Time courses of COVID-19 infection and local variation in socioeconomic and health disparities in England

Shelley H. Liu, PhD[1], Bian Liu, PhD[1,2], Yan Li, PhD[1,3], Agnes Norbury, PhD[4]*

[1]Department of Population Health Science and Policy, Icahn school of Medicine at Mount Sinai, New York, New York, USA
[2]Department of Environmental Medicine and Public Health, Icahn School of Medicine at Mount Sinai, New York, New York, USA
[3]Department of Obstetrics, Gynecology, and Reproductive Science, Icahn School of Medicine at Mount Sinai, New York, NY, USA
[4]Department of Psychiatry, Icahn School of Medicine at Mount Sinai, New York, New York, USA

*Corresponding author contact information:
Shelley H. Liu, PhD
Email: shelley.liu@mountsinai.org
Address: One Gustave L. Levy Place, Box 1077, New York, NY 10029
Phone: (630) 873-9069

Word count: 2,616

1   *What is already known on this subject?*

2   Emerging evidence suggests that the burden of COVID-19 infection is falling unequally across

3   England, with provisional data suggesting higher overall infection and mortality rates for Black,

4   Asian, and mixed race/ethnicity individuals.

5   *What does this study add?*

6   We found that regions with greater socioeconomic deprivation and poorer population health

7   measures showed a faster rise in COVID-19 cases, and reached higher peak case levels. Areas

8   with a higher proportion of Black residents were more likely to show this kind of time course,

9   even after adjusting for multiple co-occurring factors, including population density. This finding

10   merits further investigation in terms of the intersecting vulnerability factors Black and other

11   minority ethnic individuals face in England (e.g. proportion of people working in service and

12   caring roles, and the role of structural discrimination), and has implications for the ongoing

13   allocation of public health resources, in order to better mitigate such inequalities.

14   **Abstract**

15

16   **Objective:** To identify factors associated with local variation in the time course of COVID-19

17   case burden in England.

18

19   **Methods:** We analyzed laboratory-confirmed COVID-19 case data for 150 upper tier local

20   authorities, from the period from January 30 to May 6, 2020, as reported by Public Health

21   England. Using methods suitable for time-series data, we identified clusters of local authorities

22   with distinct trajectories of daily cases, after adjusting for population size. We then tested for

23   differences in sociodemographic, economic, and health disparity factors between these clusters.

24

25   **Results:** Two clusters of local authorities were identified: a higher case trajectory that rose faster

26   over time to reach higher peak infection levels, and a lower case trajectory cluster that emerged

27   more slowly, and had a lower peak. The higher case trajectory cluster (79 local authorities) had

28   higher population density (p<0.001), higher proportion of Black and Asian residents (p=0.03;

29   p=0.02), higher multiple deprivation scores (p<0.001), a lower proportions of older adults

30   (p=0.005), and higher preventable mortality rates (p=0.03). Local authorities with higher

31   proportions of Black residents were more likely to belong to the high case trajectory cluster, even

32   after adjusting for population density, deprivation, proportion of older adults and preventable

33   mortality (p=0.04).

34

35   **Conclusion:** Areas belonging to the trajectory with significantly higher COVID-19 case burden

36   were more deprived, and had higher proportions of ethnic minority residents. A higher

37   proportion of Black residents in regions belonging to the high trajectory cluster was not fully

38   explained by differences in population density, deprivation, and other overall health disparities

39   between the clusters.

Introduction

England currently has amongst the highest worldwide recorded cases of the novel coronavirus (COVID-19), with 243,303 cases as of May 17, 2020 [1]. However, increasing evidence suggests this burden disproportionately affects certain groups. Provisional data from the Office for National Statistics has indicated significantly increased COVID-19 mortality estimates for Black, Asian, and mixed race/ethnicity individuals, even after indirect adjustment for age, broad geographical region, and measures of self-reported health and disability [2,3]. There are also disparities in COVID-19 mortality across geographic regions. Based on COVID-19 deaths occurring in March and early April, the age-standardized mortality rate was twice as high in the most deprived areas of England, compared with the least deprived [4]. Importantly, a recent study assessing hypothetical vulnerability to respiratory pathogen pandemics – calculated in terms of likely demand characteristics versus supply-side differences in existing healthcare provision – found greater vulnerability in regions of England with higher economic deprivation levels [5].

