EVIDENCE SYNTHESIS BRIEFING NOTE

TOPIC: **INDOOR VERSUS OUTDOOR TRANSMISSION OF COVID-19**

Information finalized as of March 26, 2021.[a] This Briefing Note was completed by the Research, Analysis, and Evaluation Branch (Ministry of Health) in collaboration with members of the COVID-19 Evidence Synthesis Network. Please refer to the Methods section for further information.

Purpose: This document summarizes the scientific evidence on the risks of COVID-19 transmission in indoor and outdoor settings, and at large outdoor events (e.g., festivals, protests).

Key Findings:

- **Indoor vs. Outdoor COVID-19 Transmission**: Research evidence suggests the risk of SARS-CoV-2 transmission is lower in outdoor settings. A 2021 systematic review reported a low proportion of reported global SARS-CoV-2 infections occurring outdoors (<10%) and higher odds of indoor transmission (18.7 times) compared to outdoor transmission.
- **Factors Associated with Outdoor Transmission**: Factors associated with transmission include duration and frequency of personal contact, lack of personal protective equipment, and occasional indoor gathering during a largely outdoor experience. However, there are significant research gaps in the understanding of specific pathways including factors such as the weather.
  - Weather probably influences COVID-19 transmission, but not at a scale sufficient to outweigh the effects of lockdowns or re-openings in populations. Researchers suggest that no human-settled area is protected from COVID-19 transmission by virtue of weather, at any point in the year. Numerous studies investigated aspects of weather (i.e., pollution, wind speed, temperature), reporting that most infections occur indoors: A modelling study on the risks of contamination in a variety of meteorological settings reported that, even in crowded areas, the outdoor risk is much less than indoor. Monitoring meteorological forecasts and pollution, which also impacts COVID-19 transmission could be a way to alert the population of risky days and to reinforce mitigation measures for short periods of time.
- **Transmission at Large Gatherings or Events**: Due to a lack of surveillance and tracing systems, and confounding factors and variables, there has been no evidence of robustly tested transmission at outdoor mass gatherings (10,000+ people). An evidence synthesis document (March 2020) found that the impact of restricting and cancelling mass gatherings and sporting events on infectious diseases is poorly established and requires further assessment. However, mass gatherings are not homogenous, and risk should be assessed on a case-by-case basis. Research on motorcycle rallies, political rallies, religious gatherings, professional sporting events, amateur outdoor sports, and indoor concerts suggest that large gatherings have been linked to increased case numbers. For example, a mass 10-day motorcycle rally in the US contributed to substantial local and national community spread. Research on pedestrian traffic reported that street cafés present the largest average rate of new infections, followed by busy outdoor markets, and then metro and train stations. In comparison, the risk associated with walking on fairly busy streets (average density around 0.1 person/m²) is comparatively quite low.

Analysis for Ontario: Indoor transmission remains likely everywhere the virus is spreading, and outdoor transmission is still possible if other precautions (social distancing, mask use, etc.) are not taken.

[a] This briefing note includes current available evidence as of the noted date. It is not intended to be an exhaustive analysis, and other relevant findings may have been reported since completion.

Supporting Evidence

Table 1 below summarizes the scientific evidence on the relative risk of COVID-19 transmission in indoor versus outdoor settings, and factors associated with transmission (i.e., weather). It also includes information about transmission due to large indoor and outdoor events including political rallies, concerts, and religious events. There is additional information in the Appendix in Table 2 (The relative risk of COVID-19 transmission in indoor versus outdoor settings), and Table 3 (Risk of Transmission at large indoor and outdoor events).

Table 1: Evidence on the Risk of COVID-19 Transmission in Indoor and Outdoor Settings

Scientific Evidence	• **Relative Risk of Transmission in Indoor versus Outdoor Settings**: Existing evidence supports the widely-held belief that risk of SARS-CoV-2 transmission is lower in outdoor settings.[1] A 2021 systematic review identified five studies that identified a low proportion of reported global SARS-CoV-2 infections occurring outdoors (<10%), and the odds of indoor transmission was very high compared to outdoor transmission (18.7 times; 95% confidence interval, 6.0–57.9).[2] • **Factors Associated with Outdoor Transmission**: In general, outdoor reports of infection were associated with factors such as duration and frequency of personal contact, lack of personal protective equipment, and occasional indoor gathering during a largely outdoor experience.[3] However, there are significant research gaps in the understanding of specific pathways including such factors as: ○ The Role of Weather: A US commentary advised that weather probably influences COVID-19 transmission, but not at a scale enough to outweigh the effects of lockdowns or re-openings in populations. Policymakers should be aware that no human-settled area in the world is protected from COVID-19 transmission by virtue of weather, at any point in the year. Indoor transmission remains likely everywhere the virus is spreading, and outdoor transmission is still possible if other precautions (social distancing, mask use, etc.) are not taken.[4] ○ While a rapid review suggests that weather can play a role in encouraging indoor or outdoor activity (i.e., temperatures that encourage outdoor activity being associated with lower COVID-19 transmission),[5] two studies investigated aspects of weather finding that most infections occur indoors.[6,7] For example, a study found that, even in crowded areas, the outdoor risk is much lower than indoor. However, in geographical areas prone to pollution – including large urban areas with collective housing and towers – monitoring this pollution, together with meteorological forecast, could be a way to alert the population of risky days and to reinforce mitigation measures for short period of time.[8] Other factors examined include: ▪ Windspeed: Outdoor transmission that may occur in the summer would be highest on days when wind is reduced.[9] ▪ Temperature/Ultraviolet Exposure: Warmer temperatures and moderate outdoor ultraviolet exposure may offer modest reductions in transmission; however, changes in weather alone will not be enough to fully contain the transmission of COVID-19.[10] ▪ Pollution/Particulate Matter (PM): Two studies discuss the role of air pollution or PM in outdoor transmission.[11,12] High levels of urban air pollution, weather and specific climate conditions have a significant impact on the increased rates of confirmed COVID-19 total number, daily new and total deaths cases, possibly attributed to indoor and to outdoor airborne bioaerosols distribution.[13]

