Office of the Prime Minister's Chief Science Advisor
Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia

Title:

INTERN REPORT: COVID-19 and seasonality

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Output type:
PDF

Pages:
11 pp

Date:
May-20

Language:
English

Review:
-

Versions

Record number:	*Version:*	*Date V1 created:*	*Date:*	*Printed version*
PMCSA-20-8	V1	18-May-20	18-May-20	N

Archive page link:
https://dpmc.govt.nz/our-programmes/special-programmes/prime-ministers-chief-science-advisor-archives/archive/gerrard-2018-2021

Notes:
Internal report to the PMCSA

COVID-19 and seasonality

14 May 2020 – prepared under urgency

Key messages

Predictions on the seasonality of SARS-CoV-2 transmission are highly presumptive given its lack of prevalence in the population over sufficient time. Ongoing examination of the seasonality of the coronavirus will likely be complicated by the unprecedented response mounted to reduce transmission – a factor absent for established viral infections.

Summary

To date, the infectious SARS-CoV-2 virus has caused more than 4.7 million cases of COVID-19 and resulted in more than 315,000 deaths. Infections have spread in more than 210 countries and territories. Many countries will transition into new seasons in the coming months, bringing about weather conditions different to those at the early stages of the outbreak. Countries in the northern hemisphere (including the US and European countries) are entering the warmer and more humid summer. Meanwhile countries in the southern hemisphere (including New Zealand and Australia) will enter the colder and less humid winter. There is interest in whether this will affect the infection rate of SARS-CoV-2, and therefore the number of COVID-19 cases.

The transmission of some viruses in humans is known to increase during certain seasons. For example, viruses that cause respiratory tract infections (RTIs), including the common cold and the flu, have increased rates of transmission during winter. In New Zealand, the highest number of consultations for influenza or influenza-like illnesses is in July, which is the coldest month of the year. Changes in climate affect the physical stability of viruses, human behaviour patterns, and the ability of the immune system to resist infection. For example, studies have shown that these viruses, particularly influenza, are more stable and are more efficiently transmitted in colder and less humid conditions.

To determine whether SARS-CoV-2 is seasonal, it is useful to examine other respiratory viruses. SARS-CoV-2 is related to the coronaviruses SARS-CoV-1 (80% similarity) and MERS-CoV (50% similarity). Outbreaks of these have spread across Asia and the Middle East respectively. Each of the two SARS-CoV-1 outbreaks in China have occurred in spring, while MERS-CoV is also speculated to be seasonal.

More recently, researchers have developed models to indicate how the infection rates relate to changing seasons. Many models suggest that transmission and infection rates will decrease for countries heading towards warmer more humid seasons and will increase for countries going into colder and less humid seasons. These models have limitations and assumptions that affect their accuracy.

While some studies suggest that SARS-CoV-2 infections might rise in the upcoming winter in Aotearoa New Zealand, it remains too early to make firm conclusions.

Background

A virus is seasonal if the infections it causes are more prevalent during certain times of the year, or if its incidence shows regular sinusoidal peaks and troughs over periods of time.[1,2] Understanding the relationship between infectious diseases and the seasons is important, since it allows healthcare organisations to prepare appropriately to manage expected infections and disease burden.

SARS-CoV-2 is a new human coronavirus that emerged in December 2019. So far, it has infected more than 4.7 million in more than 210 countries and territories around the world. More than 315,000 deaths have ensued. A person infected with the virus is reported as a COVID-19 case. As of 18 May 2020, Aotearoa New Zealand has reported 1498 cases (confirmed and probable) while Australia has reported 7045 confirmed cases.[3,4] Both countries are currently nearing the end of autumn and heading into winter.

Meanwhile, four of the five countries with the highest number of COVID-19 cases are in the northern hemisphere. The US, Russia, UK, and Spain have each reported between 230,000 – 1.5 million cases of COVID-19.[5] These countries are moving out of cooler winter/spring weather into summer.

