Public Health England

Protecting and improving the nation's health

Transmission of COVID-19 within large events and interventions to minimise transmission

A rapid review

Contents

Main messages 3
Background 4
Methodology 5
Evidence 5
Limitations 9
Conclusions 10
Acknowledgment 11
Disclaimer 11
References 12
Annexe A. Methods 13
Annexe B. Data extraction 19
Annexe C. Excluded studies 28
About Public Health England 34

Main messages

1. The purpose of this review was to identify and examine evidence on COVID-19 transmission in relation to large scale organised events. The review includes 7 studies (one preprint): 4 outbreak investigations, 2 experimental studies and one modelling study (search date: 1 January 2020 to 26 February 2021). Except for one modelling study, all studies focused on large events in indoor settings.

2. Evidence from 4 outbreak investigations suggests that COVID-19 transmission can happen in large indoor events (such as concerts and business conferences) when no mitigation measures are in place. This is based on a small number of studies of low to medium quality which did not have comparator group.

3. The 2 experimental studies suggest that rapid antigen testing before an indoor event might be effective in reducing transmission of COVID-19. Additionally, splitting seated areas into segments (with no movement between segments), increasing the numbers of dedicated entrances and exits and increasing the space between seated participants can reduce the number and duration of contacts between participants.

4. Further research of higher methodological quality is needed to assess risk of transmission and to understand what interventions can reduce the risk of transmission, at large events both indoor and outdoor.

Background

In response to the COVID-19 pandemic, many mass events were cancelled worldwide as part of a series of measures to help slow the spread of the virus. In England, mass gatherings were banned when the first national lockdown was implemented on 23 March 2020.

As countries start to re-open, there is a need to consider the potential routes of COVID-19 transmission within mass gatherings and how best to minimise this in order that events can re-open safely. This review was conducted in March 2021, during the development of the Events Research Program which 'aims to examine the risk of transmission of COVID-19 from attendance at events and explore ways to enable people to attend a range of events safely' (1). While some spontaneous outdoor mass gatherings happened in summer 2020 and early 2021, including protests and leisure gatherings in packed beaches or parks, no organised events occurred in the UK between the start of the first lockdown in March 2020 and the initiation of events pilot work in April 2021.

'Mass events', 'large events' or 'mass gatherings' are broad terms that encompass many different types of indoor and outdoor events and settings, including religious gatherings, protests, live music, sporting and business events of varying sizes. There is evidence that COVID-19 transmission can happen in such large events (2). There is also evidence that they can result in COVID-19 spread in the community, as demonstrated, for example, following a religious mass gathering in Malaysia (3), after a 10-day motorcycle rally in the US (4), or more generally after the NBA basketball games (5). An evidence brief produced by the Public Health Agency of Canada (including studies up to 18 August 2020) also suggested that large gatherings can result in 'super-spreading' events and that there was a relationship between gathering size and transmission risk (6).

Objective

The purpose of this rapid review was to identify and assess evidence on the transmission of COVID-19 in large, organised events and associated venues (including factors associated with transmission), and to assess the effectiveness of interventions designed to minimise transmission in these settings.

Definitions

In this review, 'large, organised events' refer to organised and usually ticketed events with at least 100 people attending and their associated indoor or outdoor venues, including the performing arts, live music, sports or business. Events such as protests, rallies, religious gatherings, private events, random gatherings, and smaller gatherings (for example) were not considered as organised events within the scope of this review.

Methodology

A rapid review was conducted, following systematic methodologies but with shortcuts built in to accelerate the review process (7). A protocol was produced a priori and published on PROSPERO (CRD42021240708).

A literature search was undertaken to look for primary studies related to the COVID-19 pandemic, published (or available as preprint) between 1 January 2020 and 26 February 2021.

Title and abstract screening were completed in duplicate for 10% of the studies. Full text screening, data extraction and risk of bias assessments were conducted by one reviewer and checked by a second. Characteristics of included studies were tabulated and data combined in narrative review.

Risk of bias was assessed using a quality criteria checklist (QCC) which assesses the methodological quality of a study (8). Studies were given a quality rating of high, medium or low. Modelling studies were not assessed.

Full details on the methodology are provided in Annexe A.

Evidence

Search results

The electronic search returned 3,057 records. After removal of duplicates, 1,949 records were screened by title and abstract. Of these, 82 full-text articles were assessed for eligibility and 4 were included in this review. A further 3 studies were identified by searching reference lists of relevant reviews, citation analysis and consultation with topic experts. A PRISMA diagram is provided in Annexe A.

In total, 7 studies were included in this review of which one was a preprint: 4 outbreak investigations (2 reporting on the same outbreak), 2 experimental studies and one modelling study. Three studies were from Asia, 2 were from Europe and 2 were from the US; no studies from the UK were identified. Four of the studies reported on live music events, 2 on business conferences and one on a sporting event. Full details of the included studies can be found in Annexe B and a list of studies excluded at full-text screening can be found in Annexe C.

Q1. What evidence is there of COVID-19 transmission within large events and associated venues, and what factors associated with transmission?

Four outbreak investigations (3 epidemiological investigations and one genomic analysis) related to transmission within large events and associated venues were identified (9 to 12). Two were rated low quality and 2 rated medium. Two studies were from Japan (reporting on the same outbreak at a series of live music concerts), one study was from the US (reporting on a business conference), and one study was from Singapore (reporting on a business conference).

Outbreak investigations (Table B.1, Annexe B)

Performing arts and live music – indoor venues

Two of the studies reported on the same outbreak linked to 8 live music concerts held in 4 different venues (30 to 150 participants at each event) in February 2020 in Osaka, Japan (9,10). The epidemiological investigations showed that the index case was a symptomatic woman in her thirties who infected 23 participants while attending the first of these events. Some of these infected individuals then attended other events in the following days, leading to a total of 72 confirmed cases who were reportedly infected while attending at least one of these events. Koizumi and others reported that some participants had attended several events and that no mitigation measures were in place at the time of the concerts (held during the early stage of the pandemic), which may have facilitated transmission (9). Sugano and others aimed to assess the role of asymptomatic transmission in this outbreak, reporting that 53% of cases were likely to have been infected by an asymptomatic (or pre-symptomatic) case, and that transmission had occurred 2 to 4 days after infection.

Both studies were rated as medium quality, mainly due to the risk of information bias for exposure in that information on attendance at events was self-reported and not enough information on the events themselves was provided to assess where and in which conditions transmission might have occurred. In particular, other sources of exposure to COVID-19 cannot be ruled out: the authors noted that environmental or fomite transmission could not be discounted for some cases although it is also possible that a different index case attended one or several of these events, or that some of the secondary cases might have been infected outside of these events (no genetic analyses were performed to ensure all cases were from the same lineage).

Business events – indoor venue

An epidemiological investigation reported on a COVID-19 cluster at a company conference which took place in Singapore on 20 to 22 January 2020. The conference was attended by 111 participants from 19 countries, including 17 attendees from China (12). Seven participants with

no recent travel history to China reported positive COVID-19 test results. The primary case was not identified, although it was assumed that it was likely to be one of the participants from China, as at the time of the event, the COVID-19 outbreak was mainly occurring there. The investigation suggested that transmission could have occurred on different occasions during which close contact between cases and participants from China had happened, including during a 3-hour dinner, a 4-hour breakout session and team building games. The investigation was based on interviews with confirmed cases, contact tracing and open-source information (government websites or media reports) but it is unclear whether all conference participants or only those remaining in Singapore were included in the contact tracing. As this event happened early in the pandemic, asymptomatic cases are likely to have been missed, therefore it is possible not all cases linked to the conference were identified. This study was rated low quality.

One study reported on a large cluster of approximately 100 COVID-19 cases, identified through contact tracing, at an international business conference held in Boston (US) on 26 and 27 February 2020 (11). SARS-CoV-2 genome sequencing of 28 of these cases showed that they shared similar genome sequences, suggesting that transmission occurred between participants at the conference. However, the study did not report on potential transmission routes at the conference. The study was rated low quality because of the selection bias (only a small sample of the potentially linked cases were sequenced) and because of the lack of information on potential exposure to COVID-19.