- **Large Gatherings or Events**: A 2020 (September) rapid review found that due to lack of surveillance and tracing systems, and confounding factors and variables, there was no evidence of robustly tested transmission at outdoor mass gatherings (10,000+ people).[14] An evidence synthesis (March 2020) found that the effect of restricting and cancelling mass gatherings and sporting events on infectious diseases is poorly established and requires further assessment. The best-available evidence suggests multiple-day events with crowded communal accommodations are most associated with increased risk; however, mass gatherings are not homogenous, and risk should be assessed on a case-by-case basis.[15] Other findings from the literature discuss specific settings including:
  - Mass Motorcycle Rally: A study examined the impact of a mass 10-day motorcycle rally in South Dakota, finding that it had contributed to substantial community spread both locally and nationally. Estimates indicate that the cumulative COVID-19 caseload in at the state-level increased by between 3.6 and 3.9 cases per 1,000 population, or a total of about 3,088 cases as of September 2, 2020. This represents an increase of over 35% relative to the 9.7 cases per 1,000 population in South Dakota on July 31, 2020.[16]
  - Religious Gatherings: More than 35% of the COVID-19 cases in Malaysia (April 13, 2020) were directly linked to a mass gathering of 19,000 participants that took place on February/March 2020, which also caused a regional spike of COVID-19 cases across Southeast Asia (10% participants were from outside Malaysia).[17] When countries suspended religious mass gatherings early (e.g., Hajj), there were lower occurrences of COVID-19 transmission.[18]
  - Professional Sporting Events: Mass gatherings at NBA or NHL games impact community spread of COVID-19; as of April 30, 2020, one additional game increased the cumulative number of COVID-19 deaths in affected US counties by 11 percent.[19] Mass gatherings at English football matches were consistent with increased cases and deaths during April 2020.[20]
  - Political Rallies: Three studies report findings related to political rallies held in US cities. A study that examined multiple events found increased subsequent confirmed cases of COVID-19 by more than 250 per 100,000 residents, which ultimately resulted in more than 30,000 incremental confirmed cases of COVID-19. The rallies likely led to more than 700 deaths (not necessarily among attendees) based on county-level post-event death rates.[21] Another study that analyzed the outcomes of 19 outdoor rallies and one indoor rally concluded that even outdoor gatherings in areas with low COVID-19 incidence are followed by increased infections.[22] A study that analyzed one political rally found little evidence that COVID-19 case growth grew more rapidly at the county- or state-level (Oklahoma) in the three weeks following the campaign rally.[23]
  - Outdoor Amateur Sports: US-based youth soccer clubs in the US found the incidence of COVID-19 among youth soccer athletes is relatively low when compared to the incidence among children in the US in summer of 2020. No relationship was identified between club COVID-19 incidence and phase of return of soccer (i.e., contact or non-contact play).[24]
  - Indoor Concerts: Densely populated venues, such as eight live indoor concerts of 50-100 people that took place in Osaka, Japan in February 2020, can 'seed' infections that can spread to other, distant areas.[25] However, a German study reported that the expected additional effect of indoor mass gatherings on the burden of disease[b] is low if hygiene concepts are applied and adequate ventilation exists.[26]

[b] The sum of mortality and morbidity is referred to as the 'burden of disease' and can be measured by a metric called 'Disability Adjusted Life Years' (DALYs) DALYs are measuring lost health and are a standardized metric that allow for direct comparisons of disease burdens of different diseases across countries, between different populations, and over time. Conceptually, one DALY

	○ Pedestrian Traffic: While the risk of infection while walking on busy streets (average density around 0.1 person/m²) is low, street cafés present the largest average rate of new infections caused by the proximity of those waiting in line, followed by busy outdoor markets, and then metro and train stations. While the benefits of enforcing one-way goo traffic in (wide) walkways are unclear, changing the spacing between people in queues substantially affects disease transmission risks.[27]

is the equivalent of losing one year in good health because of either premature death *or* disease or disability. One DALY represents one lost year of healthy life (Roser & Ritchie, 2016).

