

Determining the level of social distancing necessary to avoid a second COVID-19 epidemic wave: a modelling study for North East London

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Abstract

Background: As England is starting to ease lockdown restrictions in a phased manner, it is important to determine the level of social distancing compliance, quantified here as the daily number of social contacts per person, i.e. the daily contact rate, needed to maintain control of the COVID-19 epidemic and not exceed acute bed capacity in case of a secondary wave later this year. This work uses mathematical modelling to simulate the levels of COVID-19 in North East London (NEL) and inform the level of social distancing necessary to protect the public and the healthcare demand from a secondary COVID-19 wave during 2020.

Methods: We used a Susceptible-Exposed-Infected-Removed (SEIR) model describing the transmission of SARS-CoV-2 in North East London (NEL), calibrated to data on confirmed COVID-19 associated hospitalisations, hospital discharges and in-hospital deaths in NEL. To account for the uncertainty in both the infectiousness period and the proportion of symptomatic infection, we simulated nine scenarios for different combinations of infectiousness period (1, 3 and 5 days) and proportion of symptomatic infection (70%, 50% and 25% of all infections). Across all scenarios, the calibrated model was used to assess the risk of occurrence and forecast the strength and timing of a second COVID-19 wave under varying levels of daily contact rate from July 04, 2020. Specifically, the daily contact rate required to suppress the epidemic and prevent resurgence of COVID-19 cases, and the daily contact rate required to stay within the acute bed capacity of the NEL system without any additional intervention measures after July 2020, were determined across the nine different scenarios.

Results: Our results caution against a full relaxing of the lockdown, predicting that a return to pre-COVID-19 levels of social contact from July 04, 2020 may induce a second wave up to eight times the original wave. With different levels of social distancing continuing into next year, the second wave can be avoided or the strength of the second wave can be mitigated. Keeping the daily contact rate lower than 5 or 6, depending on scenarios, for the rest of this year, can prevent increase in the number of COVID-19 cases, could keep the effective reproduction number R below 1 and a second COVID-19 wave may be avoided in NEL. A daily contact rate between 6 and 7, across scenarios, is likely to increase R above 1 and result in a secondary COVID-19 wave with significantly increased COVID-19 cases and associated deaths, but with demand for hospital based care remaining within the bed capacity of the NEL health and care system. In contrast, an increase in daily contact rate above 8 to 9, depending on scenarios, will likely exceed the acute bed capacity in NEL and may potentially require additional lockdowns. This scenario is associated with significantly increased COVID-19 cases and deaths, and acute COVID-19 care demand is likely to require significant scaling down of the usual operation of the health and care system, and should be avoided.

Conclusions: Our findings suggest that to avoid a second COVID-19 wave and to stay within the acute bed capacity of the NEL health and care system, phased relaxing of the social distancing in NEL is advised with a view to limiting the average number of social interactions in the population. Increasing the social interaction rapidly could result in a second COVID-19 wave that will likely exceed the acute bed capacity in the system, and depending on the strength of the resurgence may require additional lockdown measures.

Background

The world remains in the grip of the COVID-19 pandemic caused by the Severe Acute Respiratory Syndrome – Coronavirus 2 (SARS-CoV-2). Transmission of SARS-CoV-2 between individuals is thought to occur primarily via transfer of viral droplets via close contact between individuals, although fomites and aerosol infections have been reported [1]. As of August 07, 2020, over 18.8 million cases and over 708,000 deaths have been reported worldwide [2]. In the UK, since the first two cases were reported on January 31, 2020 and the first reported COVID-19 related death occurred on March 06, 2020, over 300,000 cases and almost 50,000 COVID-19 related deaths have been reported as of August 07, 2020 [3].

The impact of COVID-19 on boroughs in North East London (NEL) (population size 2.1 million) [5] has been significantly higher than other parts of the country (Figure 1). The first case of COVID-19 in the region was reported on February 19, 2020, and the first COVID-19 associated death was documented on March 06, 2020 [3,4]. Since then the local epidemic has spread rapidly with 7,205 confirmed cases (up to August 03, 2020) and 1,732 deaths (registered by August 01, 2020) associated with COVID-19 across NEL [3,4]. The boroughs of Newham (144.3) and Hackney (127.4) have the highest and third highest age-standardised mortality rate per 100,000 people in the country [5], while Havering, Tower Hamlets and Waltham Forest all have death rates significantly higher than the rest of London [5].