Main findings

These outbreak investigations suggest that COVID-19 transmission can occur at large indoor events but did not provide evidence on possible transmission routes within the events. It must be noted that all reported outbreaks occurred between January and March 2020 when COVID-19 was relatively unknown or understood, and current recommended infection, prevention and control (IPC) measures were not in place.

Q2. What are the effects of measures designed to minimise COVID-19 transmission within large scale events and associated venues?

Two experimental trials (one with a modelling component, both indoor live concerts) and one modelling study (the sporting event) examining the effectiveness of measures to minimise transmission at large scale events and venues were identified (13 to 15). The two experimental trials were from Spain and Germany, one was a preprint, and both were given a medium quality rating. The modelling study was from the US (not quality rated).

Experimental studies (Table B.2, Annexe B)

Performing arts and live music – indoor venues

Two experimental trials using an indoor live concert setting were carried out in Barcelona, Spain in December 2020 and Leipzig, Germany in August 2020 (13,14).

A randomised controlled trial (RCT) in Spain examined the effectiveness of same day antigen detection rapid diagnostic test (Ag-RDT) screening, together with IPC measures (including mandatory N95 respirators, temperature screening, hand sanitiser and ventilation, but no physical distancing required) to prevent COVID-19 transmission during an indoor live concert event. The 1,047 participants all tested negative (Ag-RDT) on the day and were randomly assigned to the experimental group, who entered the venue, or to the control group, who were sent home. Median time spent in the venue was 2 hours and 40 minutes, the mean age of participants was 33.6 years and 81.6% were male. At follow up 8 days later (RT-PCR testing), 2 participants from the control group tested positive and 0 from the experimental group (difference between the 2 groups was not significant). The results suggest that with rapid testing on the day of an event the risk of contracting COVID-19 at a concert may be similar to non-attendance, by reducing the risk of infected index cases attending the event. In particular, the antigen test appeared to be a practical strategy for rapid testing within these settings (negative predictive value of 99.9% for a positive RT-PCR) although in this experiment the testing was done from 12 hours before the event and samples were collected by trained staff. This study was rated as medium quality. Limitations included information bias for outcome measurement (assessed 8 days after the event and no genomic testing – if some participants tested positive at follow-up, other sources of transmission could not be ruled out), and generalisability to events at full attendance is unclear as number of participants had been limited by local health authorities.

The second experimental study (preprint) compared transmission risk in 3 different seated concert scenarios by tracking the number and duration of contacts each participant had at each stage of the event (14). In total 1,212 participants with negative tests before the event took part. Participants were given an N95 respirators, hand sanitiser and a contact tracing device before entering the venue. In the first scenario (pre-COVID-19 control) movement in the arena was unrestricted and no space between seats was required. In scenarios 2 and 3, movement was restricted to smaller areas of the arena (with a dedicated entrance/exit for each area) and different seating patterns were used to enable physical distancing. When movement was unrestricted participants' total contacts of at least 15 minutes and within 1.5 metres increased both during the concert and in the entry/exit phases while in more restricted scenarios accumulation of new contacts was limited to entry phase. Increasing the number of entrances/exits, restricting movements to smaller areas, and changing seating arrangements reduced the number of overall short and longer contacts each participant had. Increasing spacing between seated participants reduced contacts during the concert and increasing numbers of entrances/exits and limiting movement within the arena reduced contacts during entrance, half time and leaving. The study was rated high quality, though there were some

limitations. The results of this study are specific to seated indoor events and recruitment was lower than desired.

In addition, simulations were performed within this study to assess the potential impact of ventilation on airborne transmission during the concert scenarios. The results suggest that increasing air exchange rate from 0.85/h to 1.46/h reduced aerosol exposure and could result in a 10-fold reduction of the number of people exposed per infectious person.

Modelling study (Table B.3, Annexe B)

Sporting events - outdoor venues

A COVID-19 infection probability model was used to estimate relative risk of infection for a range of activities, including attendance at a sporting event at an outdoor stadium in Boston, US (capacity 13,067) (15). The model calculated risk of COVID-19 infection by 3 transmission routes (direct, airborne and fomite transmission) for different attendance levels and assuming that physical distancing was required in the corridors. The study reported that reducing capacity would result in a reduction in transmission risk. For instance, having a half-full stadium would result in a 3-fold reduction in transmission compared to a full stadium. Not having food and drink stands would reduce transmission risk even further. Modelling studies are limited by their design (assumptions; ideal scenarios not always taking into account real-life settings are a few examples) and by the fact that, for COVID-19, the models are based on emerging evidence with important uncertainties.

Main findings

Evidence from an RCT suggests that rapid antigen testing might be effective in reducing the risk of participants contracting COVID-19 at large events by reducing the risk of an index case attending the event. In addition, evidence from a cross-over study suggests that increasing the number of entrances and exits, restricting movements to a dedicated area and increasing space between seated participants can reduce the number and duration of contacts between participants attending a seated concert and, therefore, could reduce transmission. Evidence from modelling studies suggests that increased ventilation and reducing attendance would also probably result in a reduced risk of COVID-19 transmission.

Limitations

The literature search was limited to COVID-19 evidence published between 1 January 2020 and 26 February 2021 from Medline, Embase, medRxiv, SSRN and WHO COVID-19 database. Three additional studies were identified through reference list searching, citation analysis and consultation with topic experts. However, not all outbreaks have been studied and reported in scientific articles. In addition, the evidence may be subject to publication bias, whereby events where no outbreaks occurred are less likely to have been published.

The scope of events included in the review was limited to those most likely to resemble organised or ‘ticketed’ events with a focus on performing arts, live music, sport, and business.

Studies reporting on protests, rallies, religious gatherings, private events and smaller gatherings (for example) were excluded. However, some of these studies could have provided valuable insight for transmission risk/modes of transmission at certain events where there is likely to be more random mixing (that is, non-seated events). In addition, less structured events in indoor spaces, such as large events in pubs or nightclubs, and events with overnight stays on site could also have provided relevant evidence to these review questions.

Evidence for question 1 was limited to outbreak investigations during the first wave of the pandemic, limiting their relevance to the current situation now that restrictions and preventative measures are common. Design limitations means they are also subject to biases, that they may not be representative, and that the absence of comparator group does not allow for analysis of possible associations between exposure and outcome cannot be determined.

Evidence for question 2 was limited to 2 experimental studies and a modelling study. All direct evidence was for large indoor concert settings, run at limited capacity. It is unclear how these results would translate to other large event settings, durations, and capacities. It is possible participants may have changed their behaviour due to the experimental conditions.

One of the studies identified was a preprint, which has not been certified by peer-review and may be subject to change.

Conclusions

The evidence indicates that at large organised events without IPC measures in place, COVID-19 transmission can occur. However, this evidence comes from outbreak investigations, 2 of which were rated as low quality and 2 as medium. Detailed epidemiological data and genomic sequencing to verify transmission routes within the events is lacking, so it is not known if all cases in the outbreak investigations were linked to the event or, if they were, how they were linked. The evidence is also limited to indoor settings in the early stages of the pandemic, limiting their relevance to the situation over a year into the pandemic, and to outdoor settings. Further high-quality epidemiological investigations with detailed contact tracing, screening for asymptomatic cases, genomic analysis would help to clarify under what circumstances transmission is most likely.

Evidence from 2 experimental studies (one rated as medium quality and one as high) suggests that rapid testing before events, movement restriction, greater distance between seated participants and good ventilation could reduce transmission risk within large indoor events. Additional evidence from a modelling study in an outdoor stadium suggested that reducing capacity would reduce the risk of transmission.

Further studies are needed to assess the effectiveness of these, and a wider set of, measures to reduce the risk of transmission in a variety of large event settings. These studies should ideally be randomised controlled interventions powered to detect transmission risk and conducted in a range of different settings.

This rapid review was completed in May 2021.

Acknowledgment

We would like to thank Theresa Marteau (Science Board Member of the Events Research Programme) and Helen McAuslane (Public Health England) who either reviewed or input into aspects of the review.

Thanks also to colleagues within the COVID-19 Rapid Evidence Service team for their support into specific aspects of this review, especially Isobel Tudge and Lee Hooper.

Disclaimer

PHE's rapid reviews aim to provide the best available evidence to decision makers in a timely and accessible way, based on published peer-reviewed scientific papers, unpublished reports, and papers on preprint servers. Please note that the reviews: 1) use accelerated methods and may not be representative of the whole body of evidence publicly available; 2) have undergone an internal, but not independent, peer review; and 3) are only valid as of the date stated on the review.