Methods

Individual peer-reviewed articles and review articles were identified through PubMed, and Google Scholar. The search was limited to English sources and therefore may not capture the full extent of initiatives in non-English speaking countries. Full-text results extracted were limited to those available through Open Access or studies made available to the Ministry by our partners.

The COVID-19 Evidence Synthesis Network is comprised of groups specializing in evidence synthesis and knowledge translation. The group has committed to provide their expertise to provide high-quality, relevant, and timely synthesized research evidence about COVID-19 to inform decision makers as the pandemic continues. The following members of the Network provided evidence synthesis products that were used to develop this Evidence Synthesis Briefing Note:

- Evidence Synthesis Unit, Research Analysis and Evaluation Branch, Ministry of Health. March 30, 2021.

For more information, please contact the Research, Analysis and Evaluation Branch (Ministry of Health).

APPENDIX

Table 2: Relative Risk of COVID-19 Transmission in Indoor Versus Outdoor Settings

Type of Study	Setting/ Jurisdiction	Summary of Single Studies and Reviews	Reference
• Systematic review	• Outdoor, International	• Purpose: A systematic review of peer-reviewed papers, up to August 12, 2020, on transmission of COVID-19 in outdoor settings. • Results: Five identified studies found a low proportion of reported global SARS-CoV-2 infections occurred outdoors (<10%) and the odds of indoor transmission were very high compared to outdoors (18.7 times; 95% confidence interval, 6.0–57.9). Five studies described influenza transmission outdoors and two adenovirus transmission outdoors. There was high heterogeneity in study quality and individual definitions of outdoor settings, which limited the ability to draw conclusions about outdoor transmission risks. In general, factors such as duration and frequency of personal contact, lack of personal protective equipment, and occasional indoor gathering during a largely outdoor experience were associated with outdoor reports of infection. • Implications: Existing evidence supports the wide-held belief that risk of SARS-CoV-2 transmission is lower outdoors but there are significant gaps in our understanding of specific pathways.	Bulfone, T. C., Malekinejad, M., Rutherford, G. W., & Razani, N. (2021). Outdoor Transmission of SARS-CoV-2 and Other Respiratory Viruses: A Systematic Review. *The Journal of Infectious Diseases*, *223* (4), 550-561.
• Rapid Review (preprint)	• Outdoor, International	• Purpose: This rapid review identified 14 sources of evidence of outdoor transmission of COVID-19, and a further 21 sources for context and to understand the caveats that should be considered in interpreting the review findings. • Results: The review found very few examples of outdoor transmission of COVID-19 in everyday life among approximately 25,000 cases considered, suggesting a very low risk. However, risk of outdoor transmission increases when: 1) the natural social distancing of everyday life is breached; 2) there is increased population density; and 3) crowd circulation and crowd size increase, particularly for an extended duration. ○ *Weather*: There was also evidence that weather had a behavioural effect on transmission, with temperatures that encourage outdoor activity being associated with lower COVID-19 transmission. ○ *Mass Gatherings*: The review found that, due to the absence of surveillance systems and rigorous testing, there was no evidence that robustly tested transmission at outdoor mass gatherings (10,000+ people).	Weed, M., & Foad, A. (September 2020). Rapid scoping review of evidence of outdoor transmission of covid-19. *medRxiv*.

Type of Study	Setting/ Jurisdiction	Summary of Single Studies and Reviews	Reference
• Literature review	• Indoor and outdoor, International	• Purpose: This review summarizes current knowledge on the transmission pathways of the novel coronavirus and directs attention towards potentially underestimated factors that affect its propagation, notably indoor spread and outdoor risk sources. • Findings: The contributions of significant indoor factors such as ventilation systems to the spread of this virus need to be carefully ascertained. Outdoor risk sources such as aerosolized particles emitted during wastewater treatment and particulate matter, both of which may act as virus carriers, should be examined as well. ○ *Indoor Transmission*: Many studies have demonstrated that the spread and transmissibility of SARS-CoV-2 are much greater in indoor environments, especially in hospitals, laboratories, and schools, due to the presence of or proximity to viral sources as well as the increased possibility of direct contact with infected people or items. To reduce the risk of infection in indoor environments, any HVAC system without an efficient air filtration apparatus should be upgraded. Efficient management (e.g., periodically cleaning and sanitation) of the ventilation/ filtration system should be done regularly to stop pathogens from persisting on the surface of the filter. Increasing natural ventilation, not lingering directly under the air flow, and minimizing spaces that are shared by people could help to minimize the spread of the virus in indoor environments. ○ *Outdoor Transmission*: Outdoor environments may lead to a higher risk of infection than indoor environments due to a lack of knowledge regarding the importance of outdoor environments as potential pathways for SARS-CoV-2 infection, the presence of large numbers of people in such environments, and the high likelihood of contact with contaminated elements or items. Potential risk factors include wastewater, which may have an underestimated high potential for SARS-CoV-2 transmission; however, the viability of SARS-CoV-2 in wastewater has not been proven. • Implications: This study shows the influence of certain underestimated factors on the environmental behaviour and survival of the SARS-CoV-2 virus. These aspects of coronavirus propagation need to be accounted for when devising actions to limit not only the current pandemic but also future outbreaks.	Senatore, V., Zarra, T., Buonerba, A., Choo, K. H., Hasan, S. W., Korshin, G., ... & Naddeo, V. (2021). Indoor versus outdoor transmission of SARS-COV-2: Environmental factors in virus spread and underestimated sources of risk. *Euro-Mediterranean Journal for Environmental Integration*, *6* (1), 1-9.
• Preprint - Quantitative model of the physical processes of transmission	• Indoor versus outdoor, France	• Purpose: This study developed a simple model of the inhaled flow of rate of aerosol particles of respiratory origin; i.e., that have been exhaled by other humans, which allows for a simple assessment of the outdoor versus indoor risk of contamination in a variety of meteorological settings. • Outcome: For most cases, the outdoor risk is orders of magnitude less than the indoor risk and that it can become comparable only for extremely specific meteorological and geographical situations. It sheds a light on various observations of COVID-19 spreading in mountain valleys with temperature inversions while at the same time other areas are much less impacted. • Implications: Even in crowded areas, the outdoor risk is much less than indoor. However, in geographical areas prone to pollution – which include large urban areas with collective housing	Rowe, B. R., Canosa, A., Drouffe, J. M., & Mitchell, J. B. (2021). Simple quantitative assessment of the outdoor versus indoor airborne transmission of viruses and covid-19. *medRxiv*, 2020-12.

