Seasonality and its impact on COVID-19

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21st October 2020

Executive summary

- A combination of factors are likely to combine to exacerbate the epidemic of COVID-19 during the winter months. These factors include continued susceptibility of the population, the direct effect of environmental variables (such as temperature and UV light) the indirect effect of poor weather leading to people spending more time indoors and other seasonal changes in contact rates due to school opening, seasonal festivals, etc. There are other effects that may exacerbate the severity of COVID-19 disease during the winter. This paper examines the evidence of these effects.
- The direct effect of winter environmental conditions on transmission is likely to be small. Winter conditions will increase viral persistence on outdoor surfaces due to reduced temperatures and UV levels, in unheated indoor environments due to lower temperatures and in day-time outdoor aerosols due to reduced UV levels (high confidence). However, the outdoor environment is not dominant in SARS-CoV-2 transmission, and indoor environmental conditions (where the vast majority of transmission is likely to occur) are more constant.
- Changes in behaviour are expected to occur. Patterns of school opening are likely to affect transmission but the evidence is inconsistent across available studies, resulting in low confidence of the assessment. In addition, there is limited data to suggest that contacts increase in the winter months (low confidence) and that social contacts may increase towards the end of the year and then fall again in January (low confidence). Individuals appear to spend longer indoors during the winter, when ventilation rates in buildings are lower (medium confidence). All studies are based on data from previous time periods, and physical distancing measures are likely to influence observed patterns this winter, further reducing uncertainty of the assessment.
- Over the next 6-12 months changes in SARS-CoV-2 susceptibility (unrelated to seasonal factors) are likely to dominate the epidemiology. Susceptibility is likely to have a much bigger impact on transmission than environmental factors (high confidence).
- It seems likely that co-infection with influenza viruses worsens the clinical course (medium confidence). There is no evidence, at present, to suggest that other physiological changes that may occur over winter will affect the severity of disease.

Aim

To summarise the available evidence on the impact of environmental factors and associated behaviour changes on transmission of SARS-CoV-2 and the severity of COVID-19 if acquired.

Introduction

Many viral pathogens exhibit changes in disease incidence consistent with transmission being influenced by seasonal factors, although the mechanisms that drive seasonality are poorly understood.[1] In addition, other seasonal factors may influence the severity of disease if infection is acquired. This paper aims to summarise these factors as they may relate to infection with SARS-CoV-2 and its associated disease COVID-19. It sets out to estimate the magnitude in seasonal effects that might be expected and examine the drivers for these effects.

Main drivers of seasonal effects

Most respiratory pathogens, including the seasonal coronaviruses,[2] are more prevalent during the winter in temperate countries. There are a number of potential mechanisms that may lead to an increase in transmission of SARS-CoV-2 in winter months, and further factors that could alter the severity profile – that is, lead to more severe disease given infection in the winter months. These factors are listed here and the evidence for their potential role is expanded on in the following sections

Factors affecting transmission

A. Environmental conditions may improve virus survival during winter months
B. There may be seasonal changes in contact rates
C. For endemic diseases (such as the other beta coronaviruses) there may be seasonal patterns in susceptibility as a result of past seasonal outbreaks. Seasonal pattern of susceptibility are unlikely in the short term for SARS-CoV-2, however temporal changes in susceptibility (independent of the seasons) is likely to be a major driver of COVID-19 epidemiology over the coming year or so.

Factors affecting severity of disease given infection

D. Environmental drivers, can have physiological effects, making disease more severe or more likely, if infection occurs.
E. Co-circulating pathogens can exacerbate the severity of illness.

Part 1: Factors affecting Transmission

Transmission is driven by the number of infectious and susceptible individuals and the effective contact rate. The effective contact rate will be determined by the probability of infection given a contact and the number of contacts. Both are likely to vary seasonally, and it is difficult to disentangle the relative role of each from observational studies. Since the emergence of SARS-CoV-2 globally, there has been substantial investigation into both these components in order to improve forecasting and find effective ways to reduce transmission.