The NEL healthcare system comprises 3 'integrated care partnerships' (ICPs), covering 7 constituent London boroughs: 1) City of London and Hackney (combined in line with commissioning of health and care services by City and Hackney Clinical Commissioning Group (CCG) and referred to throughout as City & Hackney), 2) WEL: Waltham Forest; Newham; Tower Hamlets, 3) BHR: Barking & Dagenham; Havering; and Redbridge. The population of each ICP is served principally by a different acute NHS trust, albeit with some overlap with other areas: City & Hackney is served by Homerton University Hospital NHS Foundation Trust (HUT); WEL is served by Barts Health NHS Trust (Barts); BHR is served by Barking, Havering and Redbridge University Hospitals NHS Trust (BHRUT). Since the onset of the epidemic, data has been collated from these subsystems within NEL [8] on the number of COVID-19 cases, deaths and hospitalisations as shown in Figure 1.

NEL is highly diverse in terms of ethnicity and age as well as socio-economic mix, with large Black, Asian and minority ethnic (BAME) populations with majority of the population in Newham, Tower Hamlets and Redbridge from BAME groups [6,7]. Furthermore, Barking & Dagenham has the lowest life expectancies for males in London, while Havering has the largest proportion of people aged over 65 years of any London borough [5]. It has been widely reported that these groups, South Asian, Black, over 70s and males, have significantly higher risk of being hospitalised due to COVID-19 [9,10]. Hence, understanding the pressure of COVID-19 on the local health and care system, and the constraints needed to keep infection rates within the hospital capacity levels, is of increased importance in NEL due to its particularly vulnerable population. It is also important to support system planning over the coming 12 months. There is a need to support both COVID-19 care and those with non-COVID-19 health concerns (e.g. type 2 diabetes, cardiovascular disease and cancer, etc.), and consider how much health and care system capacity is available for those with COVID-19 and non-COVID-19 needs.

On March 23, 2020, the UK Government imposed strict social distancing measures ('lockdown'), to protect the public, slow down the virus spread, and reduce the associated morbidity and mortality and prevent excess demand on the National Health Service (NHS). As the number of daily cases and confirmed deaths started to decline in late April 2020, the first steps were taken towards lockdown easing with partial reopening of primary schools on June 01, 2020, of secondary schools from June 15, 2020 and non-essential businesses from July 04, 2020. Given the relatively high levels of ongoing infection [3], it is important to assess whether the number of infections will increase again when lockdown measures are lifted, potentially leading to a secondary wave and increasing the effective reproduction number R . To suppress the virus and control the epidemic R needs to remain below 1. The biggest step in lockdown easing came into effect in England from July 04, when restaurants, pubs and hairdressers reopened, followed by allowance of two households to meet indoors (where risk of transmission/survival of the virus is significantly higher) and relaxation of the 2 metre social distancing to rule to "1 metre plus" [11]. Lockdown easing will likely increase the daily contact rate and it is critically important to understand the extent to which such increase in the contact rate among people will affect control of COVID-19 transmission or lead to a secondary wave.

Since the onset of the epidemic in the UK, mathematical modelling has been widely used to understand the spread of COVID-19 across different settings [12], and to design optimal strategies to reduce future burden and prevent a second wave. Different mathematical models have been utilised: deterministic models on whole populations and rooted in using equations tracking Susceptible-Exposed-Infectious-Removed (SEIR) populations [13], sometimes age-stratified [14,15]; and stochastic i.e. individual-based models [16,17] for transmission between individuals in a population. Contact rate, as the daily number of contacts per person per day, is one of the key parameters within each group of models and physical/social distancing measures can be modelled by varying the contact rate. A survey on adults' behaviour in the UK during a period lockdown and comparing the results to previously collected data from Polymod [22], suggest a large reduction in daily contacts particularly outside the home, resulting in a marked reduction in the estimated reproduction number from 2.6 to 0.62 [14]. In these studies, a contact is defined as encounters with either skin-to-skin contact or a two-way conversation of at least a few words. As the UK is planning the next steps of the phased lockdown release, with reopening of schools as the first step of reopening society from September 2020 [16], it is imperative to assess how an increase in contact rate will affect R and hence ability to suppress the virus in the future. We note that these results depend on the level of compliance with additional countermeasures, including face coverings usage, hand-washing, and correct social distancing.

In this paper, we present an SEIR model for COVID-19 spread across the NEL boroughs of Hackney, Tower Hamlets, Newham, Waltham Forest, Barking & Dagenham, Havering, Redbridge, and City of London. Within the removed (R) compartment we include multiple sub-compartments to project the following outcomes: daily overall hospitalisations, daily hospitalisations within Intensive Care Units (ICUs), daily discharges from hospitals and daily deaths within hospitals from COVID-19. The novelty of our work is in combining the model with granular local data to calibrate these four projections against and hence get a robustly calibrated model able to forecast the epidemic in NEL.

We aim to determine the level of social distancing compliance, quantified here in terms of the daily number of social contacts per person, needed to maintain future control of the COVID-19 epidemic in North East London and not exceed healthcare capacity in case of a second wave later this year, via series of modelling simulations.