Type of Study	Setting/ Jurisdiction	Summary of Single Studies and Reviews	Reference
		and towers – monitoring this pollution, together with meteorological forecast, could be a way to alert the population of risky days and to reinforce mitigation measures for short period of time.	
• Preprint - Modelling study using COVID-19 case reports between March 16 to December 31, 2020, and average windspeed and maximal daily temperatures adjusting for population size	• Outdoor, United States (US)	• Purpose: This study hypothesized that slower outdoor windspeed is associated with increased risk of transmission when individuals socialize outside. • Outcome: Cases were very high in the initial wave but diminished quickly once lockdown procedures were enacted. Unadjusted and multivariable-adjusted analyses revealed that warmer days with windspeed <5.5 miles per hour (MPH) had increased COVID-19 incidence (multivariable-adjusted incidence rate ratio [aIRR]=1.50, 95% C.I.=[1.25-1.81], p<0.001) as compared with average windspeed ≥ 5.5 MPH. • Implications: The risk of transmission of COVID-19 in the summer was highest on days when the wind was reduced, suggesting that airborne transmission in shared outdoor spaces is feasible when wind is insufficient to disperse viral particles.	Clouston, S., Morozova, O., & Meliker, J. (2021). Outdoor transmission of COVID-19: Analysis of windspeed. *medRxiv*.
• Data analysis – reported COVID-19 daily case counts, and meteorological factors (temperature, relative humidity, and wind speed)	• Indoor and Outdoor, Saudi Arabia	• Purpose: The current study investigates the impact of outdoor and indoor meteorological conditions on the daily recorded COVID-19 cases in western region (Makkah and Madinah cities) of Saudi Arabia over a period of eight months from March to October 2020. • Results: The results showed that the highest daily COVID-19 cases in Makkah and Madinah were reported during the hottest months of the year (April–July 2020) when outdoor temperature ranged from 26.51 to 40.71 °C in Makkah and of 23.89–41.20 °C in Madinah, respectively. Partial negative correlation was detected between outdoor relative humidity and daily recorded COVID-19 cases. No obvious correlation could be demonstrated between wind speed and daily COVID-19 cases. ○ Almost all COVID-19 cases result from indoor infection among households. • Implications: This indicated that most of SARS-CoV-2 infection occurred in the cool, air-conditioned, dry, and bad-ventilated indoor environment in the investigated cities. These results will help the epidemiologists to understand the correlation between both outdoor and indoor meteorological conditions and SARS-CoV-2 transmissibility. These findings would be also a useful supplement to assist the local healthcare policymakers to implement and apply a specific preventive measures and education programs for controlling of COVID-19 transmission.	Habeebullah, T. M., Abd El-Rahim, I. H., & Morsy, E. A. (2021). Impact of Outdoor and Indoor Meteorological Conditions on the COVID-19 transmission in the Western Region of Saudi Arabia. *Journal of Environmental Management*, 112392.
• Preprint - Modelling study	• Outdoor, US/ International	• Purpose: To study the relative risk of COVID-19 due to weather and ambient air pollution. • Method: Estimated the daily reproduction number at 3,739 global locations, controlling for the delay between infection and detection, associating those with local weather conditions and ambient air pollution. • Results: The findings suggest there was a negative relationship between the estimated reproduction number and temperatures above 25°C, and a U-shaped relationship with outdoor ultraviolet exposure, and weaker positive associations with air pressure, wind speed, precipitation, diurnal temperature, sulfur dioxide (SO_2) and ozone.	Xu, R., Rahmandad, H., Gupta, M., DiGennaro, C., Ghaffarzadegan, N., Amini, H., & Jalali, M. S. (May 2020). The modest impact of weather and air pollution on COVID-19 transmission. *medRXiv*.