Here, we sought to identify whether local-level variation in *trajectories* (changes over time) in confirmed COVID-19 cases were related to variation in socioeconomic deprivation and self-reported racial/ethnic identity. We also assessed whether time courses of caseloads differed according to important population health measures – including healthy life expectancy, preventable mortality, and proportion of individuals with chronic health conditions that may increase susceptibility to COVID-19 morbidity and mortality. The ability of different areas to control COVID-19 infection rates over time may provide a more sensitive readout of vulnerability than cumulative case or mortality data, as this time course will depend on a combination of sociodemographic variables and local capacity to enact public health measures that help limit disease spread [5]. Critically, we examined whether differences in demographic measures between trajectories remained significant after adjusting for covariance with other factors that may affect COVID-19 caseload (population density, proportion of older adults, relative deprivation, and preventable mortality rates) [6–8].

71 **Methods**

72

73 Data on daily laboratory-confirmed COVID-19 cases for the period spanning January 30 to May

74 6, 2020 were accessed via Public Health England [9]. These case counts are reported based on

75 the date the specimen was taken from the patient, not the date the lab carried out testing and

76 reported results to Public Health England. Case data were extracted for upper tier local

77 authorities (henceforth referred to as local authorities), a level of analysis which was chosen in

78 order to balance geographical resolution against availability of up-to-date clinical and

79 sociodemographic data. Case counts were adjusted for local authority population size, using

80 population estimates provided by the Office for National Statistics (ONS), as of April 2019 [10].

81

82 We identified clusters, or homogenous groups, of local authorities with distinct COVID-19 case

83 trajectories. Clusters were identified using a partition around mediods approach [11], a clustering

84 analysis for time-series data. A dynamic time warping similarity metric was used to capture

85 nonlinear similarity between two time-series based on their shape. This metric was chosen

86 because it is has been shown in the literature to be optimal for clustering of time series data.

87 Unlike the Euclidean distance which is commonly used for cluster analysis of non-time series

88 data, the dynamic time warping distance is not sensitive to time shifts, which is helpful as some

89 local authorities may have had earlier cases than others. The clustering algorithm partitions local

90 authorities in order to maximize intra-cluster similarities in case trajectories, and maximize inter-

91 cluster differences in case trajectories. In order to identify the optimal number of clusters, 2-, 3-,

92 4-, and 5-cluster models were compared using five established cluster validity indices

93 (Silhouette, Score function, Davies-Bouldin, modified Davies-Bouldin, and COP) [12].

94

95 Sociodemographic, economic deprivation and public health data for each local authority were

96 compiled from Public Health England Fingertips repository using FingertipsR [13]. Specifically,

97 we extracted the most recent data on ethnicity (proportions of Black or Black British ethnic

98 group, Asian or Asian British ethnic group, Mixed/multiple ethnic group and White residents);

99 older adults (proportion of adults aged 65 or older), index of multiple deprivation (IMD, a

100 composite measure of deprivation calculated across multiple domains, including income,

101 employment, education, health, crime, barriers to housing and services, and living environment:

102   [14]); employment deprivation (proportion of working-age population involuntarily excluded

103   from the labor market, calculated from claimants of various out-of-work social security

104   allowances: [14]), healthy life expectancy (average number of years a person would expect to

105   live in good health based on contemporary mortality rates and prevalence of self-reported good

106   health); preventable mortality (age-standardized mortality rate from causes considered

107   preventable, per 100,000 people); pre-existing chronic health conditions (proportion of registered

108   patients with a general practitioner (GP)-recorded diagnosis of coronary heart disease, diabetes,

109   hypertension or obesity); self-reported physical activity (proportion of adults completing at least

110   150 minutes of moderate-intensity physical activity per week); and nursing home admissions

111   (permanent admissions to residential and nursing care homes, per 100,000 people aged 65+).

112   Population density was calculated as number of people per land area square kilometer, according

113   to standard area measurements of local authorities available from the Office of National

114   Statistics Open Geography portal [15].

115

116   Differences in sociodemographic, deprivation and public health measures between the clusters

117   were tested using the nonparametric Kruskal Wallis test. We presented the median and

118   interquartile range (IQR) of the measures in each cluster. In addition, separate logistic regression

119   models were used to determine whether proportions of minority ethnicity groups and deprivation

120   predicted cluster membership, after adjusting for potential confounding variables. Odds ratios

121   (OR) and 95% confidence intervals (CI) for adjusted models are presented. All statistical

122   analyses were carried out using R, version 3.6.1 (R Core Team, 2019).