Will changes in the seasons affect the rate of SARS-CoV-2 infections and therefore the numbers of COVID-19 cases? Media articles have already begun posing the same question.[6–12] Although it remains too early to know whether SARS-CoV-2 is a seasonal virus, there are some indications to suggest that rates of virus transmission will change according to changes in climate over the coming months. This report examines the evidence for and against the seasonality of SARS-CoV-2 being a seasonal virus.

General factors that affect seasonality of viral infections

Viruses responsible for respiratory tract infections (RTIs) are among those known to display seasonality. These include the four human coronaviruses (OC43, HKU1, 229E and NL63) and rhinoviruses that cause the common cold, respiratory syncytial virus (RSV) and the influenza ("flu") virus.

The transmission of these viruses occurs through four mechanisms:

1. direct contact with infected individuals;
2. contact with contaminated objects;
3. inhaling virus-containing aerosols expelled (coughs or sneezes) from an infected person; or
4. airborne transmission of aerosols that are suspended in air for long periods of time.[2,13]

As seasons change, there are three factors that will either increase, or decrease, the chances of these viral transmissions: environmental (climate and meteorological) changes; human behavioural changes; and changes to host resistance against infection.[2] Air quality, measured by levels of particulate matter, may also play a role, as it fluctuates in some regions according to season and impacts health outcomes.

1. Environmental changes that affect virus stability and transmission efficiency

Changes in seasons can change temperature, humidity and sunlight hours. Winter presents colder outdoor temperatures and lower humidity conditions.[2] Humidity is measured as absolute humidity (AH) or relative humidity (RH). AH is the mass of water vapour per volume of air. The maximum amount of water vapour, or maximum AH, that can be held in air varies with temperature. Beyond that point, the excess water vapor condenses (either into cloud, rain or fog). RH is the ratio of the AH to maximum absolute humidity at that temperature, and maximum AH is known as 100% RH. While

RH may remain similar between summer and winter, the absolute humidity is much less in winter, as the maximum amount of water vapour the air is able to hold is much less at colder temperatures.

In Aotearoa New Zealand, the lowest temperature is experienced in the month of July. A database reveals that the average July temperature (between 1981–2010) of 30 regions in NZ drops 3.3–8.2 °C lower than the average yearly temperature of that region.[14]

Respiratory tract infections, particularly those caused by influenza, also peak at this time (this will be further described in the following section). Studies have found that the stability and survivability of respiratory viruses are sensitive to both temperature and humidity.[15] For example, the influenza virus is more stable in the cold. Some reasons for this include the virus having increased half-life at lower temperatures, while at higher temperatures the viral proteins and nucleic acid are inactivated.[16,17] A study found that the influenza transmission rate was highly efficient at 5 °C, and inefficient or even blocked at 30 °C.[18] Influenza is also affected by humidity. Studies reveal that both influenza virus stability and the efficiency of its transmission increase at lower AH.[13] Another study showed that influenza was significantly more stable in aerosols at lower RH conditions (i.e. dry) and was rapidly inactivated at higher RH conditions (i.e. humid) when the temperature was kept constant.[19]

2. Human behavioural changes

Studies have proposed that people spend more of their time indoors during colder weather conditions. In turn, this extends the period of social contact within household groups, increasing opportunity for transmission of respiratory viruses.[20,21] The majority of person-to-person transmissions occurs indoors. A preprint study of transmission within 318 known clusters (three or more COVID-19 cases linked to the same venue) involving 1,245 individuals in China linked cases to transmission within indoor environments.[22] Furthermore, during colder weather, indoor heating is more frequently used, which leads to decreased RH levels – conditions in which influenza aerosols remain airborne for longer periods.[2,18,20] Exposure to these respiratory viruses can be exacerbated by inadequate ventilation systems.[20] It should be noted that there is not yet consensus on whether SARS-CoV-2 is present and infective in aerosols outside of laboratory experiments.

3. Changes to host resistance to infection

Changes in environmental factors can affect a person's defence systems that inhibit viral activity. Colder and drier conditions are known to weaken a person's immunity causing them to be more susceptible to viral infection. For example, it has been suggested that cooling of the body surface leads to vasoconstriction in the nose and upper airways, which inhibits respiratory defence systems towards viral infections.[23] In drier conditions (lower RH), the mucosal layer (made of 93–97% water) that protects the respiratory tract will reduce in thickness. This increases the chance for respiratory viruses to come into contact with epithelial cells.[24] Rhinoviruses were found to replicate better in tissues at 33 °C, a temperature which is akin to the nasal cavity in colder environments.[25] The increased replication of the virus is due to the host's inefficient antiviral response at this temperature.