Type of Study	Setting/ Jurisdiction	Summary of Single Studies and Reviews	Reference
		• Implications: The projections in 1,072 global cities suggest warmer temperature and moderate outdoor ultraviolet exposure may offer a modest reduction in transmission; however, upcoming changes in weather alone will not be enough to fully contain the transmission of COVID-19.	
• Data analysis	• Outdoor, Italy	• Purpose: This study investigates the correlation between the degree of accelerated diffusion and lethality of COVID-19 and the surface air pollution in the Milan metropolitan area, Lombardy region, Italy. • Method: Daily average concentrations of inhalable particulate matter (PM) in two size fractions PM2.5, PM10 and maxima PM10 ground level atmospheric pollutants together with air quality and climate variables (daily average temperature, relative humidity, wind speed, atmospheric pressure field and Planetary Boundary Layer-PBL height) collected between January 1and April 30, 2020 were analyzed. • Results: It seems that high levels of urban air pollution, weather and specific climate conditions have a significant impact on the increased rates of confirmed COVID-19 total number, daily new and total deaths cases, possibly attributed not only to indoor but also to outdoor airborne bioaerosols distribution. The analysis demonstrates the strong influence of daily averaged ground levels of PM concentrations, positively associated with average surface air temperature and inversely related to air relative humidity on COVID-19 cases outbreak in Milan. • Implications: COVID-19 might be ongoing during summer conditions associated with higher temperatures and low humidity levels. Presently it is not clear if this protein “spike” of the new coronavirus COVID-19 is involved through attachment mechanisms on indoor or outdoor airborne aerosols in the infectious agent transmission from a reservoir to a susceptible host in some agglomerated urban areas such as Milan.	Zoran, M. A., Savastru, R. S., Savastru, D. M., & Tautan, M. N. (October 2020). Assessing the relationship between surface levels of PM2. 5 and PM10 particulate matter impact on COVID-19 in Milan, Italy. *Science of the Total Environment*, *738*, 139825.
• Commentary	• Outdoor, US	• This commentary notes that weather probably influences COVID-19 transmission, but not at a scale sufficient to outweigh the effects of lockdowns or re-openings in populations. Policymakers should be aware of a few key points: ○ No human-settled area in the world is protected from COVID-19 transmission by virtue of weather, at any point in the year. Indoor transmission remains likely everywhere the virus is spreading, and outdoor transmission is still possible if other precautions (social distancing, mask use, etc.) are not taken. ○ Many scientists expect COVID-19 to become seasonal in the long term, conditional on a significant level of immunity, but that condition may be unmet in some regions, depending on the success of outbreak containment. In the future, seasonality could lead to worse outcomes in the winter, but in the near term, weather is unlikely to prevent SARS-CoV-2 epidemics in the summer. Policymakers should be careful about forecasts that predict lower or no transmission in hot, dry weather. ○ All pharmaceutical and non-pharmaceutical interventions are currently believed to have a stronger impact on transmission over space and time than any environmental driver. Evidence	Carlson, C. J., Gomez, A. C., Bansal, S., & Ryan, S. J. (August 2020). Misconceptions about weather and seasonality must not misguide COVID-19 response. *Nature Communications*, *11* (1), 1-4.

Type of Study	Setting/ Jurisdiction	Summary of Single Studies and Reviews	Reference
		to the contrary is currently too incomplete and disparate to change any of those interventions based on weather. ○ With current scientific data, COVID-19 interventions cannot currently be planned around seasonality. Outbreaks could easily defy expectations built on just a few months of population-level data. For example, decreased spread in the spring might lead some scientists to expect that heat directly reduces transmission, when in reality, the transmission could peak when people will aggregate indoors to escape both hot summer weather and cold winter weather. Relying on this kind of guesswork will inevitably leave policymakers unprepared. ○ When faced with uncertainty, rather than act based on any given scientific study, policymakers can turn to documents like the National Academies Studies on COVID-19, including their specific guidance on seasonality that synthesize and interrogate existing evidence.	
• Modelling	• Outdoor, Capital cities in China	• Purpose: The study examines whether immediate exposure to outdoor PM2.5 (P) will modify the rate of change in the daily number of COVID-19 infections (R) for: (1) the high infection provincial capital cities in China; and (2) Wuhan, China. • Method: Analysis of data (P and R) from January 1 to March 20, 2020. The causal relationship between P and R, and the interaction effect between key variables were investigated. • Results: A causal relationship between P and R across the high infection provincial capital cities in China was established via matching. A higher P resulted in a higher R in China. • Implications: This study sheds new light on the effect of P in an outdoor environment, the interaction effect between P and absolute humidity (AH), and the effect of NM (lockdown), on R (the dependent variable). These findings add to the recent discussions/observations that COVID-19 droplets are airborne, can suspend in the air and combine with the particulates, promoting infection via the airborne transmission pathway.	Han, Y., Lam, J. C., Li, V. O., Crowcroft, J., Fu, J., Downey, J., & Gozes, I. (March 2021). Outdoor PM2. 5 Concentration and Rate of Change in COVID-19 Infection in Provincial Capital Cities in China. *medRxiv*, 2020-05.