Methods

Mathematical model

We developed a Susceptible-Exposed-Infectious-Removed (SEIR) mathematical model to simulate the spread of COVID-19 in NEL as shown in Figure 2. Details of the model equations, parametrisation and calibration of the model are contained in the supplementary material.

We assume that SARS-CoV-2 is introduced into a susceptible population of around 2.1 million people, resembling the population of NEL, on 16th February 2020. Those exposed to the virus become infectious after a median incubation period of 5.1 days [18].

Within the model we account for the proportions of people infected that have symptoms (*symptomatic*) vs those that do not show symptoms (*asymptomatic*) and we introduce a parameter that quantifies the proportion of symptomatic cases out of all cases (ρ_{sym} with details in the supplementary material). In the literature, there is a mixed evidence on what this proportion is [19]. Hence we explored three values for this parameter, assuming 70% for the main study and varying it to 50% and 25% in the sensitivity analysis (details in the supplementary material).

Additionally, we also vary the infectiousness period within the model. Firstly, in absence of data to suggest otherwise, the infectious period is treated as equal for both symptomatic and asymptomatic cases and as a population average of all cases. A recent literature review suggested that COVID-19 infectiousness peaks in the first 5 days following symptom onset, while no live virus has been cultured after 9 days following symptom onset [20]. Based on this, and taking in consideration that the single population average parameter for infectiousness period is likely to be shortened by self-isolation of a significant proportion of symptomatic patients, we simulated three scenarios for the infectiousness periods of 1, 3 and 5 days.

In our modelling approach, we divide the removed compartment into multiple sub-compartments to reflect differential pathways for patients depending on the severity and outcome of infection. Cases are divided into asymptomatic, mild (not hospitalised) and severe (hospitalised), based on the proportion of

symptomatic cases, ρ_{sym} , and the proportion of symptomatic cases requiring hospitalisation, ρ_{severe} . This is detailed in the supplementary material.

Hospitalised cases are divided into critical and non-critical, with the former requiring an ICU bed, based on the proportion of patients requiring critical care, $\rho_{critical}$. For each of these two hospital pathways, there are distinct parameters associated with patient mortality rate and length of stay in hospital, based on observed differences [21]. The model focuses on hospitalised cases only for the purpose of healthcare planning, not taking account of any out-of-hospital deaths occurred. Further details can be found in the supplementary material.

Data

The number of daily patients hospitalised with COVID-19, in both non-critical and critical care beds, and the number of daily discharges of COVID-19 patients was obtained from the COVID-19 Dashboard produced by NHS England and NHS Improvement [27]. The number of daily COVID-19 hospital deaths were provided by NHS England [28].

All data was provided at a trust level. Data was aggregated to include the relevant NHS Trusts providing acute care in North East London, of Barking, Havering and Redbridge University Hospitals NHS Trust, Barts Health NHS Trust, and Homerton University Hospital NHS Foundation Trust.

Estimates of hospital capacity were derived from local COVID-19 response plans and reported bed capacity data during the COVID-19 pandemic [27,29]. This reflects considerable work done to increase overall hospital bed capacity with NEL, and London. Information on capacity includes general acute beds as well as critical care capacity, it notes current capacity as well capacity planned additional capacity. Capacity is broken down into 3 levels: (i) currently available, (ii) planned capacity; and (iii) planned capacity plus Nightingale hospital bed capacity. Estimates account for infection control planning to maintain certain hospital sites as COVID-free zones (equating to approximately 20-25% of overall and critical care bed capacity) to maintain a degree of non-COVID-19 care. Capacity estimates are used to assess where a secondary epidemic wave is likely to exceed acute bed capacity of the NEL health and care system.

Parametrisation and Calibration

The model is parametrised with a combination of fixed and fitted parameters listed in Tables S2 and Table S3. The model was calibrated against observed data for NEL on COVID-19 hospitalisations (both non-critical and critical care), discharges and in-hospital deaths, including all data up to July 01, 2020. Details with fitted parameters used to calibrate the model are listed in Table S3. Further details can be found in the supplementary material.

Analysis

For the main analysis of this paper, we varied the daily contact rate, c , between 3 (approximating the measured value during lockdown of 3.1) and 12 (slightly higher than the pre-COVID-19 UK average of 10.7), from July 04, 2020, within the calibrated model. We projected the number of daily COVID-19 cases, associated deaths and overall and ICU hospitalisations. We used the model projections to derive the maximum c , across different scenarios, to avoid a second COVID-19 wave, keep R below 1 and not exceed the acute bed capacity in NEL.

Since there is uncertainty about the length of time for which people are infectious, and the proportion of people with symptomatic infection, we varied the parameter that describes the infectiousness period, and the proportion of symptomatic cases, ρ_{sym} . The infectiousness period was set to 5 days and the proportion of symptomatic cases set to be 70% for the main analysis, based on published work [14,16].