In the event that this review is shared externally, please note additionally, to the greatest extent possible under any applicable law, that PHE accepts no liability for any claim, loss or damage arising out of, or connected with the use of, this review by the recipient and/or any third party including that arising or resulting from any reliance placed on, or any conclusions drawn from, the review.

References

1. Department for Digital Culture Media & Sport and others. 'Information on the Events Research Programme [Accessed 11 June 2021]'. 2021:
2. Majra D and others. 'SARS-CoV-2 (COVID-19) superspreader events'. Journal of Infection 2021: volume 82, issue 1, pages 36-40
3. Che Mat NF and others. 'A single mass gathering resulted in massive transmission of COVID-19 infections in Malaysia with further international spread'. Journal of Travel Medicine 2020: volume 27, issue 3
4. Firestone MJ and others. 'COVID-19 Outbreak Associated with a 10-Day Motorcycle Rally in a Neighboring State - Minnesota, August-September 2020'. MMWR - Morbidity & Mortality Weekly Report 2020: volume 69, issue 47, pages 1771-6
5. Wing C and others. 'Effects of large gatherings on the COVID-19 epidemic: evidence from professional and college sports'. SSRN 2020:
6. Public Health Agency of Canada. 'Emerging Evidence on COVID-19: Evidence Brief of Size of Gatherings and Characteristics of High Risk Transmission Events'. 2020
7. World Health Organization. 'Rapid reviews to strengthen health policy and systems: a practical guide'. 2017
8. Academy of Nutrition and Dietetics. 'Evidence Analysis Manual: Steps in the Academy Evidence Analysis Process'. 2016
9. Koizumi N and others. 'Assessment of SARS-CoV-2 transmission among attendees of live concert events in Japan using contact-tracing data'. Journal of Travel Medicine 2020: volume 27, issue 5, pages 20
10. Sugano N and others. 'Cluster of Severe Acute Respiratory Syndrome Coronavirus 2 Infections Linked to Music Clubs in Osaka, Japan'. Journal of Infectious Diseases 2020: volume 222, issue 10, pages 1635-40
11. Lemieux JE and others. 'Phylogenetic analysis of SARS-CoV-2 in Boston highlights the impact of superspreading events'. Science 2021: volume 371, issue 6529, pages 05
12. Pung R and others. 'Investigation of three clusters of COVID-19 in Singapore: implications for surveillance and response measures'. The Lancet 2020: volume 395, issue 10229, pages 1039-46
13. Revollo B and others. 'Same-day SARS-CoV-2 antigen test screening in an indoor mass-gathering live music event: a randomised controlled trial'. The Lancet Infectious Diseases 2021: volume 21, issue 10, pages 1365-72
14. Moritz S and others. 'The Risk of Indoor Sports and Culture Events for the Transmission of COVID-19 (Restart-19)'. medRxiv 2020
15. McCarthy JE and others. 'Modeling the relative risk of SARS-CoV-2 infection to inform risk-cost-benefit analyses of activities during the SARS-CoV-2 pandemic'. PLoS ONE 2021: volume 16, issue 1, pages e0245381

Annexe A. Methods

This report employed a rapid review approach to address the review questions:

> Q1. What evidence is there of COVID-19 transmission within large events and associated venues, and what factors are associated with transmission?
>
> Q2. What are the effects of measures designed to minimise COVID-19 transmission within large scale events and associated venues?

Our rapid review approach follows systematic methodologies, but with shortcuts built in to accelerate the review process (7). In particular, only 10% of the screening on title and abstract were screened in duplicate; and full text screening, data extraction and risk of bias assessment were performed by one reviewer and checked by another one.

Notes

The focus of this review was on organised events in a dedicated venue; random gatherings or gatherings occurring outside of an established venue were out of scope.

For the purpose of this review, a large gathering was defined as one with 100 or more people in attendance.

Protocol

A protocol was produced a priori and published on PROSPERO (CRD42021240708).

Sources searched

Medline, Embase, medRxiv, SSRN and WHO COVID-19 Research Database.

Search strategy

Searches were conducted for studies published between 1 January 2020 and 26 February 2021.

Search terms covered key aspects of the research question, including terms related to the intervention. The search strategy for Ovid Medline is presented in Box A.1.

Reference lists of relevant primary studies were searched as well as any reviews or evidence summaries identified. In addition, topic experts were consulted via the wider project working group.

In addition, a Google search was conducted to identify any non-indexed studies. Finally, citation analysis was performed on Web of Science and Google Scholar (co-citation analysis, snowballing and related articles) using the 5 studies identified from the database searches.

Although this was not part of the search strategy outlined in the protocol, it was agreed a posteriori by the review team due to the lack of evidence identified.

Status of studies that had been identified as preprints were checked on 11 June 2021 to see whether they had been published as peer-reviewed and updated accordingly.

Box A.1. Search strategy Ovid Medline

1. ((indoor or outdoor or mass or large or group or sport* or business* or public or commercial or social) adj2 (gathering* or event* or venue* or crowd* or audience* or spectator* or facility or facilities or attendance or attendees or setting* or arena*)).tw,kw.
2. closed environment*.tw,kw.
3. (gathering* and size).tw,kw.
4. performing art*.tw,kw.
5. live music.tw,kw.
6. festival*.tw,kw.
7. (theatre* or theater*).tw,kw.
8. (operat* or hospital* or surg*).tw,kw.
9. 7 not 8
10. cinema*.tw,kw.
11. ((band or comedy or music or unseated or seated or ticketed) adj10 (venue* or event* or facility or facilities)).tw,kw.
12. ((music* or opera* or outdoor* or indoor*) and (concert or concerts)).tw,kw.
13. choir*.tw,kw.
14. county show*.tw,kw.
15. (exhibition or exhibitions).tw,kw.
16. (stadium* or stadia).tw,kw.
17. tournament*.tw,kw.
18. trade show*.tw,kw.
19. (venue* and (open* or reopen*)).tw,kw.
20. ((indoor* or outdoor*) and transmission).tw,kw.
21. superspread*.tw,kw.
22. Crowding/
23. Sports/
24. Music/
25. Singing/
26. Private Facilities/
27. Public Facilities/
28. Toilet Facilities/

29. "Sports and Recreational Facilities"/

30. 1 or 2 or 3 or 4 or 5 or 6 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29

31. exp coronavirus/

32. exp Coronavirus Infections/

33. ((corona* or corono*) adj1 (virus* or viral* or virinae*)).ti,ab,kw.

34. (coronavirus* or coronovirus* or coronavirinae* or CoV or HCoV*).ti,ab,kw.

35. covid*.nm.

36. (2019-nCoV or 2019nCoV or nCoV2019 or nCoV-2019 or COVID-19 or COVID19 or CORVID-19 or CORVID19 or WN-CoV or WNCoV or HCoV-19 or HCoV19 or 2019 novel* or Ncov or n-cov or SARS-CoV-2 or SARSCoV-2 or SARSCoV2 or SARS-CoV2 or SARSCov19 or SARS-Cov19 or SARSCov-19 or SARS-Cov-19 or Ncovor or Ncorona* or Ncorono* or NcovWuhan* or NcovHubei* or NcovChina* or NcovChinese* or SARS2 or SARS-2 or SARScoronavirus2 or SARS-coronavirus-2 or SARScoronavirus 2 or SARS coronavirus2 or SARScoronovirus2 or SARS-coronovirus-2 or SARScoronovirus 2 or SARS coronovirus2).ti,ab,kw.

37. (respiratory* adj2 (symptom* or disease* or illness* or condition*) adj10 (Wuhan* or Hubei* or China* or Chinese* or Huanan*)).ti,ab,kw.

38. ((seafood market* or food market* or pneumonia*) adj10 (Wuhan* or Hubei* or China* or Chinese* or Huanan*)).ti,ab,kw.

39. ((outbreak* or wildlife* or pandemic* or epidemic*) adj1 (Wuhan* or Hubei or China* or Chinese* or Huanan*)).ti,ab,kw.

40. or/31-39

41. 30 and 40

42. limit 41 to yr="2020 - 2021"

43. limit 42 to english language

Inclusion and exclusion criteria

Article eligibility criteria are summarised in Table A.1.