Table 3: Evidence of the Transmission of COVID-19 at Large Outdoor or Indoor Events

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
• Evidence synthesis	• Evidence review	• Mass gatherings, international	• Various	• Results: The effect of restricting and cancelling mass gatherings and sporting events on infectious diseases is poorly established and requires further assessment. The best-available evidence suggests multiple-day events with crowded communal accommodations are most associated with increased risk. Mass gatherings are not homogenous, and risk should be assessed on a case-by-case basis.	• Nunan, D., & Brassey, J. (March 2020). What is the evidence for mass gatherings during global pandemics? *Centre for Evidence-Based Medicine, Oxford.*
• Data and statistical analyses; difference-in-differences model	• Anonymized cellphone data, foot traffic data to track resident and non-resident behaviours • County-level COVID-19 case data before and after the event	• A 10-day (August 7-16, 2020) motorcycle rally with concerts, live performances, races and bike shows with over 460,000 participants in Sturgis, South Dakota (SD), United States (US) (population of 7,000; 26,000 in the county)	• Guidelines provided by the City of Sturgis for food service, recommended social distancing and masks but media reports suggest these practices were rare	• Overall: This study documents that the Sturgis Rally contributed to substantial community spread both locally and nationally. Locally, we find a significant increase in cases in the county that hosted the event, in the broader cluster that encompasses adjoining counties, and statewide, with larger effects detected with the time lag from the inception of the event. Estimates indicate that the cumulative COVID-19 caseload in South Dakota increased by between 3.6 and 3.9 cases per 1,000 population, or a total of about 3,088 cases as of September 2, 2020. This represents an increase of over 35% relative to the 9.7 cases per 1,000 population in South Dakota on July 31, 2020. Other findings include: ○ *Decline in Stay-at-Home Behaviours*: Foot traffic at restaurants and bars, hotels, entertainment and retail venues increased to 90% during the event and stay-at-home behaviour declined among residents (9.4 to 10.9% in median hours spent at home). ○ *Increased Cases*: Counties outside the state of SD that contributed the highest inflows of Sturgis attendees saw COVID-19 cases rise by 6.4 to 12.5% following the Sturgis event relative to counties without any detected attendees.	• Dave, D., McNichols, D., & Sabia, J. J. (2021). The contagion externality of a superspreading event: The Sturgis Motorcycle Rally and COVID-19. *Southern economic journal*, *87*(3), 769-807.

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
				○ *Increased Health Costs*: The Sturgis Rally generated public health costs, which may range from CAD $4.6 and $10.4 billion.[c]	
• Preprint-modelling study to infer the global number of infections from pedestrian trajectories and orientations	• Field data on crowds and models for disease transmission via respiratory droplets (which overlook air flows)	• Pedestrian traffic in various scenarios: street cafés, outdoor markets, metro and train stations, walking on busy streets	• Without masks	• Purpose: Crowds of unrelated people in outdoor settings might be a blind spot of COVID-19 outbreak statistics, because infections in these settings are inherently hard to trace. The models allow authors to: 1) rank daily-life situations involving crowds by the rate of new infections that they are expected to cause; and 2) assess the efficiency of some redesigning strategies in mitigating the spread of the virus. • Outcome: ○ *Ranked Venues*: Street cafés present the largest average rate of new infections caused by an attendant (i.e., the proximity of those waiting in line), followed by busy outdoor markets, and then metro and train stations, whereas the risks incurred while walking on fairly busy streets (average density around 0.1 person/m²) are comparatively quite low. ○ *Density*: In scenarios with a moving crowd, density is the main factor influencing the estimated infection rate. ○ *Interventions in Public Spaces*: While the benefits of enforcing one-way goo traffic in (wide) walkways are unclear, changing the spacing between people in queues substantially affects disease transmission risks.	• Garcia, W., Fray, B., & Nicolas, A. (2021). Assessment of the risks of viral transmission in non-confined crowds. *arXiv preprint arXiv:2012.08957*.
• Analysis	• Case reports	• A religious gathering that took place in Malaysia between February 27 to March 1, 2020, which was attended by more than 19,000 people, including 1,500 from India,	• None	• Background: As of April 13, 2020, Malaysia had recorded the highest number of COVID-19 cases in Southeast Asia (4,817 cases and 77 deaths). • Result: The authors suggest that more than 35% of the COVID-19 cases in Malaysia are directly linked to the mass gathering that took place on February/March 2020. This event also caused a regional spike of COVID-19 cases across Southeast Asia. Nearly, 10% of attendees were overseas participants from Brunei, Thailand, Cambodia,	• Mat, N. F. C., Edinur, H. A., Razab, M. K. A. A., & Safuan, S. (2020). A single mass gathering resulted in massive transmission of

[c] The study reported figures of USD $3.8 and $8.7 billion. All Canadian Dollar (CAD) amounts were calculated using Purchasing Power Parities (PPPs) as published by the Organisation for Economic Co-operation and Development (OECD) for 2019 (1 United States Dollar [USD] = 1.2 CAD). PPPs are the rates of currency conversion that eliminate the differences in price levels between countries (OECD, 2019).