Results

Across all nine scenarios, for varying proportion of symptomatic cases and infectiousness period, the model was calibrated to closely match the NEL observed data (Figure S1 in the supplementary material). All fitted parameters are summarised in Table S3 of the supplementary material.

Figure 3 shows the model-projected daily cases, cumulative deaths and daily number of hospitalised patients (hospitalisations) for varying levels of daily contacts per person (or daily contact rate), c , for a population-average infectiousness period of 5 days and a proportion of symptomatic infection of 70%. Our results suggest that significant relaxation of social distancing measures in NEL, with an average of more than 6 daily contacts per person from 4th July 2020 leads to a resurgence of COVID-19 cases and a secondary epidemic wave (Figure 3 (d)-(f)). The size of a secondary COVID-19 wave depends on the level of social distancing compliance i.e. on the average number of daily contacts per person.

With full relaxation of social distancing and return to pre-COVID-19 levels of social contact ($c \approx 11$), a secondary COVID-19 wave may occur up to 8 times larger than the original wave in terms of number of infections (Figure 3 (d)) and for the peak number of patients hospitalised with COVID-19 and associated deaths (Figure 3 (f) & Figure 4 (b)). In addition to a surge in the number of daily cases, hospitalisations and deaths, the health and care demand will exceed the acute bed capacity in NEL in this scenario.

A secondary COVID-19 wave, including excess demand on acute care, may be prevented however, if some level of social distancing remains in place for the rest of the year. Specifically, to prevent a significant secondary wave in NEL, the average daily contact rate after July 04 must not exceed 6 (Figure 3 (a)-(c)). With this level of compliance with social distancing, the burden from COVID-19 would be less in terms of total cases, hospitalisations and deaths (Figure 4 (a) to (c)), and the acute bed capacity demand not exceeded (Figure 5 (a)-(b)) and R will remain below 1 (Figure 5 (c)-(d)). Hence avoiding a secondary wave of COVID-19 in NEL would require reduction in pre-COVID-19 average daily contact rate to around 50% of its pre COVID-19 level in the region for the rest of the year.

A secondary wave remains within the bed capacity of the health and care system for an average number of daily contacts per person of up to 7 to 8 (Figure 5 (a)-(b)). However, this scenario is associated with a significantly increased numbers of total cases, hospitalisations, discharges and deaths (Figure 5). A daily contact rate of 8 gives an end-of-year death total of over 4,000, a more than threefold increase compared to if daily contacts were kept to 6 or lower. Going from a population average rate of daily contacts of 8 to 9 increases the peak in COVID-19 hospitalisations from 2500 to 4200, crossing all 3 overall bed capacity scenarios, including the maximum capacity (current plus planned plus Nightingale) of approximately 2900 beds (Figure 3).

When we vary the infectiousness period to be 3 or 1 days, and the proportion of symptomatic infection to be 50% or 25%, the overall results remain consistent, with a secondary epidemic wave present unless restricted social distancing is present. Across all 9 scenarios, for varying levels of infectiousness period and proportion of symptomatic infection, the limit on the average number of daily contacts to suppress a second wave is between 5 and 6, while the maximum average number of contacts for a secondary peak to remain within NEL capacity levels is between 8 (in 7 scenarios) and 9 (in 2 scenarios). Across scenarios, a longer infectiousness period pushes a secondary wave further into the future, and a lower proportion of symptomatic infections leads to a smaller peak in hospitalisations for equivalent c values. Therefore, we find it is the balance between infectiousness period and the proportion of infections that are symptomatic that controls the timing and the strength of a potential secondary wave in NEL. Results for all 9 scenarios are summarised in Figures S1-S12 of the supplementary material.

Discussion

Our findings suggest that a phased relaxation of the lockdown in NEL is necessary to avoid a potential secondary COVID-19 wave later this year and not exceed the acute bed capacity in the region. Good compliance with social distancing measures and a maximum of 5-6 daily contacts per person on average, equivalent to a 45%-55% reduction in pre-COVID-19 average daily contacts, is necessary to keep the virus suppressed and keep the reproduction number R below 1 for the rest of this year, across all nine scenarios modelled, varying the infectiousness period and proportion of symptomatic infections.

Our results suggest that lockdown is a highly effective strategy in reducing infections and mortality, and that lifting of lockdown fully in the near term would likely lead to a resurgence of cases and a secondary COVID-19 peak, as shown by other modelling studies [13-17].