123

124   **Results**

125

126   Two clusters of local authorities were identified, based on daily population-adjusted COVID-19

127   laboratory confirmed case counts (Figure 1a). All five cluster validity indices supported the

128   identification of two clusters. A cluster of 79 local authorities had significantly higher

129   population-adjusted daily case trajectories. Members of this cluster tended to be located close to

130   or contain major urban centers (including Manchester, Newcastle upon Tyne, Liverpool,

131   Birmingham, Sheffield and London), however members of this cluster also included less densely

132   populated areas (such as Cumbria, Northumberland, and Herefordshire; Figure 1b). A second

6

133   cluster of 71 local authorities followed a lower daily case trajectory. These areas tended to be

134   less densely populated, including the south-west region, but also included several London

135   boroughs (Hillingdon, Richmond, Westminster, Camden, Islington, City of London, Tower

136   Hamlets and Greenwich; Figure 1b, inset).

137

138   Both clusters followed a similar temporal pattern, with case counts increasing until early April

139   and then declining. However, as of May 6, 2020, the median cumulative number of cases per 1

140   million population in the high trajectory cluster was 2947.64 [IQR: 2543.85, 3350.20], as

141   compared with 1717.96 [IQR: 1376.34, 1999.41] cases per 1 million population in the low

142   trajectory cluster ($p<0.001$). Figure 1a shows that this was due to a faster rate of rise, and higher

143   overall peak level in the higher case, compared to the lower case trajectory cluster.

144

145   Table 1 presents the socio-demographic and health factors in the two clusters. Local authorities

146   in the high trajectory cluster had significantly higher proportions of Black and Black British

147   ethnic group residents ($p=0.026$). Local authorities in the high trajectory cluster had a median of

148   2.36% [IQR: 0.49%, 8.55%] Black residents, compared with a median of 0.89% [IQR: 0.57%,

149   2.14%] Black residents in the low trajectory cluster group. There was also higher proportions of

150   Asian and Asian British ethnic group residents in the high trajectory cluster, with a median of

151   7.41% [IQR: 2.33%, 15.57%] as compared with a median of 3.71% [IQR: 1.80%, 8.28%] in the

152   low trajectory cluster group. Local authorities in the high trajectory cluster group had

153   significantly lower proportions of white residents ($p=0.011$), while they did not differ on the

154   proportions of Mixed/multiple ethnic group residents ($p=0.101$).

155

156   Local authorities in the high trajectory cluster also had significantly lower proportions of

157   older adult males and females aged 65+ ($p=0.005$; $p=0.004$). However, there were higher rates of

158   admission into nursing homes among older adults aged 65+ in the high trajectory cluster

159   ($p=0.088$).

160

161   There was significantly greater deprivation, quantified through both the multiple index of

162   deprivation and employment deprivation, in the high case trajectory cluster ($p<0.001$; $p<0.001$).

163   The high case trajectory cluster also had significantly greater population density ($p<0.001$). This

164   was a median of 2526 [IQR: 1269, 4735] persons per land area square kilometer in the high case

165   trajectory cluster, compared with 589 [IQR: 322, 2546] persons per land area square kilometer in

166   the low case trajectory cluster.

167

168   The cluster of local authorities with a high daily case trajectory had significantly poorer health

169   measures. It had higher preventable mortality per 100,000 persons for males and females

170   (p=0.003; p=0.027), and had lower healthy life expectancy for males (p=0.009). Further,

171   significantly lower proportion of adults were physically active (p=0.001), and there was higher

172   prevalence of diabetes (p=0.001).

173

174   Table 2 presents results from logistic regression models. Because population density varies

175   significantly between clusters, and high population density could facilitate the spread of an

176   infectious disease, we adjusted for it in logistic regression models. In adjusted models, local

177   authorities with higher proportions of Black residents were significantly more likely to belong to

178   the high case trajectory cluster (OR 1.14 [95% CI: 1.02 – 1.29], p=0.026), and local authorities

179   with higher proportions of White residents were significantly less likely to have high case

180   trajectory membership (OR 0.97 [95% CI: 0.93, 0.99], p=0.041).

181

182   Next, to identify whether higher proportion of minority ethnic groups is associated with higher

183   probability of belonging to the high case trajectory, we also adjusted for additional covariates.

184   Local authorities with higher proportions of Black residents were more likely to belong to the

185   high case trajectory cluster (p=0.035), even after adjusting for population density, deprivation,

186   proportion of older adults and preventable mortality. The adjusted odds ratio corresponding to a

187   1% increase in Black residents was 1.20 (95% CI: 1.03 – 1.45).

188

189   Higher index of multiple deprivation scores were also significantly associated with high case

190   trajectory after adjusting for differences in population density, proportion older adults, and

191   proportion of Black, Asian and Mixed/Multiple ethnic groups (OR = 1.08 [95% CI: 1.03 – 1.14],

192   p=0.002). Further, in adjusted models, higher employment deprivation was significantly

193   associated with high case trajectory (OR = 1.21 [95% CI: 1.09 – 1.35], p<0.001).

194

8

Discussion

Our findings suggest that the burden of COVID-19 falls disproportionately on areas in England with higher deprivation, a higher proportion of Black and Asian residents, a higher prevalence of chronic diseases, more physical inactivity, and lower healthy life expectancy, and higher mortality from preventable causes.