Table A.1. Inclusion and exclusion criteria

	Included	Excluded
Population	All populations – no restrictions	
Settings	UK and international Large (greater than100 people) organised events and associated venues. To include performing arts, live music, sports and business events held in indoor or outdoor venues:	• small gatherings (Less than100 people) • religious gatherings not part of a live event • large gatherings occurring outside of an established venue, for example, community protests

	Included	Excluded
	i) Performing arts and live music indoor venues ii) Performing arts and live music outdoor venues iii) Sporting events, indoor venues iv) Sporting events, outdoor venues v) Business events, indoor venues vi) Business events, outdoor venues	or unscheduled community gatherings • random gatherings • settings which may have a venue, but involve overnight or long-term stay (for example, cruise ships) • school and workplace events, and those held in health and social care settings • private events, such as gatherings with family or friends, parties, weddings, funerals, or other celebrations • leisure facilities such as gyms • nightclubs and pubs, unless organised live / ticketed event within that setting
Context	COVID-19 pandemic	Other infectious diseases
Intervention/ exposure	Q1: Transmission • attendance at a large-scale event or associated venue • any factors associated with transmission (for example, behavioural, environmental, structural or demographic factors, or including factors surrounding the event such as transportation) Q2: Interventions (mitigation measures) • any non-pharmaceutical intervention designed to minimise transmission of COVID-19 within or associated with the event, for example, controlled capacity, social distancing, use of physical barriers, pre-entry testing, adequate ventilation	Q1: Transmission • transmission of COVID-19 within any other context, and as detailed in 'settings' exclusions Q2: Interventions • closure of venues • re-opening of venues alongside wider national or regional lifting of restrictions
Outcomes	• SARS-CoV-2 transmission / cases • COVID-19 outbreak Measures: • incidence of COVID-19 • prevalence of COVID-19 • attack rate/secondary attack rate • reproduction number	• deaths associated with COVID-19 • disease progression • prevalence/rates of asymptomatic, pre-symptomatic or symptomatic COVID19

	Included	Excluded
	• narrative reporting (outbreak investigation)	
Language	English	Any other language, due to lack of translation time and resources
Date of publication	1 January 2020 to 26 February 2021	
Study design	• experimental and observational studies • case series, outbreak investigations and surveillance reports	• systematic or narrative reviews • guidelines • opinion pieces • modelling studies*
Publication type	Published and preprint	

*As specified in the protocol, modelling studies were coded at the screening stage as 'modelling' to be drawn upon if required. Due to the limited evidence identified for question 2, modelling studies were included.

Screening

Title and abstract screening were completed by 2 reviewers: 10% of the eligible studies were screened in duplicate (disagreements were resolved by discussion) and the remainder were screened independently by 2 reviewers (half each).

Full text screening was done by one reviewer and checked by a second. Disagreements were resolved by discussion with a third reviewer.

Figure A.1 illustrates this process.

Data extraction and risk of bias assessment

Data extraction was done by one reviewer and checked by a second.

Each study was assessed for risk of bias using the Academy of Nutrition and Dietetics quality criteria checklist (QCC) for primary research (8). This tool, not specific to nutrition, can be applied to most study designs and is therefore suitable for rapid reviews with mixed types of evidence. The QCC tool is comprised of 10 questions, 4 of which are considered critical (focused on selection bias, group comparability/confounding, interventions/exposure, and outcome). A study is rated as high quality if the answers to the 4 critical questions is 'yes' with at least one additional 'yes' to the remaining 6 questions. The study is rated as low quality if 2 or more of the critical questions are answered 'no' and/or if more than or equal to 50% of the remaining questions are answered 'no'. Otherwise, the study is rated as medium quality.

Risk of bias assessment was done by one reviewer and checked by a second. QCC ratings are reported in the data extraction tables (Annexe B). Modelling studies were not assessed.

Synthesis

A narrative synthesis is provided. Variations across populations and subgroups, for example cultural variations or differences between ethnic, social or vulnerable groups is considered, where evidence is available.

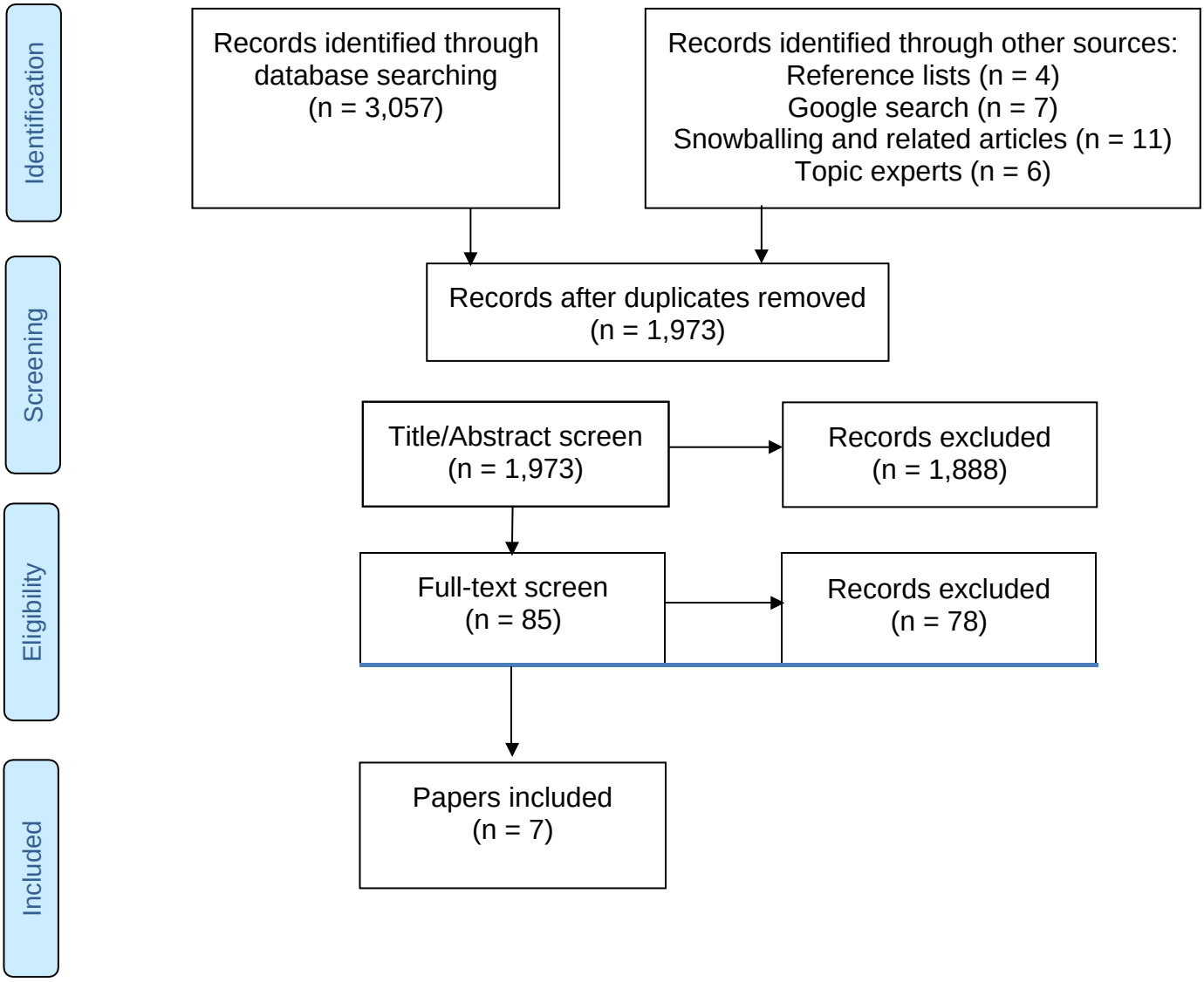

Figure A.1. PRISMA diagram

Accessible text version of figure A.1

A PRISMA diagram showing the flow of studies through this review, including n=3,057 studies identified through database searching.
From these, records removed before screening were:
Duplicate records removed (n=1,973)
n=1,973 records screened of which n=1,888 were excluded, leaving n=85 papers sought for retrieval.
n=78 papers were excluded, leaving n=7 papers included

Annexe B. Data extraction

Table B.1. Outbreak investigations (question 1)