4. Relationship of air quality with illness outcomes

Another factor observed to contribute to rates of respiratory virus disease is the level of air pollution. In general, patients with cardiovascular and respiratory illnesses have an increased severity of disease and risk of death if they have had long term exposure to airborne particulate matter ($PM_{2.5}$; particles of 2.5 micrometres or less in diameter).[26] One recent study, not yet peer reviewed, found that increased exposure to airborne particulate matter (as little as 1 microgram per cubic metre of $PM_{2.5}$) is associated with an 8% increase in COVID-19 death rates.[27] The study, based on data from more than 3000 counties in the US, correlated long-term $PM_{2.5}$ exposure with deaths as outcomes after COVID-19 cases. Some studies have tried correlate air quality (levels of $PM_{2.5}$) with seasonality. The level of particulate matter is known to fluctuate across time, but seasonal patterns vary in different regions. For example, one study reveals that $PM_{2.5}$ levels are high in the Beijing, Tianjin and Hebei regions in China during autumn and winter, while another study examining 12 cities in Ontario, Canada, reports that $PM_{2.5}$ levels are 30–40% higher in summer compared to winter.[28,29]

Seasonality and behaviour of other respiratory viruses

SARS-CoV-2 is a respiratory virus that causes an RTI commonly referred to as COVID-19. Due to its recent emergence, there are few peer-reviewed publications on the seasonality of COVID-19, with a growing number released as preprints (not yet peer reviewed). Therefore, predicted seasonal transmission of SARS-CoV-2 is inferred from the pattern of transmission observed for other respiratory viruses. As mentioned above, the four human coronaviruses, RSV and rhinovirus, which are responsible for the common cold, are known to display peak infections during winter.[30,31] Similarly, the incidence of influenza infections also peaks in winter.[32] Studies in Aotearoa New Zealand have revealed that medical consultation for influenza and influenza like illnesses typically peaks between the 27th and 34th week of each year, which are the months of July and August.

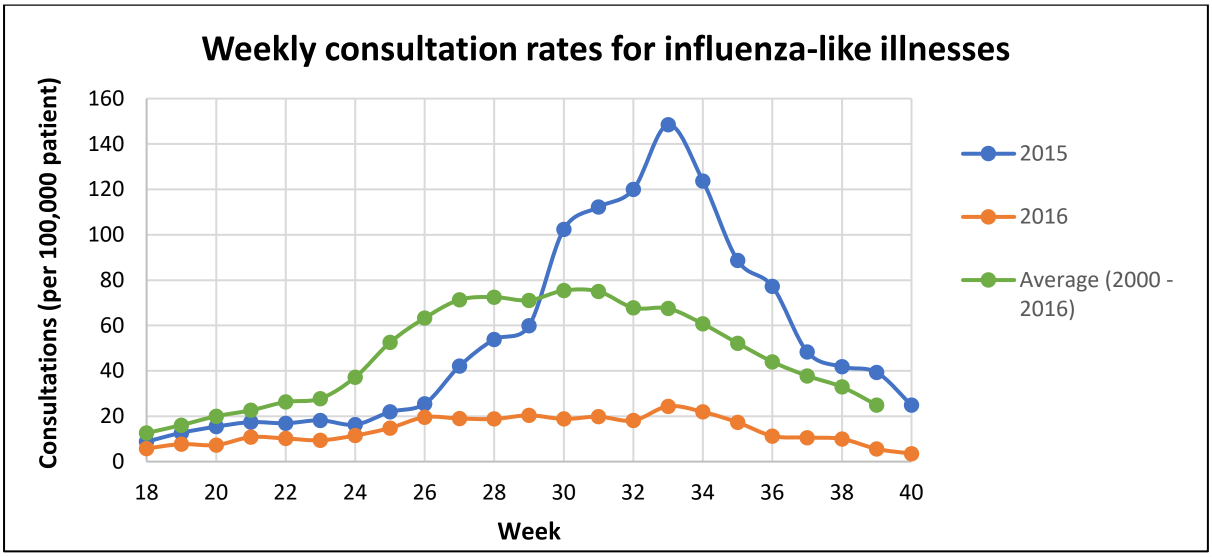

Figure 1: Weekly consultation rates for influenza-like illness in New Zealand during 2015 and 2016, and average rates between 2000–2016.[33]