We find that if the average daily contact rates per person increase to 7-8, while a secondary COVID-19 wave will occur, the increased number of hospitalisations will remain within the acute bed capacity of the local health and care system. However, such scenarios are highly undesirable, leading to multi-fold increases in the numbers of cases, hospitalisations, discharges and deaths. As seen during the primary epidemic wave, a surge in COVID-19 hospitalisations can lead to severe disruption of the health and care system leaving patients unable to receive the care they require, with elective procedures postponed or cancelled, and likely avoidance of attendance due to fears around infection leading to an increase in excess deaths [30]. Furthermore, the infection risk to staff of having a significant proportion of hospital capacity used by COVID-19 patients places immense burden on the local health and care system. Hence, although we find that such scenarios of increased social contact are within certain operational limits, they have many negative consequences and should be avoided.

Furthermore, the analysis shows the sensitivity of the epidemic to the degree of social contact, with a relatively small increase in average social contact leading to very much worse outcomes in terms of public protection and stress to the health and care system. We note here, as discussed in more detail further in this section, that our model does not account for the varying level of risk of COVID-19 on different segments of the population, whose ability to safely engage in social contact will vary, e.g. comparison of lower-risk population such as children vs. older generations. Furthermore, the relatively broad definition of a contact does not capture the significant differences in the probability of a contact spreading infection, depending on factors such as household

composition, location and contact duration. While there is insufficient data on the contact duration necessary for infection to spread, CDC use an operational definition of more than 15 minutes in their guidance on exposure to COVID-19 [32]. It is unknown what proportion of contacts recorded in literature surveys meet this narrower criteria, however the number of these 'higher-risk' contacts is likely to be lower than the overall number of daily contacts. Our population average social contact parameter, c , does not attempt to capture these levels of nuance. Nevertheless, this work further highlights the need for careful and strategic relaxing of social distancing in order to control future COVID-19 outbreaks.

The pertinent question in the UK is when and how social distancing measures might be fully relaxed and whether we are prepared to reopen schools alongside society in September [16]. Our findings suggest that, if some level of social distancing remains in place, with daily contacts at most 45-55% of that pre-COVID-19 depending on the assumed level of infection that is asymptomatic, a potential second wave would be much less severe. Although previous studies have modelled the potential impact of social distancing on viral spread [14-16], our study is the first to quantify the average number of daily contacts per person required for viral prevention and control in a setting in the UK later this year. We illustrate that small changes to the current social distancing measures would allow hospitals and ICUs to operate within capacity. However, any increase in daily contacts above an average of 6 is likely to induce a second wave and over 8 daily contacts on average would exceed the capacity of acute care.

Ongoing surveys on a representative sample of UK adults about their contact patterns on the previous day, by colleagues at LSHTM suggest that the number of daily contacts has reduced 73% with the imposed lockdown measures [14]. More recent data reveal that although there was a small increase in the average number of contacts per person per day in the first two weeks of July, with the reopening of non-essential business from July 04, 2020, to around 4 contacts per person per day (personal communication with authors of [14]), this still remains below the limit of 6 that we suggest as necessary to avoid a secondary wave. Hence people remain cautious as society reopens and our findings suggests this needs to remain in place in future.

The measures suggested by our findings to control the spread of COVID-19 later this year and prevent the NEL health care system from exceeding acute bed capacity are in line with current UK policy [23]. These measures are avoiding large gatherings, and avoiding close contact with more than six people per day. The recent introduction of phased relaxation of lockdown measures, such as reopening of schools and businesses, are important to protect education and the economy. However, since there are still infections present, it is important to keep tracking the epidemic trends and react in a timely way to any future surge, as has been the case in other countries [24]. In particular, close attention should be paid to monitoring population groups with unique risks such as those living in intergenerational and overcrowded households, where people with a lower risk of COVID-19 complications mix with those who have greater COVID-19 risk levels.

While lockdown strategies can suppress the virus, reopening of society is important to protect the economy. Maintaining the balance between saving lives and saving livelihoods is crucial [25]. It is also important to allow people to maintain important social links more easily, particularly where individuals are reliant on public transport and other more shared spaces to do so. Phased reopening of society, with preparedness to react quickly if the epidemic metrics start to surge are crucial over the next few months as we plan for a possible second wave. Our results give quantification on the level of compliance with social distancing that is necessary to prevent a potential future secondary wave later this year.

The work we present here has some limitations. Our model does not include granulated population structure. We do not consider age stratification and the associated risks of different age groups. We do not consider contact patterns characteristic of population groups with different employment types, household compositions or social behaviours. We have used a single parameter to describe the average daily contact rate rather than a contact matrix representing mixing within and between population groups. Hence the amount of social contacts per person per day derived here as necessary for future outbreak control is an average value for the entire population. This means our result of 5-9 contacts as the limit for our system is not a hard line for all individuals and will vary depending on individual COVID-19 risk. For example, with reopening of schools, school-age children returning to school may have more than 8 contacts per day while having lower risk of COVID-19, while older generations are at much higher risk and so may remain shielded with contacts well below 8. We also note that neglecting population structure can overestimate the size of outbreaks [26]. This is due to the susceptible subpopulations of different groups actively shielding or becoming depleted. Furthermore, the broad definition of a contact means that all contacts are not equal in terms of probability of spreading infection. As a result, we expect our study to underestimate the average contact rate that is safe for avoiding a second wave.