Reference	Study design	Methods	Main messages	Risk of Bias
Koizumi and others, 2020 (9)	Study type: epidemiological investigation Objective: to study the outbreak at a series of concerts in Osaka Setting: 8 live concerts in 4 different venues (50-100 capacity), Osaka, Japan Study period: 15-25 February 2020 Participants: mainly women 30-50 years old attend these events	Outcome: number of primary, secondary and tertiary COVID-19 cases Exposure: attendance at one or more of the concerts (between 30 and 150 participants to each event) Data collection: 1. To identify primary cases: Central and local government registries for 15 February – 15 April 2020. 2. To identify secondary and tertiary cases: Contact traced those who were confirmed in Osaka (48/74 cases).	1. 74 cases (RT- PCR positive) that participated in at least one of these events identified; 103 cases including secondary and tertiary cases. 2. Suspected index case: woman in her 30s who had symptoms (such as, cough, fever) when attending concert on 15 February. Positive diagnostic 28 February. 3. Factors that might have facilitated the spread: a) Early stage of pandemic, no mitigation measures in place b) Some participants attended several events 4. Factors that might have minimised secondary transmission: a) After symptom onset (= after the events), participants did not socialise, and many wore face masks	Study design: outbreak investigations do not have pre-determined research questions or methods, are uncontrolled (no comparator group) and are non-representative (specific settings). Bias: Information bias: 1. Little detail given about the venues (such as, layout, interior or exterior, staff) 2. Other transmission routes are possible (including other index cases). 3. No distinction if cases were paying attendees only or included staff as well. QCC rating: medium
Sugano and others, 2020 (10)	Study type: epidemiological investigation Objective: clarify the time between initial exposure and being able to transmit	Outcome: number of primary, secondary and tertiary COVID-19 cases Exposure: attendance at one or more of the concerts Data collection:	1. 72 (+ 1 index case) primary cases found linked to attendance at one or more of the 8 concerts at the 4 clubs. 2. Overall, 108 cases (70 females, 38 males) when including secondary and tertiary cases possibly epidemiologically linked to concerts.	Study design: outbreak investigations do not have pre-determined research questions or methods, are uncontrolled (no comparator group) and are non-representative (limited population).

	SARS-CoV-2. Assess the role of asymptomatic cases in transmission. Same event as Koizumi and others	1. Central government collected and publicly available anonymous data of positive cases. 2. Includes source of exposure, contacts and date of positive test.	3. As in Koizumi and others, suspected index case was a woman in her 30s (symptomatic) who infected 23 participants at the first of these events (15 Feb, club A). 4. Of these 23, 17 attended another event the day after (also in club A) where 4 additional people were infected. For these 4 cases, transmission route could not be determined. 5. Four cases from club A attended other events in club R on 17 and 18 Feb, resulting in 2 additional cases. 6. Four cases from club A went to club S on 19 Feb and infected 32 people. 7. One case from club S went to club F on 21 Feb and infected 3 cases. 8. 32% of cases were infected by symptomatic case and 53% by asymptomatic (or pre-symptomatic) cases. For the other cases, transmission routes could not be determined (environmental transmission could not be discarded).	Bias: Information bias: 1. Little detail given about the venues (such as, layout, interior or exterior, staff). 2. Other transmission routes are possible (including other index cases). Recall bias: Index case wasn't detected until 27 February (12 days after exposure event) so contact tracing didn't start until then and relied on self-reporting of activities and contacts. QCC rating: medium
Lemieux and others, 2021 (11)	Study type: phylogenetic investigation Objective: to investigate the introduction and spread of COVID-19 in the Boston area	Outcome: number of COVID-19 cases linked to business conference Exposure: attendance at the business conference Contact tracing: Public health investigation including contact tracing carried out by	Results related to the outbreak at the business conference 1. Approximately 100 cases associated with this event were identified through contact tracing. 2. Genome sequencing done on 28 of these cases, which showed a phylogenetic cluster (shared very similar virus genome sequences) that	Study design: limited to genetic analysis, no epidemiological investigation. Bias: Selection bias: only 28 of the 100 cases linked to the conference were genetically sequenced.

	during the first wave of the pandemic Setting: Business conference, Boston, US Study period: Conference: 26 to 27 February Investigation: February-November 2020 Participants: samples from 772 individuals. Conference: 100 linked cases, 28 sequenced.	Massachusetts public health department identified cases associated with conference Genomic analysis: 1. Genome sequencing of positive nasopharyngeal samples collected between 5-11 March 2020 (including samples from confirmed early cases). 2. Analysis with help of global GISAID database 3. Analyses performed by constructing a phylogenetic tree. 4. Identification of major lineages showed major clusters happened at a business conference and at a nursing home.	occurred in a narrow window of time. Two main variants were identified: the C2416T (sequenced cases from the conference were the first known cases in the US) and the G26233T (which had not been noted before in any public genome databases). 3. Genomic and epidemiological evidence suggests that the conference contributed to the spread of COVID-19 in the US.	Information bias: there is no reporting on activities and contacts of cases at the conference. Meaning possible exposure and transmission routes cannot be found. QCC rating: low
Pung, R. and others 2020 (12)	Study type: epidemiological investigation Objective: investigate potential COVID-19 outbreaks linked to 3 separate events in Singapore Setting: business conference, Singapore Study period:	Outcome: number of cases of COVID-19 linked to each of these 3 events Exposure: attendance of one of the three events: tour group from China, company conference or a church Contact tracing: Business conference: 1. First case reported by Malaysian International Health Regulation (IHR) focal point. 2. Contact tracing of 15 participants remaining in Singapore. 3. Cases outside of Singapore linked to the conference were	Results for outbreak at the business conference: 1. First participant (B1) to test positive identified on 4 February 2020 in Malaysia 2. Six further participants tested positive for SARS-CoV-2 3. Three local cases found through contact tracing 4. Three cases outside of Singapore reported to investigation after positive test result. 5. Two through contact tracing, one through activity mapping, 1 unclear how detected	Study design: outbreak investigations do not have pre-determined research questions or methods, are uncontrolled (no comparator group) and are non-representative (limited population). Bias: Selection bias: only those still in Singapore followed up. Those outside of Singapore who didn't report a positive test result were not included. Therefore, potential to miss asymptomatic cases and those whose results weren't

	1. Conference: 20 to 23 January 2020. 2. Investigation: 4 to 14 February 2020 Participants: 111 participants at the conference from 19 countries.	included in outbreak investigation when reported to have a positive test. 4. Activity mapping, done through contacting the organisers and interviewing cases, of the conference to establish potential points of contact between cases and other close contacts of cases.	Analysis of the seating plan and events of the conference 1. At a 3-hour Chinese banquet-style dinner two pairs of cases were seated at tables together, with 3 and 2 attendees from China respectively. 2. Four cases attended a 4hour breakout session, with 41 others, 10 of which were from China. 3 of the cases and 3 of the 10 people from China had been seated together at the banquet. 3. Team building games with close contact also occurred, hand shaking reported, no further detail. 4. One hundred fifty-three close contacts of the cases in Singapore were required to quarantine 5. Thirteen secondary cases identified among family of B1 in Malaysia and close contacts of B7 in France.	reported. Didn't report symptoms not tested. Information bias: 1. No information given on whether the attendees from China were COVID-19 positive at the time of the conference. The conference occurred in January when the focus of COVID was on China. 2. Cannot determine if all transmission was human to human contact (food sharing was reported) transmission via fomites and food possible routes. QCC rating: low

Table B.2. Experimental studies (question 2)

Reference	Study design	Methods	Main messages	Risk of Bias
Revollo and others, 2021 (13)	Study type: open label randomised clinical trial Objective: to assess the effectiveness of a comprehensive prevention	Outcome: difference in incidence of RT-PCR confirmed COVID-19 cases at 8 days after the concert between the experimental and control groups Testing and data collection 1. Onsite screening on the day of the experiment (8am-3.30pm):	1. All 1,047 participants tested negative (Ag-RT) and were randomised; 960 participants included in the analyses: 2. Experimental group: 465 (51 did not entered the venue; 7 lost to follow-up) 3. Control group: 495 (29 lost to follow-up).	Study design: randomised and controlled, not blinded, experimental trial Bias: Hawthorne effect: participants aware they were taking part in study.

