------------|-----------------------------|
| Population density group + year of study, age, sex and occupation | Vaccinated | 1 (least dense) | 1 | 0.4407 |
|                                      |                    | 2                        | 1.05 (0.95–1.16)    |                             |
|                                      |                    | 3 (most dense)           | 1.07 (0.97–1.18)    |                             |
|                                      | Unvaccinated       | 1 (least dense)          | 1                    |                             |
|                                      |                    | 2                        | 0.99 (0.91–1.09)    |                             |
|                                      |                    | 3 (most dense)           | 0.99 (0.91–1.07)    |                             |
| Rural or urban + year of study, age, sex and occupation | Vaccinated | Rural | 1 | 0.0350 |
|                                      |                    | Urban                    | 1.04 (0.94–1.16)    |                             |
|                                      | Unvaccinated       | Rural                    | 1                    |                             |
|                                      |                    | Urban                    | 0.90 (0.83–0.99)    |                             |

Abbreviation: LRT, likelihood ratio test.

4 | DISCUSSION

Among 6177 individuals from the UK Flusurvey cohort, we found no evidence for an association between either population density or rural/urban status and rate of ILI symptoms over six winters (2011–2016). No evidence for interaction between population density and vaccination status on ILI symptom rate was found. However, there was weak evidence to suggest that the ILI symptom rate was lower in urban areas compared with rural areas among unvaccinated individuals, whereas no difference was seen among vaccinated individuals.
The results of this study do not support findings from some other observational studies that found more densely populated areas to be associated with higher influenza or ILI incidence.\(^3\)\(^4\)

This inconsistency may be because the previous studies were mainly ecological studies that cannot reliably be extrapolated to the individual level. Hence, the only comparable study was a Taiwanese cross-sectional study, which found evidence to suggest that increased population density was associated with extended epidemics of H1N1.\(^7\) However, that study was limited by its cross-sectional design and its hospital-based nature, which meant that it only captured more severe influenza cases.

The difference in results may also reflect differences in outcome definitions. In many of the previous studies, the outcome was influenza related mortality or hospitalisation.\(^3\)\(^-\)\(^5\) This is not comparable with our symptom-based ILI definition: Whereas influenza mortality/hospitalisation only captures the most severe influenza events, using ILI symptoms can capture milder episodes that represent the majority of cases.\(^13\)

In addition, many of the previous studies utilised historic data, mostly from the 1918 influenza pandemic.\(^4\)\(^5\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)\(^\)...
design, data interpretation, supervision. Both authors read and approved the final manuscript.

PEER REVIEW
The peer review history for this article is available at https://publons.com/publon/10.1111/irv.13032.

DATA AVAILABILITY STATEMENT
Flusurvey data collected from the Influenzanet platforms, aggregated and anonymised, are available at influenza.net. Interested researchers wishing to conduct scientific research can access data upon request and upon discussion with other members of the Influenzanet Scientific Committee (influenzanet.info). England and Wales census data are available online on the Office for National Statistics website (https://www.ons.gov.uk/). Postcode population density statistics are available online (https://www.nomisweb.co.uk/census/2011/ks101ew).

ORCID
Louis Tunnicliffe https://orcid.org/0000-0001-8537-2855
Charlotte Warren-Gash https://orcid.org/0000-0003-4524-3180

REFERENCES
1. Public Health England. Surveillance of influenza and other respiratory viruses in the UK Winter 2018 to 2019. Public Health England; 2019:1-57.
2. Aligne CA. Overcrowding and mortality during the influenza pandemic of 1918: Evidence from US Army camp AA Humphreys, Virginia. Am J Public Health. 2016;106(4):642-644. doi:10.2105/AJPH.2015.303018
3. Dalziel BD, Kissler S, Gog JR, et al. Urbanization and humidity shape the intensity of influenza epidemics in US cities. Science. 2018;362(6410):75-79. doi:10.1126/science.aat6030
4. Garrett TA. Pandemic economics: the 1918 influenza and its modern-day implications. Federal Reserve Bank St Louis Rev. 2008;90. doi:10.20955/r.90.74-94
5. Chowell G, Bettencourt LM, Johnson N, Alonso WJ, Viboud C. The 1918–1919 influenza pandemic in England and Wales: spatial patterns in transmissibility and mortality impact. Proc R Soc B. 2008;275(1634):501-509. doi:10.1098/rspb.2007.1477
6. Nishiura H, Chowell G. Rurality and pandemic influenza: geographic heterogeneity in the risks of infection and death in Kanagawa, Japan (1918–1919).
7. Kao CL, Chan TC, Tsai CH, et al. Emerged HA and NA mutants of the pandemic influenza H1N1 viruses with increasing epidemiological significance in Taipei and Kaohsiung, Taiwan. 2009–10. PLoS ONE. 2012;7(2):e31162. doi:10.1371/journal.pone.0031162
8. Brooks-Pollock E, Tilston N, Edmunds WJ, Eames KT. Using an online survey of healthcare-seeking behaviour to estimate the magnitude and severity of the 2009 H1N1v influenza epidemic in England. BMC Infect Dis. 2011;11(1):1-8. doi:10.1186/1471-2334-11-68
9. Eames KT, Brooks-Pollock E, Paolotti D, Peraosa M, Gioannini C, Edmunds WJ. Rapid assessment of influenza vaccine effectiveness: analysis of an internet-based cohort. Epidemiol Infect. 2012;140(7):1309-1315.
10. Dominguez Á, Soldevila N, Torner N, et al. Usefulness of clinical definitions of influenza for public health surveillance purposes. Viruses. 2020;12(1):95. doi:10.3390/v12010095
11. Office for National Statistics. National Records of Scotland. Northern Ireland Statistics and Research Agency. 2011 Census aggregate data. UK Data Service; 2016.
12. Office for National Statistics. 2001 Census aggregate data. UK Data Service; 2011.
13. Leung NH, Xu C, Ip DK, Cowling BJ. The fraction of influenza virus infections that are asymptomatic: a systematic review and meta-analysis. Epidemiology. 2015;26(6):862.
14. Feth D, Jones A, Hill T, et al. Inequalities in rural communities: adapting national deprivation indices for rural settings. J Public Health. 2018;40(2):419-425. doi:10.1093/pubmed/fdy048
15. Moghadami M. A narrative review of influenza: a seasonal and pandemic disease. Iran J Med Sci. 2017;42(1):2-13.
16. Casalegno JS, Eibach D, Valette M, et al. Performance of influenza case definitions for influenza community surveillance: based on the French influenza surveillance network GROG, 2009-2014. Euro Surveill. 2017;22(14):30504. doi:10.2807/1560-7917.ES.2017.22.14.30504
17. Jutel A, Baker MG, Stanley J, Huang QS, Bandaranayake D. Self-diagnosis of influenza during a pandemic: a cross-sectional survey. BMJ Open. 2011;1(2):e000234. doi:10.1136/bmjopen-2011-000234
18. Vahidy FS, Nicolas JC, Meeks JR, et al. Racial and ethnic disparities in SARS-CoV-2 pandemic: analysis of a COVID-19 observational registry for a diverse US metropolitan population. BMJ Open. 2020;10(8):e039849. doi:10.1136/bmjopen-2020-039849
19. Ministry of Housing, Communities and Local Government. The English indices of deprivation 2019. London: Ministry of Housing, Communities and Local Government; 2019:1-87.
20. Batty GD, Gale CR, Kivimäki M, Deary IJ, Bell S. Comparison of risk factor associations in UK Biobank against representative, general population based studies with conventional response rates: prospective cohort study and individual participant meta-analysis. BMJ. 2020;368.