Importantly, local differences in race/ethnicity and deprivation scores significantly predicted membership of the higher case trajectory cluster after adjusting for differences in population density – suggesting these effects are not simply the result of higher proportions of ethnic minority residents and higher deprivation levels in dense urban areas where COVID-19 is likely to be more prevalent [16].

The geographic disparities in case trajectories were in general consistent with the trend in COVID-19 mortality data, where the death toll in the most deprived areas of England and Wales were approximately twice that in the least deprived areas [17]. Often, populations living in deprivation also are co-living with a higher burden of chronic health conditions that elevate risk for COVID-19 morbidity and mortality, producing a compounded effect [18–20]. Similar health inequalities in COVID-19 outcomes have been reported elsewhere with regard to socioeconomic and demographic profiles. [21–24]. Our results are also aligned with estimates based on individual-level data from the UK Biobank, which showed a 2 to 4-fold higher risk of COVID-19 infection among Black, Asian, and minority ethnic (BAME) communities than their white counterparts, after adjusting for socioeconomic status, lifestyle, obesity, and comorbidities [25].

However, it is important to note that it is difficult to separate racial, socioeconomic, and health contributions when reporting COVID-19 disparities – and, crucially, that insufficient contextualization of findings may lead to misunderstandings that undermine the goal of eliminating health inequalities [26]. For example, recent analysis from the Office for National Statistics suggests that occupation may pay an important role in COVID-19 exposure and mortality – with workers in social care, public transport, and sales/retail all found to have increased death rates [27]. The increased exposure to other individuals and reduced ability to

226   maintain physical distancing associated with these roles is likely to interact with findings

227   stratified by ethnicity groups, as there are significantly greater proportions of BAME individuals

228   employed in caring and customer service professions [28]. Further, there are demonstrable long-

229   term health implications of structural inequality and discrimination with respect to race and

230   ethnicity. Research has demonstrated that the cumulative effects of physiological responses to

231   external stressors, especially racial discrimination, are linked to increased risk of chronic health

232   conditions such as cardiovascular disease and diabetes (the 'weathering' hypothesis, [29,30]) –

233   further exacerbating risk from COVID-19 [31,32]. Finally, migrant groups in the UK may have

234   limited healthcare entitlements, and face additional barriers to healthcare access, including fear

235   of the imposition of high charges and/or sharing of their data with immigration enforcement

236   agencies [3,33].

237

238   Interestingly, areas with a high daily case trajectory had a significantly lower proportion of older

239   adults (aged 65 or above), which preliminarily suggests that it may not be older population that is

240   driving the higher burden of COVID-19 infection in these regions. However, as the healthy life

241   expectancy of males is significantly lower in the high trajectory areas, and the admissions into

242   nursing homes is higher in the high trajectory areas, it is possible that older adults in these areas

243   may have poorer health; however, this warrants further study.

244

245   The burden of COVID-19 deaths has fallen disproportionately in major urban centers –

246   particularly London, Liverpool, Birmingham and Manchester [4,17]. As expected, local

247   authorities in these cities tended to belong to the high case trajectory cluster. However, we note

248   that within London, some wealthier local authorities (e.g. Westminster, City of London)

249   belonged to the lower case trajectory cluster. People with means may be more able to enact

250   physical distancing, and have the ability to leave London, as 250,000 people were estimated to

251   have left London in mid-March prior to the lockdown based on smartphone data [34].

252

253   This study had some limitations. There may be some local differences in availability and

254   provision of COVID-19 testing, although this is not expected to be a significant limitation, as

255   there is standardized government guidance for members of the public who suspect they have

256   COVID-19, to contact NHS 111 or visit nhs.net, rather than contacting their GP. Further, there

257   may be outflow and inflow of residents to areas which were not their primary residence prior to

258   and during the lockdown period, which could slightly alter the data profile of local authorities.

259   Our ecological study design serves as an important complement to analyses of individual-level

260   patient data, to help understand how structural inequities at the population level affect COVID-

261   19 burden. Here, we also adjusted for multiple potential confounders in our models to better

262   identify associations between proportions of ethnicity groups in a local authority, or deprivation

263   of the local authority, and COVID-19 case burden.