	intervention that includes systematic same-day screening (antigen test), N95 face masks and adequate air ventilation on the prevention of SARS-CoV-2 transmission at a live indoor concert. Settings: live indoor concert (2 indoor rooms, one outdoor smoking area) in Barcelona, Spain (high community transmission at the time of the event). Study period: 1. Event: 12 December 2020. 2. Testing: 20 December 2020 Participants: 1. 18 to 59 years old, recruited from a list of subscribers to live music events (exclusion criteria included comorbidities such as hypertension and diabetes.).	nasopharyngeal swab collected for in-situ testing by Ag-RDT (antigen detecting rapid test; results in 15min) and transcription mediated amplification (TMA; antibody test; results in 24-48h). All TMA positive samples then re-tested by RT-PCR and viral cell culture. 2. Follow-up on day 8: nasopharyngeal swab collected for all participants and tested by RT-PCR, Ag-RDT and TMA. 3. Health questionnaire at day 0 and day 10 filled by participants (app). Randomisation: participants Ag-RDT negative randomised to intervention or control groups, stratified by age, gender and previous COVID-19. Intervention group: on entry participants given a mandatory N95 mask, and temperature screening. No physical distancing mandate, hand sanitiser available, staff to prevent crowding, all access doors open for fresh air replacement, CO2 levels monitored. Control group: participants sent home.	Baseline screening 1. Of the 960 participants included in the analysis (all Ag-RDT negative), 28 were TMA positive (13 experimental, 15 control; all of them had tested positive for SARS-CoV-2 a median of 50 days before). 2. Of these 28, 2 were RT-PCR positive (one each arm; Ct=37 for both), but cell culture negative. 3. Negative predictive value for Ag-RDT screening: 99.9% (95%CI 99.5-100) for positive RT-PCR and 99.8% (95%CI 99.3-100) for positive TMA. Follow-up testing on Day 8 1. 0/465 in experimental group tested positive using RT-PCR. (estimated incidence 0.14%; 95% CI 0 to 0.61) 2. 2/495 in control arm tested positive using Ag-RDT and RT-PCR. (0.31%; 95% CI 0.04 to 0.73); Ct=26.3 and 28. 3. Bayesian estimate for the incidence between the experimental and control groups: -0.15% (95%CI -0.72 to 0.44) No staff members became infected. CO2 concentration didn't exceed recommended threshold of 800 ppm (at the time of the study) at any point.	Information bias: follow-up testing was done 8 days after the event; authors noted it maximised likelihood of identifying cases from the events, although transmission outside the event could not be discarded as no genomic testing. Funders were linked to events economy in Barcelona but were clearly stated (and no role in the study). QCC rating: medium

	2. 1,140 responded, 1,047 participated (82% male; mean age 33.6 years). 3. 58 staff also included (but separated from results).	Duration: 5 hours; participants spent median of 2hr40mins inside. Statistical analysis: Bayesian beta-binomial model to analyse number of infected cases in each group. Bayesian Markov Chain Monte Carlos method to estimate negative predictive values of Ag-RDT test using as reference tests RT-PCR and viral cell culture.	European recommended air quality thresholds have since been updated, now would be median/good air quality.	
Moritz and others, 2020 (14) **PREPRINT** (v3; November 2020) (Website of the project: https://restart19.de/en/the-project/)	Study type: semi-experimental study (with a modelling component) Objective: to investigate COVID-19 transmission risk during an experimental indoor large concert event. Setting: live concert under experimental conditions; Leipzig arena (indoor), Germany. Reproduction number in Germany approximately 1. Study period: 22 August 2020 Participants: 2,825 registered, 1,407	Outcome: 1. Experimental: number of contacts, short (more than or equal to 5min) and long (more than or equal to 15min) within 1.5m of another participant, accumulated by each participant in each scenario. 2. Simulation: number of exposed people per infectious person rates between two ventilation systems. Experiment: 1. Tested within 48h before event. Those who tested negative invited to participate. On arrival, participants equipped with contact tracing device, N95 masks and hand sanitiser. 2. Three different scenarios, each treated as separate events and had same structure (one concert/event).	Experimental results: 1. Mean ±SD total number of contacts **over whole event**: a) S1: more than or equal to 15min: 8.9 ±3.5; more than or equal to 5min:14.1 ±5.2 b) S2: more than or equal to 15min: 4.7 ±1.9; more than or equal to 5min: 6.1 ±2.4 c) S3: more than or equal to 15min: 1.3 ±0.9; more than or equal to 5min: 2.2 ±1.5 2. Mean ± SD total number of contacts during **entrance period**: a) S1: more than or equal to 15min: 5.1 ±2.5; more than or equal to 5min: 8.7 ±4.1 b) S2: more than or equal to 15min: 3.7 ±1.6; more than or equal to 5min: 4.9 ±2.1	Study design: non-randomised, not blinded experimental study and model Bias: 1. Limited generalisability: Only applies to sitting indoor events. 2. Underpowered: arena capacity ~8000, aimed to recruit ~4000 but only 1212 recruited. 3. Potential bias if participants dropped out after 1 or 2 scenarios, so that numbers may have been lower at later (more segregated) events (number of participants in each scenario not reported). 4. Hawthorne effect: participants aware they were taking part in study. QCC rating: high

	screened, 1 had a positive test and was excluded. 1,212 took part (18-50 years old; 63.3% female, no obesity, and no pre-existing conditions). Recruited through media campaign.	a) **S1**, control: as pre-pandemic (2 main entrance/exit without restriction, no space between seats, toilets unchanged, usual catering). b) **S2**: moderate measures (arena divided in 4 quadrants, each with its own entrance/exit, participants restricted to their quadrant, checkboard pattern seating, every other urinal closed, catering restricted by quadrant). c) **S3**: strong measures (8 quadrants with own entrance/exits, pairwise seating with 1.5m in-between seats, catering and toilets as S2). <u>Duration:</u> 10 hours total (participants free to stay as long as they wanted). Including 2 hours for check in and 3 concerts. <u>Aerosol exposure simulation:</u> 1. Current ventilation system in arena compared to an alternative system to compare maximum number of exposed people per infectious person rates (modelled for S2; interpolated for S1 and S3). 2. Model: computational fluid dynamics model for aerosol exposure simulation. Natural	c) S3: more than or equal to 15min: 1.1 ±0.6; more than or equal to 5min: 2.0 ±1.3 3. Mean ± SD total number of contacts **during halftime**: a) S1: more than or equal to 15min: 1.8 ±1.3; more than or equal to 5min: 3.1 ±2.4 b) S2: more than or equal to 15min: 1.9 ±1.2; more than or equal to 5min: 2.6 ±1.5 c) S3: more than or equal to 15min: 0.8 ±0.7; more than or equal to 5min: 1.2 ±1.9 4. Mean ± S1: more than or equal to 15min: 4.5 ±2.1; more than or equal to 5min: 5.3 ±2.3 a) S2: more than or equal to 15min: 2.3 ±1.2; more than or equal to 5min: 2.7 ±1.3 b) S3: more than or equal to 15min: 1.0 ±0.3; more than or equal to 5min: 1.0 ±0.3 <u>Simulation results:</u> <u>Aerosol exposure simulation</u> 1. Version 1: current ventilation – air ejected from roof corners, jet nozzles to push air around, air rises to roof where its renewed; air exchange rate: 1.46/h.	

		history model developed as extended SEIR model for effect of event on SARS-CoV-2 epidemic spread simulation.	2. Version 2: no jet nozzles to reduce air rollers, air suctioned in the ceiling; air exchange rate: 0.85/h. 3. Maximum number of exposed people per infectious person was 10 in version 1 and 108 in version 2 4. Increased ventilation associated with reduced density of aerosols and therefore reduced exposure. 5. Scenarios 2 and 3 further reduced exposure under both ventilation conditions. <u>Effect of event on SARS-CoV-2 epidemic spread simulation</u> Estimated incidence attributed to MGE for an incidence of 100/100,000 per week and 100,000 people attending MGE each month: 1. S1: 2.3% 2. S2: 1.1% 3. S3: 0.4%	

Table B.3. Modelling studies (question 2)