While we have made every effort to characterise the pandemic in a way that resembles that of the UK, some of the parameters we have used are from a variety of sources across different settings within the published literature. Since the purpose of the study was a large scale sensitivity analysis on the impact of the daily contact rate on mitigating a secondary pandemic wave, such parametrisation is sufficient. We did not consider other control measures that might decrease the reproduction number, e.g. shielding of vulnerable population groups. We assumed that isolation of cases and contacts is completely effective and that all symptomatic cases are eventually reported. We also assumed that contact is required for transmission of COVID-19 between two individuals while indirect transmission via fomites might be possible. While relaxing these assumptions may affect outcomes such as the size of a potential secondary peak quantitatively, we don't expect these to change the overall message of our work.

We note that our study only looks at contact rate as the main driver of transmission of the virus and does not account for behavioral changes that alter transmission in some other way. For example, if people follow guidance on social distancing and mask wearing even when socially mixing, this may reduce the transmission probability even as a given level of contact is maintained [31]. We have not considered the policy of compulsory face coverings imposed in England from 24th July. But we note that if we assume 45% mask efficacy with 70% compliance, resulting in a 30% overall reduction in risk, then the number of effective contacts could be 30% higher than the values reported here. Incorporating this and other non-pharmaceutical interventions within the model is something we plan to explore in future. Additional, complementary work on this is ongoing by some of the authors, focusing on assessing the impact of this policy combined with reopening schools and society from September 2020 and with ongoing test-trace-isolate strategy on the COVID-19 epidemic next year.

The methodology we have used here can easily translate to other settings. NHS Right Care [30] have a tool that uses demographic factors (deprivation, age, population and ethnicity) to compare different Clinical Commissioning Groups (CCGs) and provides a 'nearest-10' comparator group for each CCG. By identifying the CCGs that are similar to those in NEL, future work can compare COVID-19 deaths and hospitalisations across such CCGs and use these to re-calibrate the model. This will allow us to explore whether the compliance with social distancing that we are suggesting here is applicable to similar CCGs.

In summary, we show that phased relaxing of the lockdown in NEL is necessary to avoid secondary COVID-19 wave and not exceed the acute bed capacity in the health and care system. Good compliance with social distancing measures, with a maximum of 5-6 daily contacts per person on average (i.e. a 45-55% reduction in pre-COVID-19 average daily contacts), is necessary to keep COVID-19 suppressed and keep R below 1.

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Declarations

Ethics approval and consent to participate

This study used secondary anonymised data set for which no ethics approval or consent to participate was required.

Consent for publication

Not applicable

Availability of data and material

The datasets used and analysed during this study and the numerical codes used to generate the outcomes of this paper are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Contributions

JPG, NC, IE and KB had the idea for this study. JPG designed the study and NC, IE and KB collated and prepared the data for modelling. NC undertook the modelling with support from JPG and WW. JPG, NC and KB drafted the paper with input from WW, IE and WL. All authors approved the final version of the manuscript.

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Figures

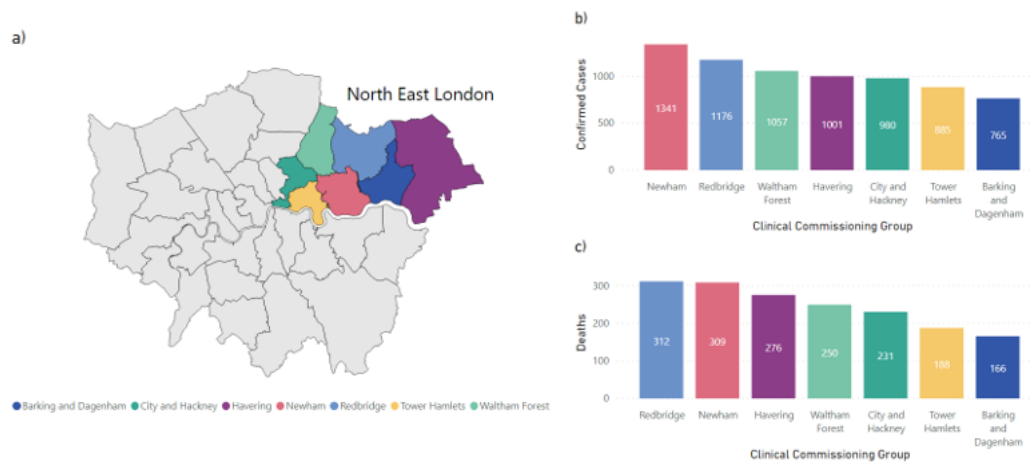


Figure 1

a) NHS Clinical Commissioning Group (CCG) London boundaries, with North East London CCGs highlighted. b) Number of confirmed cases of COVID-19 for North East London Clinical Commissioning Groups, up to 3rd August [3]. c) Number of deaths due to COVID-19 for North East London Clinical Commissioning Groups, for deaths that occurred up to 24th July, registered up to 1st August [4].