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
		South Korea, Brunei, China, Japan and Thailand involving sharing of communal spaces, collective eating, shared sleeping area		Vietnam, the Philippines and Indonesia. In fact, there were also participants from China and South Korea. When these overseas participants returned to their respective countries, cases linked to this gathering were reported across Southeast Asia.	COVID-19 infections in Malaysia with further international spread. *Journal of travel medicine*.
• Analysis	• Case reports in countries where mass religious events had been cancelled versus those that had not	• Mass religious gatherings (e.g., Umrah, Hajj)	• Policies on holding, restricting or cancelling mass religious gatherings	• Results: The study identified a clear relation between early suspension of religious mass gatherings and lower occurrence of COVID-19 transmission in countries that took such measures promptly. • Implications: There are lessons to national and international health organizations for other mass gatherings in the context of the pandemic.	• Hoang, V. T., Gautret, P., Memish, Z. A., & Al-Tawfiq, J. A. (2020). Hajj and Umrah mass gatherings and COVID-19 infection. *Current tropical medicine reports*, 1-8.
• Modelling	• Data from National Basketball Association (NBA) and National Hockey League (NHL) games played from March 1-11, 2020 and reported cases from 38 counties	• NBA and NHL games, US	• None	• Results: In this paper, researchers present estimates for the impact of mass gatherings in the form of NBA or NHL games on the community spread of COVID-19. The findings suggest that one additional game increased the cumulative number of COVID-19 deaths in affected US counties by 11%. The researchers recommend that banning mass gatherings is an effective non-pharmaceutical intervention to slow the spread of COVID-19.	• Alexander, A., Martin, H., & Lackner, M. (June 2020). Mass gatherings contributed to early COVID-19 spread: Evidence from US sports (No. 2003). *Working paper.*
• Modelling	• Reported cases, deaths; games played in February/ March 2020, attendance	• Outdoor English football league games (approximately 200 per week across England and Wales)	• Limited social distancing	• Purpose: This study examines the potential impact of mass outdoor events on the spread of an airborne virus. • Results: Football matches were consistent with increased cases, and deaths during April 2020. Once researchers control for a range of factors believed to help explain the spread of the virus other than mass outdoor events, they	• Olczak, M., Reade, J., & Yeo, M. (2020). Mass outdoor events and the spread of an airborne virus:

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
				found that small but significant effects remain of football match activity in an area on measures of mortality in April. • This evidence suggests that the return of fans to stadia, even for outdoor events, and even for sparsely attended matches, may have significant effects on mortality measures, and the spread of COVID-19, and hence ought to be considered with caution.	English football and COVID-19. *Available at SSRN 3682781*.
• Modelling	• Data on political rallies held between June 20 and September 22, 2020, and four-week post-event data; case and death reports; county-level testing data	• Political rallies held in US cities – two indoor (i.e., Tulsa, Phoenix) and nine outdoor	• Limited compliance with public health measures	• Purpose: To investigate the effects of large group meetings on the spread of COVID-19 by studying the impact of eighteen Trump campaign rallies. The method is based on a collection of regression models, one for each event, that capture the relationships between post-event outcomes and pre-event characteristics, including demographics and the trajectory of COVID-19 cases, in similar counties. • Results: The authors conclude that the events increased subsequent confirmed cases of COVID-19 by more than 250 per 100,000 residents. Extrapolating this figure to the entire sample, these eighteen rallies ultimately resulted in more than 30,000 incremental confirmed cases of COVID-19. ○ *County-level Outcomes*: The rallies likely led to more than 700 deaths (not necessarily among attendees) based on county-level post-event death rates.	• Bernheim, B. D., Buchmann, N., Freitas-Groff, Z., & Otero, S. (2020). *The effects of large group meetings on the spread of COVID-19: The case of Trump rallies.* Stanford Institute for Economic Policy Research (SIEPR).
• Preprint - Analysis	• Cellphone data to assess compliance with stay-at-home policies, case reports	• Indoor political rally attended by 6,000 to 12,000 people in Tulsa, Oklahoma, US	• Stay-at-home policy in effect, small number of attendees wearing masks, limited social distancing, temperature checks prior to entry	• Purpose: To assess the impact of an indoor mass political rally on the spread of COVID-19 in the state of Oklahoma. • Result: ○ *Stay-at-Home Orders:* There was no decline in net stay-at-home behavior in Tulsa county, reflecting important offsetting behavioural effects. ○ *Case Numbers*: The authors found little evidence that COVID-19 case growth grew more rapidly in Tulsa County, its border counties, or in the state of Oklahoma in the three weeks following the campaign rally. Difference-in-differences estimates further provide no evidence that COVID-19 case rates grew faster in counties that drew relatively larger shares of residents to the event. • Implications: Offsetting behavioural responses to the rally — including voluntary closures of restaurants and bars in	• Dave, D. M., Friedson, A. I., Matsuzawa, K., McNichols, D., Redpath, C., & Sabia, J. J. (July 2020). *Risk aversion, offsetting community effects, and covid-19: Evidence from an indoor political rally*. National Bureau of