Studies on the other two human coronaviruses, MERS-CoV and SARS-CoV-1 can also provide further clues on the seasonality of SARS-CoV-2. The genome of SARS-CoV-2 is most like SARS-CoV-1, with 79% sequence identity. It is moderately alike that of MERS-CoV, with 50% similarity.[34]

Unlike other respiratory viruses, the seasonal behaviour of these two coronaviruses are still poorly understood, in part due to the short duration of their outbreaks.

The earliest case of SARS-CoV-1 infection was reported in November 2002 in Guangdong Province, China. This outbreak had lasted until its containment on 5 July 2003, with the last confirmed case reported on 15 June 2003.[35,36] Over this period, 8,096 infections were recorded in China (5,327), Hong Kong (1,755), Taiwan (346), Canada (251) and Singapore (238). These five countries constituted 97.8% (7,917) of the total cases.[37] In between December 2003 and January 2004 there were three more sporadic cases of SARS-CoV-1 infections in China. Subsequent studies have indicated that this coronavirus is more infectious during periods of lower temperatures and lower RH. Lin *et al*. found that the incidence of SARS-CoV-1 infections in Hong Kong was 18-fold higher on days with lower air temperature compared to days with higher air temperature.[38] The authors also found that an increase of 1 °C in air temperature was associated with an average reduction of 3.6 cases. Chan *et al*., who studied the viability of SARS-CoV-1 at different temperatures and at different RH, found that high temperature and high RH can, synergistically, reduce stability of SARS-CoV-1.[39] Furthermore, the authors found that the viability of the virus had significantly reduced by more than threefold after incubation at 38 °C with 95% RH compared to viability of the virus observed after incubation at room temperature with 40–50% RH.

A further study reported that MERS-CoV infections in Saudi Arabia were correlated with the temperature, humidity and ground visibility on the days that preceded the reporting of cases.[40] Compared to controls, the incidence of cases nine days after high mean temperatures (0.77 times) were found to be lower than cases occurring after low minimum temperatures (1.29 times). The incidence of cases 8–9 days after maximum humidity were lower (0.68 times) compared to cases occurring after low maximum humidity (1.35 times). Cases arising seven days after low minimum visibility were lower (0.79 times) compared to that of high minimum visibility (1.27 times).

Another study found that MERS-CoV was more stable at 20 °C and 40% RH, compared to 30 °C and 30% RH or 30 °C and 80% RH.[41] There are, however, some contradictory data about these conditions and the activity of MERS-CoV. One report revealed that out of 1680 cases of MERS-CoV infections in Saudi Arabia between 2012 and 2017, the three consecutive months that produced the highest total cases were in the summer months of April (234), May (275) and June (287).[42] Whereas, the three consecutive months that produced the lowest total cases were in the winter months of November (53), December (69) and January (36). In agreement with this, another report showed increased incidence of infections between April and August, citing high temperature, low RH, high ultraviolet index and low wind speed as contributors.[43] The latter two reports suggest that the viral outbreaks are more favourable during the summer period.

Research on SARS-CoV-2 and COVID-19 cases to suggest seasonality

SARS-CoV-2 has spread rapidly in many countries, but the numbers of cases per capita vary dramatically around the world. Some ecological studies have attempted to correlate the size of outbreaks with climate and weather data. These models suggest that cooler and temperate climates may favour the spread of SARS-CoV-2 compared to warmer and tropical climates.[44–47] Some of these studies, which have yet to be peer reviewed, have been criticised as premature, as they may fail to consider differing containment measures and other confounding factors. Even where a link is found between temperature, humidity and disease transmission, this only accounts for a small part in differing rates of transmission.[45]

In another recent analysis, not yet peer reviewed, suggests that SARS-CoV-2 transmission is strongly associated with temperature *only* in the early stages of the outbreak.[48] Looking across outbreaks in 15 different countries, cases appear to reach a critical point where temperature is no longer a factor.