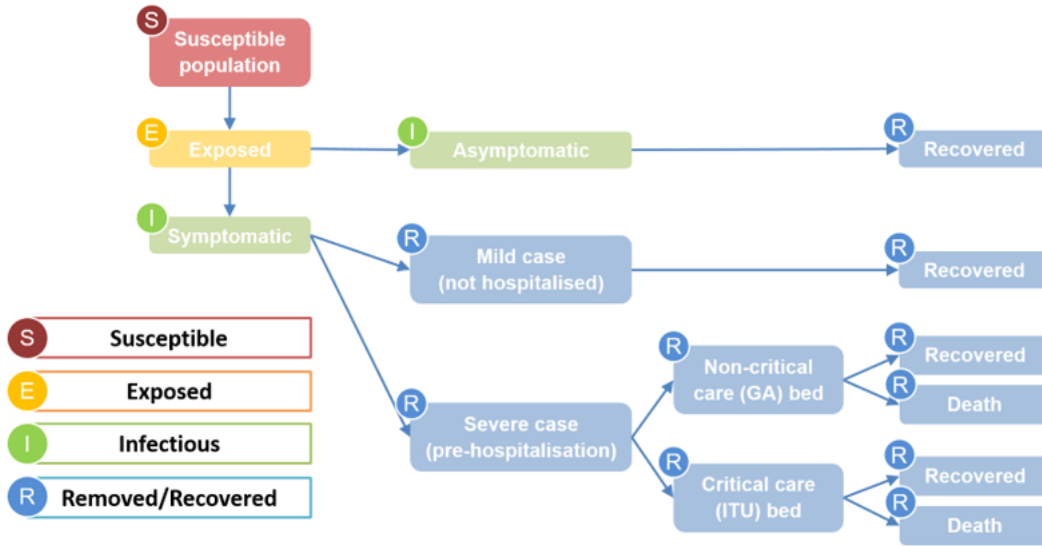


Figure 2

Schematic of the possible pathways within the SEIR epidemiological model. Arrows show the progression through the stages from susceptible to removed/recovered.