264

265   Our findings imply that structural inequities related to race/ethnicity, socioeconomic deprivation,

266   local health disparities and environmental factors may be "root causes" of disparities in COVID-

267   19 infection in England. The interaction between these factors is likely to multifaceted and

268   complex [26], and may evolve over time. The identified clusters of COVID-19 caseload

269   trajectory and their varied associations with contextual factors may also have important

270   implications for future resource allocation strategies and public health planning, at the national

271   level. Recent calls to the research community have highlighted the importance of reporting

272   socioeconomic as well as racial/ethnic disparity data in order to properly understand COVID-19

273   health inequalities [26,35]. We conclude that public health practitioners and policymakers should

274   recognize both the collective contribution of social determinants of health and their

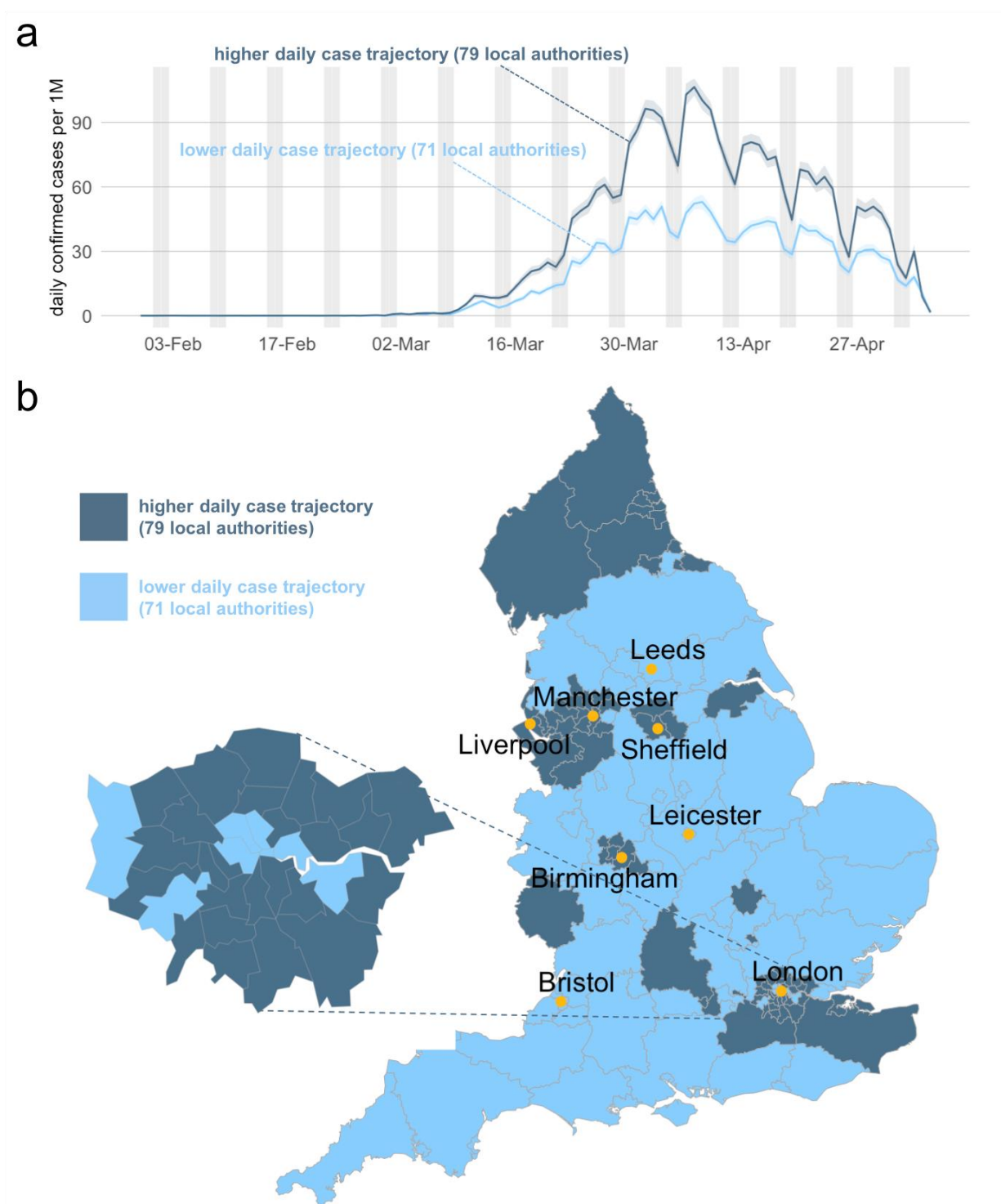275   intersectionality, to better mitigate the burden of COVID-19 and reduce health disparities.

Figure 1. Cluster analysis of daily COVID-19 case data by local authority region
a Analysis of daily case data identified two trajectory clusters: a higher daily case trajectory
(formed of 79 local authorities), and a lower case trajectory cluster (formed of 71 local

12

279   authorities. Data plotted here represent the mean (standard error) of laboratory-confirmed
280   COVID-19 cases each day, per 1 million (1M) population (data from Public Health England).
281   Grey shading represents weekends (Saturdays and Sundays), when number of reported cases
282   tends to be lower. **b** Cluster assignment, plotted for each region (unitary or upper tier local
283   authorities). Boundary data are correct as of December 2019 (source: Office for National
284   Statistics Open Geography portal). Inset shows a magnification of the Greater London area. The
285   eight largest cities by population size are labeled.