A) Environmental factors

Ecological studies of environmental impacts on SARS-CoV-2 transmission

Between March-August 2020 there have been 173 peer-reviewed articles that aim to explore the effect of meteorological factors on SARS-CoV-2 transmission. The findings and quality of analysis was summarised in a (unpublished) systematic review,[3] where 21 studies were examined further. There was substantial variability in the quality of the analysis, including approaches to account for confounding (eg. human mobility and physical distancing measures, population density and socio-economic factors) and consideration of collinearity between climatic variables. We use this systematic review to focus on findings from high quality studies. A majority of studies are retrospective ecological analyses where the outcome variable is either the reported number of COVID-19 cases or estimates of the reproduction number (Rt), and the association of climate variables are examined to explain the variability in the outcome. Several studies report a higher incidence of COVID-19 cases (or Rt) associated with reduced temperature, relative humidity and solar radiation (UV); while the relationship is consistent the variation explained by climate is low. For example, in Runkle et al. (2020)[4] an *excess fraction* of COVID19 cases associated with climate variables was estimated in 8 US cities, and was at most 6.8-9.1% in one city (New Orleans), and in Meyer et al. (2020)[5] it was reported that "temperature only explained a modest amount of the total variation", and that anticipation of a decline in transmission due to warm temperatures alone is not warranted. Many studies assume a log-linear negative relationship between climate variables and COVID-19 cases,[5,6] but where non-linear relationships are used,[4] a "U-shaped" association with temperature was observed, with winter temperatures associated with a higher incidence.

Ecological studies of environmental impacts on other seasonal coronavirus transmission
A systematic review of the seasonality of human coronaviruses has recently been published.[2] A total of 40 studies were included from 21 different countries. High activity during winter months was observed for seasonal coronaviruses in temperate countries outside China, with about half of all positive cases being detected within three months. Low temperature with higher relative humidity was found to be associated with higher proportion of sCoV cases, as was dew point (a measure of saturation humidity)[1].

Kissler et al.[7] fitted a strain-specific regression model that took account of changes in susceptibility to human seasonal coronavirus positivity data from the US National Respiratory and Enteric Virus Surveillance System and a two-strain SEIRS model to the same data. The two models gave qualitatively similar results, and suggested that the seasonal amplitude in R_0 was around $\pm$10% from the mean, with a peak in November. It is not clear whether this seasonal pattern of transmission is due to environmental or behavioural factors.

Studies on SARS-CoV-2 survival

[1] It is important to recognise that most studies report relationships with relative humidity rather than absolute humidity. Relative humidity describes the fraction of water vapour in the air and varies significantly with temperature. Colder air can hold less moisture, hence condensation/dew forms when temperatures drop below the dew point temperature. Outdoor air under cold winter conditions with a high relative humidity, will have a low relative humidity under warmer indoor conditions, however the absolute humidity remains the same. Studies on influenza survival suggest that it is absolute rather than relative humidity that is the important parameter[16].

The impact of temperature, relative humidity and UV on the survival of SARS-CoV-2 and other coronaviruses on surfaces and in the aerosol state have been the subject of laboratory studies. However, only a limited number of papers have reported data at temperatures lower than 20°C. Chan et al (2020)[8] demonstrated prolonged survival of SARS-CoV-2 on surfaces at 4°C with only 90% loss of infectivity over one week compared to 99.999% reductions in 5 days for virus at 20-25°C. Similar extended survival at low temperatures have been reported for other coronaviruses such as MERS.[9–11] Longer survival times are also reported for SARS-CoV-2 in solution at 4°C.[12] Relative humidity also has an impact on survival of virus on surfaces with reduced survival at higher relative humidity but the impact is far less than temperature and UV in the relative humidity ranges found in the UK.[13] These low temperature data are relevant for outdoor surfaces in colder seasons.

Dabisch et al (2020)[13] have published data on aerosol stability of SARS-CoV-2 at a range of temperatures including 10°C. In the absence of simulated sunlight, mean decay rates for infectious virus were less than 2% per minute for all relative humidity levels at 20°C and below. Therefore, lower temperatures will not significantly affect the potential for airborne spread as the virus is highly aerosol stable under all temperature/relative humidity ranges found in the UK. However lower UV levels (consistent with a UK winter) will increase virus survival in outdoor aerosols.