Reference	Model characteristics	Scenarios and outcome measures	Finding
McCarthy and others, 2021 (15)	Objective: to develop a model of infection probability for diverse range of activities, including large outdoor sporting event. Settings: activity = well-defined set of interactions with clear bounds taking place over a period of time less than a day, including attending a sporting event as a spectator. Model: calculation of probability of being infected by one of the 3 main routes: 1) airborne transmission, 2) fomite transmission 3) direct transmission. Model parameters: For sports stadium: mask protocol, seating arrangement, time spent entering, time spent walking to one's seat, social distancing requirement in corridors, duration of game, concessions (which include ordering and eating), how risk decays with distance, aerosol risk, air volume in the stadium, bathroom design and constraints, presence or absence of screening of attendees. Study period: for sports game at stadium: 190 minutes game time plus time to enter and exit stadium.	Outcome: estimation of relative risks rather than absolute risks to take into account uncertainties. Baseline scenario: full stadium Comparator scenarios: half-full stadium, 21% full stadium and 21% full stadium with no eating or drinking. Assumptions for the sporting event: 1. Masks required. 2. 190min game duration. 3. Different seating arrangements, with different physical distance in-between, considered. 4. Different scenarios for time spent, such as, entering, walking in corridors.	Results for example of a sporting event 1. Simulation based on the TD Garden Stadium in Boston (US), considering all steps of such events (such as, entry, sitting, eating). Full capacity: 13,067. 2. "Risk unit" is the risk of spending one foot from a stranger. It is used to express relative risk and therefore to compare between mitigation strategies. 3. Estimated relative risks with different level of attendance: a) Full stadium: 1,044 risk units (of which 696 are from the seated portion). b) Half-full stadium: 335 risk units (of which 219 are from the seated portion) c) 21%-full stadium: 125 risk units (of which 77 are from the seated portion) d) 21%-full stadium, no eating or drinking: 83 risk units.

Annexe C. Excluded studies

Reference	Reason for exclusion
Adam, DC. and others, Clustering and superspreading potential of SARS-CoV-2 infections in Hong Kong	Wrong setting: not large organised events
Afroj, S. and others, Spatio-Temporal Patterns of the COVID-19 Pandemic in Bangladesh	Wrong outcomes: temporal trends
Ahmed, QA and others, The cancellation of mass gatherings (MGs)? Decision making in the time of COVID-19	Wrong setting: religious gathering (Hajj)
Aleta, A and others, Quantifying the importance and location of SARS-CoV-2 transmission events in large metropolitan areas	Wrong setting/exposure: community (metropolitan areas)
Althouse, BM. and others, Superspreading events in the transmission dynamics of SARS-CoV-2: Opportunities for interventions and control	Wrong setting/exposure: mixture of excluded settings including private events, cruise ships and workplaces
Anonymous, WHO Releases New Guidance For Outdoor Events And Mass Gatherings Amid Pandemic	Wrong study design: news article on guidance
Aravindakshan, A and others, Restarting after COVID-19: A Data-driven Evaluation of Opening Scenarios	Wrong setting: whole country, no specified events Wrong intervention: effect of easing restriction policies
Asif, IM and others, Returning Athletes Back to High School Sports in the COVID-19 Era: Preparing for the Fall	Wrong study design: opinion piece/guidelines
Atherstone, C, Time from Start of Quarantine to SARS-CoV-2 Positive Test Among Quarantined College and University Athletes - 17 States, June-October 2020	Wrong population: quarantined student athletes Wrong exposure: quarantining wasn't linked to an event
Atrubin, D and others, An Outbreak of COVID-19 Associated with a Recreational Hockey Game - Florida, June 2020	Wrong setting/exposure: less than 100 people at event and focused on players only
Ayub, AJ and others, Projecting the impact of behaviour and isolation interventions and super spreader events from mass gatherings and international travel on Malaysia's COVID-19 epidemic trajectories using an augmented SEIR model	Wrong exposure/outcomes: how national restrictions and policies affect cumulative cases and deaths Wrong setting: super spreader events, international travel and community
Azad, S and others, Tracking the spread of COVID-19 in India via social networks in the early phase of the pandemic	Wrong outcome: community case rates
Bhatia, R and others Suspension of mass gathering: A life saving measure against COVID-19	Wrong study design: editorial article

Brandl, M and others, Mass gathering events and undetected transmission of SARS-CoV-2 in vulnerable populations leading to an outbreak with high case fatality ratio in the district of Tirschenreuth, Germany	Wrong setting/exposure: skiing, beer festivals (multiple days and unknown sizes), private events Wrong outcome: crude case fatality rate, community transmission
Brooks Pollock, E and others, The Population Attributable Fraction (PAF) of cases due to gatherings and groups with relevance to COVID-19 mitigation strategies	Wrong exposure: everyday normal life contacts Wrong context: not COVID-19 specific, social contact data from a decade ago
Buldu, JM and others, The resumption of sports competitions after COVID-19 lockdown: The case of the Spanish football league	Wrong population: only league players Wrong setting: national football league, no specified organised event
Carlin, P and others, Effects of Large Gatherings on the COVID-19 Epidemic: Evidence From Professional and College Sports	Wrong setting: communities that host sporting events Wrong exposure: hosting games (not attendance at one or more of the games) Wrong outcome: community caseloads and mortality rates
Carmody, S and others, When can professional sport recommence safely during the COVID-19 pandemic? Risk assessment and factors to consider	Wrong study design: editorial article
CDC, Resources for Large Community Events & Mass Gatherings	Wrong study design: guidelines
Chau, NVV and others, Superspreading Event of SARS-CoV-2 Infection at a Bar, Ho Chi Minh City, Vietnam	Wrong setting: a bar with no specified organised event
Chau, PH and others, Construction of the Infection Curve of Local Cases of COVID-19 in Hong Kong using Back-Projection	Wrong setting: Hong Kong, no specified events Wrong outcome: community transmission
Chaw, L and others, Analysis of SARS-CoV-2 Transmission in Different Settings, Brunei	Wrong setting: large multi-day religious event (Tablighi Jama'at gathering)
Chaw, L and others, SARS-CoV-2 transmission in different settings: Analysis of cases and close contacts from the Tablighi cluster in Brunei Darussalam	Wrong setting: large multi-day religious event (Tablighi Jama′at gathering)
Che Mat, NF and others, A single mass gathering resulted in massive transmission of COVID-19 infections in Malaysia with further international spread	Wrong setting: large multi-day religious event (Sri Petaling gathering)
Chen, J and others, Travel rush during Chinese Spring Festival and the 2019-nCoV	Wrong setting: Chinese spring festival Wrong exposure: travel Wrong outcome: link between number of travellers and cases
Cuschieri, S and others, Mass Events Trigger Malta's Second Peak After Initial Successful Pandemic Suppression	Wrong exposure: small/ private (religious holiday) or unorganised events (hotel pool party) Wrong outcome: community cases, measures taken as a result

Dave, D and others, The contagion externality of a superspreading event: The Sturgis Motorcycle Rally and COVID-19	Wrong setting: motorcycle rally set over 10 days (settings which may have a venue, but involve overnight or long-term stay) Wrong outcome: impact on local community
Dave, D and others, Risk Aversion, Offsetting Community Effects, and COVID-19: Evidence from an Indoor Political Rally	Wrong setting: Tulsa county Wrong outcome: deaths, behavioural changes, community spread
Deforche, K and others, Behavioral changes before lockdown, and decreased retail and recreation mobility during lockdown, contributed most to the successful control of the COVID-19 epidemic in 35 Western countries	Wrong setting: western countries Wrong intervention/exposure: mobility restrictions and behavioural changes Wrong outcome: link between restriction implementation and R number change
DiFiori, JP, Return to sport for North American professional sport leagues in the context of COVID-19	Wrong study design: guidelines
England, R and others, The Potential for Airborne Transmission of SARS-CoV-2 in Sport: A Cricket Case Study	Wrong setting/exposure: small gathering Less than100 people and focused on players
Escher, AR Jr, An Ounce of Prevention: Coronavirus (COVID-19) and Mass Gatherings	Wrong study design: editorial article
Farahani, AJ and others, Salient points to observe in mass ceremonies during the COVID-19 pandemic	Wrong study design: letter
Farthing, TS and others, Assessing the efficacy of interventions to control indoor SARS-Cov-2 transmission: an agent-based modeling approach	Wrong setting: used a small gathering (less than100) as benchmark Wrong outcome: interventions that work best at controlling transmission
Firestone, MJ and others, COVID-19 Outbreak Associated with a 10-Day Motorcycle Rally in a Neighboring State - Minnesota, August-September 2020	Wrong setting: Minnesota Wrong exposure: 10 day motorcycle rally (may have a venue, but involve overnight or long-term stay)
Frieden, TR and others, Identifying and Interrupting Superspreading Events-Implications for Control of Severe Acute Respiratory Syndrome Coronavirus 2	Wrong study design: opinion piece
Furuse, Y, Risk at mass-gathering events and the usefulness of complementary events during COVID-19 pandemic	Wrong study design: letter to the editor
Furuse, Y and others, Clusters of Coronavirus Disease in Communities, Japan, January-April 2020	Wrong setting: restaurants and bars Wrong outcomes: unclear detail on clusters, rates of symptomatic/ asymptomatic illness
Gallego, V and others, The COVID-19 outbreak and implications for the Tokyo 2020 Summer Olympic Games	Wrong study design: editorial
Greene, SK and others, Detecting Emerging COVID-19 Community Outbreaks at High	Wrong setting/exposure: no specific large organised event