286

	High trajectory cluster (n=79)	Low trajectory cluster (n=71)	
	Median (interquartile range)	Median (interquartile range)	p-value
Racial/ethnic composition and older adults			
[1]Black (%)	2.36 [0.49, 8.55]	0.89 [0.57, 2.14]	0.026
[2]Asian (%)	7.41 [2.33, 15.57]	3.71 [1.80, 8.28]	0.016
Mixed/Multiple ethnic group (%)	2.08 [1.07, 4.17]	1.57 [1.17, 2.48]	0.101
White (%)	85.49 [65.75, 95.97]	92.66 [85.92, 95.74]	0.011
65+ Male (%)	15.16 [11.84, 18.20]	17.18 [13.55, 20.11]	0.005
65+ Female (%)	17.98 [14.23, 20.95]	20.06 [16.00, 22.88]	0.004
Deprivation and population density			
[3]IMD score	25.66 [19.24, 31.10]	19.00 [14.76, 26.35]	<0.001
[3]IMD decile	4.00 [2.00, 7.00]	7.00 [4.00, 9.00]	<0.001
[4]Employment deprivation	0.13 [0.11, 0.17]	0.11 [0.08, 0.14]	<0.001
[5]Population density (persons per km^2)	2526 [1269, 4735]	589 [322, 2546]	<0.001
Health factors			
[6]Healthy life expectancy (M)	61.42 [59.22, 64.68]	63.15 [61.40, 65.66]	0.009
[6]Healthy life expectancy (F)	62.40 [59.17, 64.82]	63.99 [60.99, 65.90]	0.058
[7]Preventable mortality per 100,000 (M)	251.20 [218.40, 288.75]	220.40 [195.30, 258.30]	0.003
[7]Preventable mortality per 100,000 (F)	147.60 [124.20, 170.10]	133.80 [117.40, 154.50]	0.027
[8]Diabetes (%)	7.30 [6.53, 8.13]	6.82 [6.12, 7.35]	0.001
[8]Overweight/Obese (%)	64.04 [59.05, 67.15]	62.66 [60.33, 65.44]	0.196
[8]Coronary Heart Disease (%)	3.12 [2.34, 3.85]	3.12 [2.51, 3.69]	0.934
[8]Hypertension (%)	13.80 [12.10, 15.70]	14.27 [12.66, 15.97]	0.363
Physically active (%)	65.60 [61.61, 68.74]	68.12 [65.50, 70.97]	0.001
[9]Nursing home admissions per 100,000	600.80 [452.20, 735.95]	558.20 [460.60, 627.60]	0.088
[10]Cumulative COVID-19 infections per 1M	2947.64 [2543.85, 3350.20]	1717.96 [1376.34, 1999.41]	<0.001

287 **Table 1. Socio-demographic, health factors and burden of COVID-19.**
288 [1]Black denotes Black or Black British ethnic group; [2]Asian denotes Asian or Asian British ethnic
289 group; [3]IMD, Index of Multiple Deprivation, a composite deprivation score encompassing
290 income, employment, education, health, crime, barriers to housing and services, and living
291 environment; [4]Employment deprivation scale (proportion of the working-age population in an
292 area involuntarily excluded from the labour market, due to factors such as unemployment,

293   sickness, disability or carer responsibilities) represents the most recently available data, from
294   2015. [5]Population density is defined as number of persons per land area square kilometer.
295   [6]Healthy life expectancy (average number of years a person would expect to live in good health
296   based on contemporary mortality rates and prevalence of self-reported good health: M, for males;
297   F, for females); [7]Preventable mortality represents the age-standardized mortality rate from causes
298   considered preventable per 100,000 population for 2016-2018 (M, for males; F, for females).
299   [8]Chronic conditions: percentage of registered patients with a general practitioner (GP)-recorded
300   diagnosis of coronary heart disease, diabetes, hypertension or obesity; [9]permanent admissions to
301   residential and nursing care homes, per 100,000 people aged 65+. [10]Cumulative COVID-19
302   infections per 1 million (1M) population are those reported as of May 6, 2020. *$p < 0.05$, **$p <$
303   0.01; Kruskal Wallis tests. Data provided by Public Health England.