The activity of UV on SARS-CoV-2 on sunlight exposed surfaces has been modelled from laboratory data for different locations in the world.[14] While normal summer equinox UV levels equivalent to that observed in London is estimated to result in a 90% reduction in viral infectivity in 30 minutes on surfaces, the time taken for similar loss in infectivity at the vernal, spring and winter equinox are estimated to be 77, 173, and >300 minutes. Therefore, temperature and UV data suggests that outdoor virus contaminated surfaces in winter are likely to retain their infectivity for far longer than in summer.
Within indoor settings, several studies have explored the potential for airborne transmission of SARS-CoV-2 and other relevant viruses (SARS-CoV-2 and influenza).[15,16] In dry indoor places i.e., less humidity (< 40% RH), the chances of airborne transmission of SARS-CoV-2 are higher than that of humid places (i.e., > 90% RH), and this is hypothesised to be due to a slower rate of virus inactivation and opportunity for increased circulation within stable environments.[17] It is also possible that the lower humidity environment enables greater evaporation of virus carrying respiratory aerosols, leading to a higher proportion of virus remaining airborne. English homes that are single occupancy, older dwellings and within in the north of England are more likely to be heated at temperatures below 18oC, which has been described as a threshold for healthy living.[18] As might seem intuitive, indoor ventilation, such as opening of windows, reduces with the onset of cooler temperatures which may further impact humidity within indoor household settings.[19] The possible changes in time spent outdoors versus indoors is briefly described in a subsequent section.

Overall, environmental conditions consistent with the outdoor winter environment will increase viral persistence on surfaces due to reduced temperatures and UV levels. Some impact may be also be expected in unheated indoor environments due to lower temperatures and in day time outdoor aerosols due to reduced UV levels (high confidence). However, the overall impact of these effects is likely to be small, as very little transmission occurs outdoors. The indoor environment (where the vast majority of transmission occurs)

is held more constant throughout the year. Other factors are likely to be more important, such as the decrease in ventilation rate during the winter and an increased time spent indoors (see below). These indirect effects are likely to play a more significant role in facilitating transmission during the winter than the direct effect of seasonal changes in temperature and UV light (medium confidence).

B: Seasonal changes in contact rates

School closure

The regular patterns of opening and closing schools has a major role in determining the epidemiology of many diseases,[20] including other respiratory infections, such as influenza.[21] At present it is unclear what role children play in the transmission of SARS-CoV-2, with low secondary attack rates observed in educational settings[22]. However, recent data suggests that children might play a larger role in transmission than previously thought – particularly secondary school aged children. For instance, recent population-based swabbing studies[23] suggest that, excluding young adults, the highest rates of swab positivity are being observed in secondary school children. Furthermore, the ONS household infection study suggests that children are more likely to bring infection into the home and are more infectious than adults (though they appear to be less susceptible).[24] It therefore seems likely that the patterns of school terms will influence the transmission of SARS-CoV-2, with opening schools associated with an increase in incidence (low confidence).

Other changes in behaviour

There are few longitudinal social contact surveys prior to and including 2020 and so there is weak evidence on how seasonality affects changes in contact patterns. An unpublished analysis of over 6000 contact diaries completed by FluWatch study participants between 2006 and 2010[25] suggests that contact rates were higher during the autumn/winter than in spring/early summer (adjusted IRR 1.21 (1.11-1.33) $p<0.001$). In addition, Sandmann and Van Leeuwen have recently studied time use data collected in the UK between 2014 and 2015.[26] The authors analysed over 16,500 diary entries from over 9,000 individuals.[27] They found that during winter, slightly more time is spent at home across all ages (compared to spring/summer). More time is also spent in leisure activities compared to the autumn; and particularly in week 52, except by children. Visits to bars, cafes and restaurants (typically indoors) increase in November and December, particularly in older age groups (45+ years), but decrease in January. Time spent on transport is also lower in January and February, but is fairly constant at other times in the year. Wetter weather, colder weather and shorter daylight hours typically lead to greater time spent indoors, as shown in a European study that explored seasonal effects of individual UV exposure, and possible negative effects of indoor transmission and low temperatures may become more important.[28] A recent UK report illustrates that time spent outdoors is lower in October 2020 compared to September 2020.[29] In many buildings ventilation rates are lower during the heating season (Oct-April).

Overall, there is evidence to suggest at-risk contacts increase during the winter (medium confidence) and in the absence of interventions these contacts may be more likely to occur indoors and with settings of multiple households. This may be particularly true during the run up to Christmas (high confidence).