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
				downtown Tulsa, increases in stay-at-home behaviour, displacement of usual activities of weekend inflows, and smaller-than-expected crowd attendance — may be important mechanisms for limiting transmission.	*Economic Research.*
• Preprint-Analysis	• County-level case counts 15 days following each gathering	• Nineteen US counties where mass outdoor gatherings (i.e., rallies) and one indoor rally occurred from August 17 to September 30, 2020 as compared with counties without gatherings	• Information not available	• Purpose: To examine if outdoor mass gatherings in counties with low COVID-19 incidence are also followed by infections. • Results: In the two weeks following the gatherings, the COVID-19 incidence increased significantly in 14 of 20 counties. The county with the highest incidence increase (3.8-fold) had the 2nd lowest incidence before the gathering. The county with the highest decrease (0.4-fold) had the 3rd highest incidence before the gathering. At the gathering date, the average incidence of counties with gatherings was lower than the rest of the United States, and after the gathering, it increased 1.5-fold, while the rest of the United States increased 1.02-fold. • Implications: These results suggest that even outdoor gatherings in areas with low COVID-19 incidence are followed by increased infections, and that further precautions should be taken at such gatherings.	• Miron, O., Yu, K. H., Wilf-Miron, R., & Davidovich, N. (October 2020). COVID-19 infections following outdoor mass gatherings in low incidence areas: Retrospective cohort study. *medRxiv*.
• Survey	• Survey of youth soccer club directors	• Youth outdoor soccer throughout the US	• Various phased approaches: socially distanced, non-contact play and contact play	• Purpose: To determine the incidence of COVID-19 among youth soccer athletes and the risk mitigation practices utilized by youth soccer organizations. • Results: One-hundred and twenty-four respondents had reinitiated soccer, representing 91,007 players with a median duration of 73 days (IQR: 53-83 days) since restarting. Of the 119 that had progressed to group activities, 218 cases of COVID-19 were reported among 85,861 players. Youth soccer players had a lower case rate and incidence rate than children in the US (254 v. 477 cases per 100,000; incidence rate ratio [IRR]=0.511, 95% CI = [0.40-0.57], p<0.001) and the general population from the counties where data was available (268 vs. 864 cases per 100,000; IRR=0.202 [0.19–0.21], p<0.001). After adjusting for local COVID-19 incidence, there was no relationship between club COVID-19 incidence and phase of return (non-contact: b=0.35±0.67, p=0.61; contact: b=0.18±0.67,	• Watson, A. M., Haraldsdottir, K., Biese, K., Goodavish, L., Stevens, B., & McGuine, T. (2021). COVID-19 in youth soccer during summer 2020. *Journal of Athletic Training*.

Type of Study	Type of Data	Setting/Jurisdiction	Public Health Measures Taken	Summary of Findings	Reference
				p=0.79). Soccer clubs reported utilizing a median of 8 (IQR: 6-10) risk reduction procedures. • Implications: The incidence of COVID-19 among youth soccer athletes is relatively low when compared to the background incidence among children in the US in summer of 2020. No relationship was identified between club COVID-19 incidence and phase of return of soccer.	
• Analysis	• Case counts of attendees; secondary and tertiary cases	• Eight indoor concert events (50-100 people), Osaka, Japan that took place between February 15 – 25, 2020	• None	• Overall: The authors identified 74 individuals who participated in one or more of the eight concert events and who were subsequently confirmed as SARS-CoV-2-positive by polymerase chain reaction (primary cases). Including secondary and tertiary cases, the eight 'Live House' events resulted in a total of 103 COVID-19 cases across 15 prefectures. Of the 74 primary cases identified, 48 (65%) were found in Osaka. The contact-tracing data for these cases identified that 12 of the 48 primary cases (25%) transmitted the virus to 20 cases (secondary cases). Of those 20 secondary cases, six cases transmitted the virus to seven tertiary cases. • Implications: The data demonstrate that densely populated venues, such as live concerts, can 'seed' infections that can spread to other, distant areas.	• Koizumi, N., Siddique, A. B., & Andalibi, A. (2020). Assessment of SARS-CoV-2 transmission among attendees of live concert events in Japan using contact-tracing data. *Journal of Travel Medicine*, *27*(5).
• Experimental	• Simulation	• Seated indoor events (concerts), Germany	• All participants tested negative 48 hours prior to the event, wore N95 masks • Three seating scenarios: 1) no restrictions; 2) moderate restrictions; and 3) strong restrictions	• Purpose: The study investigated transmission risk of SARS-CoV-2 by droplets and aerosols during an experimental indoor mass gathering event (MGE) using N95 masks and contact tracing devices, and conducted a simulation study to estimate the resulting burden of disease under conditions of controlled epidemics. • Results: The number of exposed contacts was <10 for scenarios with hygiene concept (masks, physical distancing) and good ventilation, but substantially higher otherwise. Of subsequent cases, 0%-23% were attributable to MGEs. • Implications: Overall, the expected additional effect of indoor MGEs on burden of infections is low if hygiene concepts are applied and adequate ventilation exists.	• Moritz, S., Gottschick, C., Horn, J., Popp, M., Langer, S., Klee, B., ... & Mikolajczyk, R. (November 2020). The risk of indoor sports and culture events for the transmission of covid-19 (restart-19). *medRxiv*.

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