304

	Odds ratio of belonging to high case trajectory	95% CI	p-value
Models adjusted for population density			
[1]Black (%)	1.14	1.02 – 1.29	0.026
[2]Asian (%)	1.03	0.99 – 1.08	0.134
Mixed/Multiple ethnic group (%)	1.08	0.76 – 1.53	0.674
White (%)	0.97	0.93 – 0.99	0.041
Older adults (%)	0.92	0.81 – 1.03	0.140
[3]IMD score	1.08	1.03 – 1.14	0.001
[4]Employment deprivation	1.19	1.09 – 1.31	<0.001
Models adjusted for population density, % older adults, % Black, % Asian, % Mixed/Multiple ethnic group			
[3]IMD score	1.08	1.03 – 1.14	0.002
[4]Employment deprivation	1.21	1.09 – 1.35	<0.001
Models adjusted for population density, deprivation, % older adults and preventable mortality			
[1]Black (%)	1.20	1.03 – 1.45	0.035
[2]Asian (%)	1.02	0.97 – 1.08	0.465
Mixed/Multiple ethnic group (%)	1.14	0.68 – 1.99	0.634
White (%)	0.95	0.90 – 1.00	0.083

305 **Table 2. Adjusted models of socio-demographic factors and burden of COVID-19.**
306 [1]Black denotes Black or Black British ethnic group; [2]Asian denotes Asian or Asian British ethnic
307 group. [3]IMD, Index of Multiple Deprivation, a composite deprivation score encompassing
308 income, employment, education, health, crime, barriers to housing and services, and living
309 environment. [4]Employment deprivation scale (proportion of the working-age population in an
310 area involuntarily excluded from the labour market, due to factors such as unemployment,
311 sickness, disability or carer responsibilities) represents the most recently available data, from
312 2015. Odds ratios and associated confidence intervals were calculated using logistic regression
313 adjusted for different covariates. Data provided by Public Health England.

References

1 COVID-19 situation update worldwide, as of 18 May 2020. European Centre for Disease Prevention and Control. https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases (accessed 18 May 2020).

2 Coronavirus (COVID-19) related deaths by ethnic group, England and Wales - Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/coronavirusrelateddeathsbyethnicgroupenglandandwales/2march2020to10april2020#ethnic-breakdown-of-deaths-by-age-and-sex (accessed 13 May 2020).

3 Aldridge RW, Lewer D, Katikireddi SV, *et al.* Black, Asian and Minority Ethnic groups in England are at increased risk of death from COVID-19: indirect standardisation of NHS mortality data. *Wellcome Open Res* 2020;**5**:88. doi:10.12688/wellcomeopenres.15922.1

4 Deaths involving COVID-19 by local area and socioeconomic deprivation - Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/deathsinvolvingcovid19bylocalareasanddeprivation/deathsoccurringbetween1marchand17april (accessed 18 May 2020).

5 Nicodemo C, Barzin S, Lasserson DS, *et al.* Population Vulnerability to Unexpected Health Shocks: Geographical Disparities in England at the Time of COVID-19. Rochester, NY: : Social Science Research Network 2020. https://papers.ssrn.com/abstract=3571524 (accessed 13 May 2020).

6 Khunti K, Singh AK, Pareek M, *et al.* Is ethnicity linked to incidence or outcomes of covid-19? *BMJ* 2020;**369**. doi:10.1136/bmj.m1548

7 Bhala N, Curry G, Martineau AR, *et al.* Sharpening the global focus on ethnicity and race in the time of COVID-19. *The Lancet* 2020;**0**. doi:10.1016/S0140-6736(20)31102-8

8 Lancet T. Redefining vulnerability in the era of COVID-19. *The Lancet* 2020;**395**:1089. doi:10.1016/S0140-6736(20)30757-1

9 Coronavirus (COVID-19) in the UK. https://coronavirus.data.gov.uk/ (accessed 13 May 2020).

10   Population estimates - Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates (accessed 13 May 2020).

11   CRAN - Package dtwclust. https://cran.r-project.org/web/packages/dtwclust/index.html (accessed 13 May 2020).

12   Arbelaitz O, Gurrutxaga I, Muguerza J, *et al.* An extensive comparative study of cluster validity indices. *Pattern Recognition* 2013;**46**:243–56. doi:10.1016/j.patcog.2012.07.021

17

13   Fox S, Flowers J, Thelwall S, *et al. fingertipsR: Fingertips Data for Public Health*. 2020. https://CRAN.R-project.org/package=fingertipsR (accessed 13 May 2020).

14   English indices of deprivation 2019. GOV.UK. https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019 (accessed 15 May 2020).

15   Standard Area Measurements (2019) for Administrative Areas in the United Kingdom. http://geoportal.statistics.gov.uk/datasets/standard-area-measurements-2019-for-administrative-areas-in-the-united-kingdom (accessed 13 May 2020).

16   Stier A, Berman M, Bettencourt L. COVID-19 Attack Rate Increases with City Size. Rochester, NY: : Social Science Research Network 2020. https://papers.ssrn.com/abstract=3564464 (accessed 15 May 2020).