Spatiotemporal Resolution - New York City, June-July 2020	Wrong outcome: community transmission hotspots
Chen, Q and others, Why crowding matters in the time of COVID-19 pandemic? - a lesson from the carnival effect on the 2017/2018 influenza epidemic in the Netherlands	Wrong context: influenza season and COVID-19 Wrong setting: no established venue
Gulrandhe, P and others, Repercussions of mass gathering: Covid-19 pandemic	Wrong study design: review
Hasan, A and others, Superspreading in early transmissions of COVID-19 in Indonesia	Wrong exposure: no specific large organised event Wrong outcome: community transmission
Hoang, VT and others, The Tokyo Olympic Games and the Risk of COVID-19	Wrong study design: review
Hughes, D and others, The Australian Institute of Sport framework for rebooting sport in a COVID-19 environment	Wrong study design: review
Lau, MSY and others, Characterizing superspreading events and age-specific infectiousness of SARS-CoV-2 transmission in Georgia, USA	Wrong setting/exposure: community, no specific large organised event Wrong outcome: community transmission
Le, TD and others, Influences of reopening businesses and social venues: COVID-19 incidence rate in East Texas county	Wrong setting/exposure: no specific large organised event Wrong interventions: lifting of restrictions
Leclerc, QJ and others, What settings have been linked to SARS-CoV-2 transmission clusters?	Wrong study design: systematic review
Lemieux, JE and others, Phylogenetic analysis of SARS-CoV-2 in the Boston area highlights the role of recurrent importation and superspreading events	Preprint of article included
Lewis, D, Superspreading drives the COVID pandemic - and could help to tame it	Wrong study design: news article
Limbachia, J and others, Organizing a Mass Gathering Amidst a Rising COVID-19 Public Health Crisis: Lessons Learned From a Chinese Public Health Forum in Vancouver, BC	Wrong outcome: discussing prevention strategies put in place. No follow up of attendees
Luethy PM and others, Estimating the Burden of COVID-19 Symptoms Among Participants at the 2020 USA Curling Club Nationals Tournament	Wrong population: focused on the players and officials. Very little focus on the spectators.
Mack, CD and others, Implementation and Evolution of Mitigation Measures, Testing, and Contact Tracing in the National Football League, August 9-November 21, 2020	Wrong exposure: work related contact for staff and players in National Football League (NFL), no particular event specified
Majra, D and others, SARS-CoV-2 (COVID-19) superspreader events	Wrong outcome: effect on community outside of super spreader events (events not specified)

Manfred, N and others, CO2 measurements in instrumental and vocal closed room settings as a risk reducing measure for a Coronavirus infection	Wrong outcome: CO_2 measurements
McCarthy, JE and others, A deterministic linear infection model to inform Risk-Cost-Benefit Analysis of activities during the SARS-CoV-2 pandemic	Preprint of included article
Medizinische Fakultat der, MLU, Risk prediction of indoor Sports And culture events for the Transmission of COVID-19	Website for German RESTART-19 study
Miller, SL and others, Transmission of SARS-CoV-2 by inhalation of respiratory aerosol in the Skagit Valley Chorale superspreading event	Wrong setting: small gathering (less than100 people), not an organised large event
Miron, O and others, Association of Mass Gatherings and COVID-19 Hospitalization	Wrong outcome: community level hospitalisation rates
Miron, O and others, COVID-19 Mortality Following Mass Gatherings	Wrong outcome: community level mortality rates
Mulcahey, ML and others, Sports Medicine Considerations During the COVID-19 Pandemic	Wrong setting/population: athletes Wrong exposure: training and taking part in sports Wrong outcome: effect on population and guidelines for safe return
Muller, N and others, Severe Acute Respiratory Syndrome Coronavirus 2 Outbreak Related to a Nightclub, Germany, 2020	Wrong setting: not organised large event i
Parker, J and others, Advancing toward normal operations for arenas and stadiums	Wrong study design: guidance
Popa, A and others, Genomic epidemiology of superspreading events in Austria reveals mutational dynamics and transmission properties of SARS-CoV-2	Wrong exposure: community in Austria, doesn't specify events Wrong outcomes: genome sequences found in Austria
Qian, H and others, Indoor transmission of SARS-CoV-2	Wrong exposure: variety of excluded settings including homes, transport, restaurants, shopping centres
Santos-Ferreira, D and others, TEAM to Defeat COVID-19: A Management Strategy Plan to Address Return to Play in Sports Medicine	Wrong study design: review Wrong setting/population: athletes Wrong intervention/exposure: about return to play
Sassano, M and others, Transmission of SARS-CoV-2 and Other Infections at Large Sports Gatherings: A Surprising Gap in Our Knowledge	Wrong study type: opinion article
Scerri, M and others, Sports and sportsmen as role models - or otherwise - in the COVID-19 era	Withdrawn from publication Wrong population: athletes Wrong outcome: behaviour
Schumacher, YO and others, Resuming professional football (soccer) during the	Wrong population: footballers and staff during football season

COVID-19 pandemic in a country with high infection rates: a prospective cohort study	
Scott, N and others, Modelling the impact of reducing control measures on the COVID-19 pandemic in a low transmission setting	Wrong setting: community of Victoria, Australia Wrong intervention: relaxing of restrictions
Scott, N and others, Modelling the impact of relaxing COVID-19 control measures during a period of low viral transmission	Same as above
Signorelli, C and others, Major sports events and the transmission of SARS-CoV-2: analysis of seven case-studies in Europe	Wrong study design: letter
Sokhna, and others, The Grand Magal of Touba was spared by the COVID-19 pandemic	Wrong setting: religious gathering (The Grand Magal)
Sookaromdee, P and others, Sport stadium as spreading source of COVID-19	Wrong study design: letter to the editor
Sun, Z and others, Community venue exposure risk estimator for the COVID-19 pandemic	Wrong exposure: community
Timpka, T, Sport in the tracks and fields of the corona virus: Critical issues during the exit from lockdown	Wrong study design: opinion piece Wrong population: athletes
Valencia, C and others, Asymptomatic and Presymptomatic Transmission of 2019 Novel Coronavirus (COVID-19) Infection: An Estimation from a Cluster of Confirmed Cases in Ho Chi Minh City, Vietnam	Wrong setting: not organised large event
Weed, M and others, Rapid Scoping Review of Evidence of Outdoor Transmission of COVID-19	Wrong study design: systematic or narrative review

About Public Health England

Public Health England exists to protect and improve the nation's health and wellbeing, and reduce health inequalities. We do this through world-leading science, knowledge and intelligence, advocacy, partnerships and the delivery of specialist public health services. We are an executive agency of the Department of Health and Social Care, and a distinct delivery organisation with operational autonomy. We provide government, local government, the NHS, Parliament, industry and the public with evidence-based professional, scientific and delivery expertise and support.

Public Health England
Wellington House
133-155 Waterloo Road
London SE1 8UG
Tel: 020 7654 8000

Prepared by: Daphne Duval, Bethany Walters, Nicola Pearce-Smith, Rachel Clark
For queries relating to this document, please contact: enquiries@ukhsa.gov.uk

Gateway number GOV-15229

PHE supports the UN Sustainable Development Goals