C: Changes in susceptibility

The review provided here suggests small to moderate effects of climatic variables and seasonal changes in contact patterns for SARS-CoV-2. This might initially seem surprising when compared to the large effects of seasonality on viral diseases such as influenza, norovirus and other beta coronaviruses. The main difference between these endemic viruses and SARS-CoV-2 is that a majority of the population remain susceptible to SARS-CoV-2 infection. Susceptibility is the primary driver of SARS-CoV-2 transmission. The relationship between these many factors is illustrated in a modelling analysis by Baker et al. (2020)[30]. A climate-dependent epidemic model is used to simulate the SARS-CoV-2 pandemic by examining different scenarios that include varying the effects of climate parameters. During the early stages of this emerging pathogen, climate drives only modest changes to pandemic sizes and for up to the first five years much of the dynamics are driven by population susceptibility. After this point, or once population susceptibility is reduced by vaccination, climatic variables may then have a stronger effect on transmission. That is, seasonal changes in susceptibly are unlikely to be a major driver of transmission in the short term (high confidence). However, temporal changes in susceptibility (independent of season) are likely to be a major driver of dynamics over the coming months, as susceptibility is reduced via natural infection (particularly in younger age groups) and eventually vaccination (medium confidence). In the longer term, it is likely that seasonal fluctuations in susceptibility, brought about in past seasonal changes in infection, is likely to help magnify seasonal affects due to behavioural change or environmental factors, leading to winter peaks in incidence (low confidence).

Part 2: Factors affecting severity of disease

D. Seasonal physiological changes

Vitamin D deficiency

It has been hypothesised that one possible mechanism behind increased respiratory disease in winter is Vitamin D deficiency associated with reduced exposure to solar radiation. Reduced exposure to solar radiation is likely to occur from spending less time outdoors, for example during the winter months. In a recent UK survey of 'indoor workers' very few report spending time outdoors unless commuting or being outdoors during the weekend.[31] Vitamin D plays a role (among other functions) in optimizing ling function and lung innate immunity.[32] A recent meta-analysis using data from RCTs in high- and low-income settings confirmed a consistent reduction in acute respiratory infections in participants that take Vitamin D supplementation, with greater protection in those with confirmed deficiencies.[33] In a recent (June 2020) rapid review by NICE,[34] there is currently no evidence to support taking Vitamin D to specifically prevent or treat COVID19, due to lack of available evidence. Another consideration is that individuals with co-morbidities, those more likely to self-isolate, and the elderly may have a higher incidence of vitamin D deficiency, potentially increasing the likelihood of adverse risks should they become infected with SARS-CoV-2.[35] According to clinincaltrials.gov there are 52 registered trials that are exploring the impacts of Vitamin D on COVID19, including 4 in the UK. From the above information there is insufficient evidence to assess whether vitamin D deficiency will impact any seasonal effects of COVID19. With results from trial expected to appear soon, the uncertainty in assessments should improve.

Other physiological changes

Low absolute humidity has been associated with increased susceptibility of mice to severe influenza after challenge.[36] The hypothesis is that dry air impairs mucociliary clearance, innate antiviral defence, and tissue repair, contributing to enhanced susceptibility to viral respiratory disease and illness in the winter.[17] It is unclear if seasonal changes in innate immunity and mucosal integrity is a significant factor in reality. At present there is little evidence that physiological changes would significantly affect the average clinical course of COVID-19 during winter months.

E: Co-infection with other seasonal viruses

Stowe et al.[37] assessed the interaction between influenza and SARS-CoV-2 infection by extracting information on patient outcomes from national surveillance data. Over 19,000 individuals were tested for both influenza and SARS-CoV-2 between January and April 2020. In total, 58 individuals had a SARS-CoV-2 and influenza coinfection, 992 had a positive influenza result and were negative for SARS-CoV-2, and 4,443 had a positive SARS-CoV-2 result and were negative for influenza. Seventy percent of patients with a positive test could be linked to a hospital admission. They found that the risk of death was 5.92 times higher in co-infected patients (95% CI, 3.21-10.91) compared with those with neither influenza nor SARS-CoV-2. The odds of ventilator use or death and ICU admission or death was greatest among coinfected patients showing evidence of an interaction effect compared to SARS-CoV-2/influenza acting independently. Drake et al. reviewed the CoCIN data.[38] They did not observe any difference in mortality associated with co-infection in univariate or multivariate analysis. However, they did find that co-infected patients had a much longer average length of stay than COVID-19 patients who tested negative for influenza, and most positive influenza tests were in adults under 70 years old, who are at low risk of death. In mice, sequential infection with influenza and SARS-CoV-2 led to more severe outcomes. [39] It seems likely, therefore, that co-infection with influenza leads to worsened patient outcomes (medium confidence). It is not clear, however, whether significant co-infection is likely to occur. Stowe et al. found that the risk of testing positive for SARS-CoV-2 was 68% lower among influenza positive cases, suggestive of possible competition between the two viruses, and high levels of social distancing would expect to reduce the circulation of influenza and other respiratory viruses (low confidence).

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