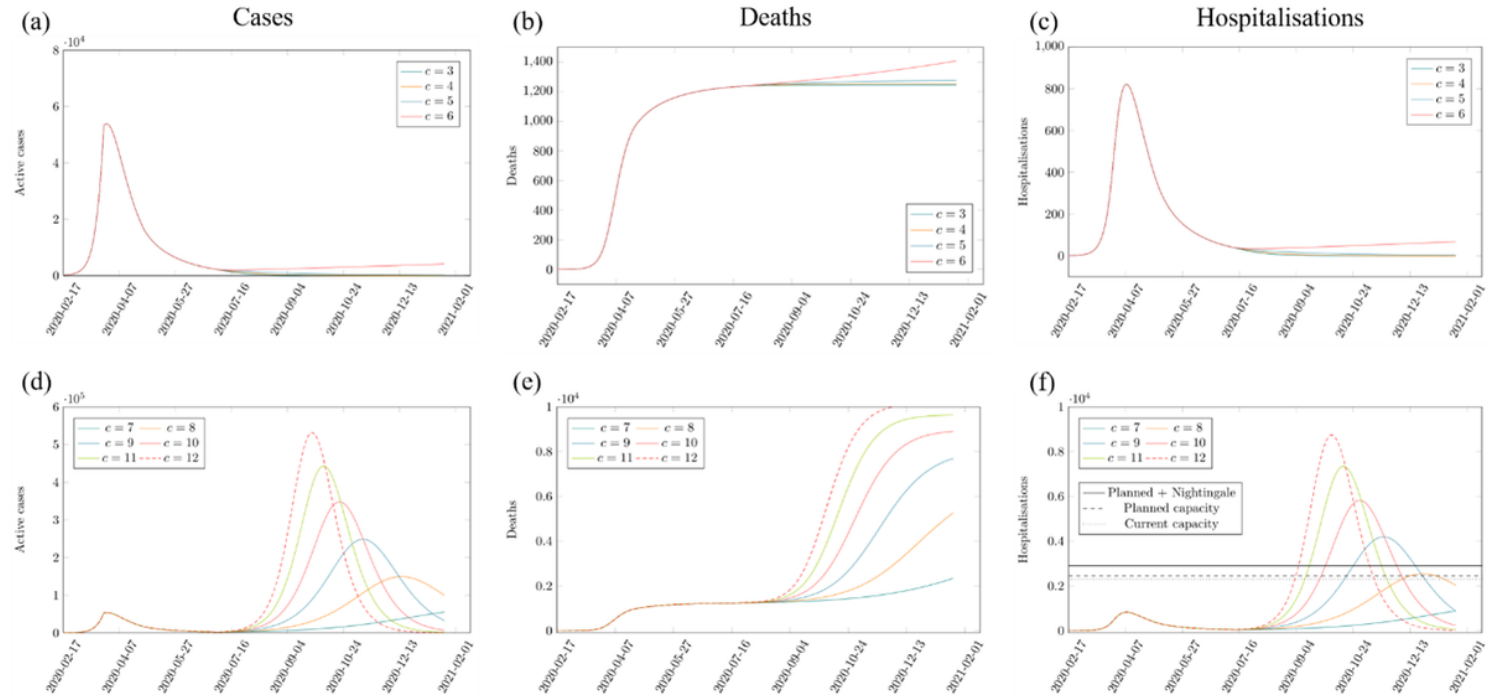


Figure 3

Projections of the mathematical model forecasting the number of COVID-19 cases (left panels), deaths (centre panels) and hospitalisations (right panels) for varying numbers of daily contacts, c . Panels (a)-(c) show high levels of social distancing, $c = 3$ to 6 , and (d)-(f) show low social distancing, $c = 7$ to 12 . Infectiousness period = 5 days, proportion of symptomatic infections = 70%. Estimates for hospital capacity levels are given in (f) for reference.

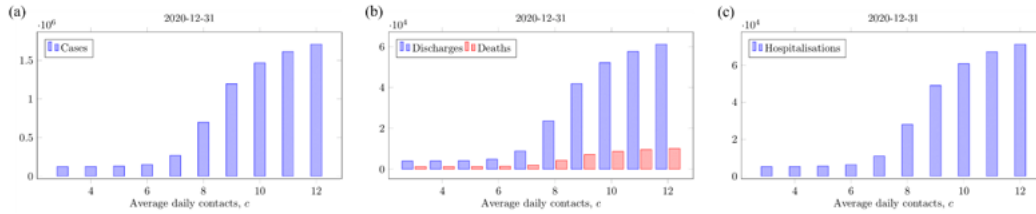


Figure 4
 Cumulative number of COVID-19 cases (a), hospital discharges and deaths associated with COVID-19 (b) and hospitalisations with COVID-19 (c) for different levels of compliance with social distancing quantified by the number of daily contacts, c , from 4 July 2020. The cumulative totals for 2020 are considered, including forecasts up to 31 December 2020. For $c > 6$ the number of cases, deaths, hospitalisations and discharges increase significantly. The results shown here assume an infectiousness period of 5 days and that symptomatic infections comprise 70% of all infections.

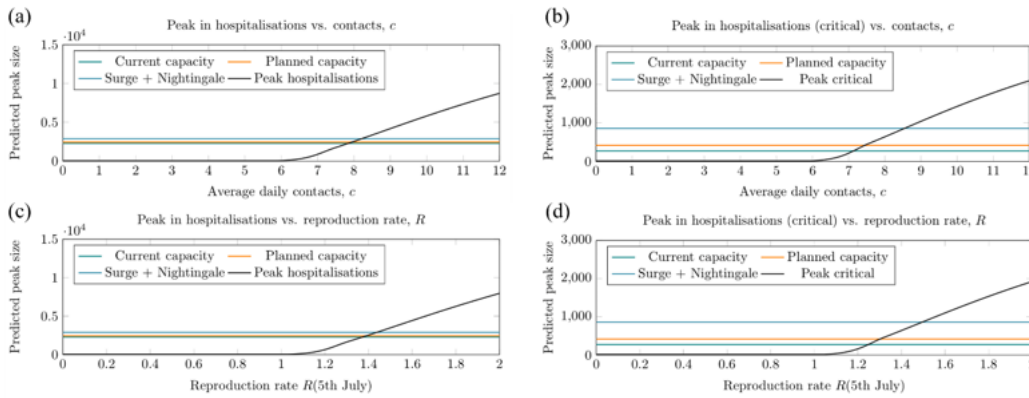


Figure 5
 Predicted size of the secondary COVID-19 wave (black lines), measured by the peak in all COVID-19 hospitalisations (left panels) and critical care COVID-19 hospitalisations (right panels) for different levels of compliance with social distancing from 4 July 2020 as a function of the daily number of contacts, c , (top row) and the effective reproduction number, R (on 5 July 2020, bottom row). Estimates for hospital capacity levels (coloured lines) are given for reference. For $c > 6$, R is above 1 and a secondary wave is predicted. The results shown here assume an infectiousness period of 5 days and that symptomatic infections comprise 70% of all infections.

Supplementary Files

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- [supplement1.pdf](#)