In a rapid review, produced by the National Academies of Sciences, Engineering and Medicine, the authors describe research on the survivability of SARS-CoV-2 under various laboratory conditions.[49] They conclude that while these studies might show a reduced survival rate for SARS-CoV-2 in higher temperature and humidity, there is a plethora of different factors that “influence and determine transmission in the ‘real world’.”

Challenges in understanding the seasonality of SARS-CoV-2

Dr Maria Van Kerkhove, head of the World Health Organization (WHO) emerging diseases and zoonoses unit, has stated that "to look at seasonality, you need to look at patterns over time".[50] The outbreak of COVID-19 has not yet completed a full year, and so it is too early to make firm conclusions.

The above-mentioned models that have predicted the seasonality of SARS-CoV-2 have limitations. This is partially due to variations in testing rates between different regions, likely leading to underreporting of true case numbers. Further, 83% of testing was conducted in non-tropical areas, and 90% of cases were recorded in countries with temperature range between 3–17 °C.[51] Also, 72% of the measurements are done in countries with absolute humidity between 3–9 g m^{-3}, and 90% of the cases have arisen from regions with the same humidity range.

Conclusion

Given the recent emergence of the SARS-CoV-2 virus, it is too soon for conclusive evidence that directly demonstrates seasonality. Ecological models investigating correlation between COVID-19 case numbers and climatic factors are limited in the insight they can provide and are confounded by the extreme interventions staged by governments to break the chain of transmission.

Despite a lack of direct evidence, the behaviour of other respiratory viruses suggests that the cool temperature and lack of humidity in winter may favour SARS-CoV-2 transmission. Other respiratory viruses, such as influenza, are well-known for their seasonality, and there is some evidence that the related coronaviruses SARS-CoV-1 and MERS-CoV may fluctuate based on climatic factors.

However, as noted in another rapid review, even if seasonal effects are present, other public health measures are far more impactful on disease transmission: "Physical distancing supported by effective public policy measures will have a greater impact on managing the spread of SARS-CoV-2 than seasonal climate."[52]

Finally, this report ends with the cautious remarks made by some of the world's health and disease experts on the seasonality of COVID-19.

Professor Marc Lipsitch, director of the Centre for Communicable Disease Dynamics at Harvard T.H. Chan School of Public Health, stated that:

> "… *we may expect modest declines in the contagiousness of SARS-CoV-2 in warmer, wetter weather and perhaps with the closing of schools in temperate regions of the northern hemisphere, it is not reasonable to expect these declines alone to slow transmission down enough to make a big dent*".[53]

Dr Anthony Fauci, director of the U.S. National Institute of Allergy and Infectious Diseases in Bethesda, stated that:

> "*One should not assume that we are going to be rescued by a change in the weather. You must assume that the virus will continue to do its thing*".[11]

Dr Michael Ryan, executive director of WHO Health Emergencies Programme, stated that:

> "*We do not know yet what the activity or the behaviour of this virus will be in different climatic conditions. We have to assume that the virus will continue to have the capacity to spread*" and that "*It is a false hope to say yes it will just disappear in summertime, like influenza virus. There is no evidence right now to suggest that that will happen*".[54]

Acknowledgements

We thank Stephen Lo, an intern supported by the MacDiarmid Institute, who prepared this paper. We also thank Dr John A. Taylor from the University of Auckland and Dr Felicia Low from Koi Tū: The Centre for Informed Futures for reviewing this summary.

Further reading

- Seasonality of COVID-19: Impact on the spread and severity, Rapid Research Information Forum
- Rapid expert consultation on SARS-CoV-2 survival in relation to temperature and humidity and potential for seasonality for the COVID-19 pandemic, National Academies of Science, Engineering and Medicine
- COVID-19 and the weather, Koi Tū: The Centre for Informed Futures

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