17   Iacobucci G. Covid-19: Deprived areas have the highest death rates in England and Wales. *BMJ* 2020;**369**. doi:10.1136/bmj.m1810

18   Barnett K, Mercer SW, Norbury M, *et al.* Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *The Lancet* 2012;**380**:37–43. doi:10.1016/S0140-6736(12)60240-2

19   Kontopantelis E, Mamas MA, van Marwijk H, *et al.* Chronic morbidity, deprivation and primary medical care spending in England in 2015-16: a cross-sectional spatial analysis. *BMC Medicine* 2018;**16**:19. doi:10.1186/s12916-017-0996-0

20   Baker C. Health inequalities: Income deprivation and north/south divides. Published Online First: 22 January 2019.https://commonslibrary.parliament.uk/insights/health-inequalities-income-deprivation-and-north-south-divides/ (accessed 15 May 2020).

21   Haynes Norrisa, Cooper Lisa A., Albert Michelle A. At the Heart of the Matter: Unmasking and Addressing COVID-19's Toll on Diverse Populations. *Circulation*;**0**. doi:10.1161/CIRCULATIONAHA.120.048126

22   Dennison Himmelfarb CR, Baptiste D. Coronavirus Disease (COVID-19): Implications for Cardiovascular and Socially At-risk Populations. *Journal of Cardiovascular Nursing* 2020;**Publish Ahead of Print**. doi:10.1097/JCN.0000000000000710

23   Report 22 - Equity in response to the COVID-19 pandemic: an assessment of the direct and indirect impacts on disadvantaged and vulnerable populations in low- and lower middle-income countries. Imperial College London. http://www.imperial.ac.uk/medicine/departments/school-public-health/infectious-disease-epidemiology/mrc-global-infectious-disease-analysis/covid-19/report-22-equity/ (accessed 15 May 2020).

24   Walker P, Whittaker C, Watson O, *et al.* Report 12: The global impact of COVID-19 and strategies for mitigation and suppression. 2020. doi:10.25561/77735

25   Prats-Uribe A, Paredes R, Prieto-Alhambra D. Ethnicity, comorbidity, socioeconomic status, and their associations with COVID-19 infection in England: a cohort analysis of UK Biobank data. *medRxiv* 2020;:2020.05.06.20092676. doi:10.1101/2020.05.06.20092676

26   Chowkwanyun M, Reed AL. Racial Health Disparities and Covid-19 — Caution and Context. *New England Journal of Medicine* 2020;**0**:null. doi:10.1056/NEJMp2012910

27   Coronavirus (COVID-19) related deaths by occupation, England and Wales - Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/causesofdeath/bulletins/coronaviruscovid19relateddeathsbyoccupationenglandandwales/deathsregistereduptoandincluding20april2020 (accessed 15 May 2020).

28   Employment by occupation. https://www.ethnicity-facts-figures.service.gov.uk/work-pay-and-benefits/employment/employment-by-occupation/latest (accessed 15 May 2020).

29   Geronimus AT, Hicken M, Keene D, *et al.* "Weathering" and Age Patterns of Allostatic Load Scores Among Blacks and Whites in the United States. *Am J Public Health* 2006;**96**:826–33. doi:10.2105/AJPH.2004.060749

30   Forde AT, Crookes DM, Suglia SF, *et al.* The weathering hypothesis as an explanation for racial disparities in health: a systematic review. *Annals of Epidemiology* 2019;**33**:1-18.e3. doi:10.1016/j.annepidem.2019.02.011

31   Krieger N. A glossary for social epidemiology. *Journal of Epidemiology & Community Health* 2001;**55**:693–700. doi:10.1136/jech.55.10.693

32   Devakumar D, Shannon G, Bhopal SS, *et al.* Racism and discrimination in COVID-19 responses. *The Lancet* 2020;**395**:1194. doi:10.1016/S0140-6736(20)30792-3

33   Medecins du Monde's (MdM) 2019 Observatory Report Left Behind: The State of Universal Healthcare Coverage. MHADRI. 2019.https://mhadri.org/2019/12/17/medecins-du-mondes-mdm-2019-observatory-report-left-behind-the-state-of-universal-healthcare-coverage/ (accessed 13 May 2020).

34   Oxford COVID-19 Impact Monitor. https://www.oxford-covid-19.com/ (accessed 18 May 2020).

35   Khalatbari-Soltani S, Cumming RG, Delpierre C, *et al.* Importance of collecting data on socioeconomic determinants from the early stage of the COVID-19 outbreak onwards. *J Epidemiol Community Health* Published Online First: 7 May 2020. doi:10.1136/jech-2020-214297