Risk mitigation for South Australian choirs: a rapid literature review

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Contents

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Glossary

Airborne particles
Any particles in the air of any size including aerosols, droplets, airborne viruses, moulds and pollens

Aerosol particles
Airborne particles of ≤5µm diameter

Attack rate
The percentage of an at-risk population that contracts the disease during a specified time

COVID-19 (Corona virus disease 2019)
A new infectious respiratory disease caused by the SARS-CoV-2 virus. It was first identified in 2019 in China.

Direct contact
Direct body-surface-to-body-surface contact between an infected person and a susceptible person

Droplet particles
Airborne particles of ≥5-10µm

Fomite
An inanimate object that, when contaminated with or exposed to infectious agents (such as bacteria or viruses), can transfer disease to a new host

Indirect contact
Contact of a susceptible person with a contaminated intermediate object that carries and transfers the microorganisms

MERS (Middle Eastern respiratory syndrome
A viral respiratory disease caused by a coronavirus. It was first identified in 2012 in Saudi Arabia.

Minimum infectious dose
The minimum number of infectious particles that causes infection or illness

Reproductive number
The expected number of cases directly generated by one case in a population

RNA (Ribonucleic acid)
A long usually single stranded chain of genetic information used in making protein in all living cells

SARS (Severe Acute Respiratory Syndrome)
A viral respiratory disease caused by a coronavirus. It was first identified in February 2003 in China.

SARS-CoV-1 (Severe acute respiratory syndrome coronavirus 1)
The virus responsible for Severe Acute Respiratory Syndrome first identified in February 2003

SARS-CoV-2 (Severe acute respiratory syndrome coronavirus 2)
The virus responsible for the COVID-19 disease

Virion
The entire infectious virus particle consisting of an outer shell and an inner core of nucleic acid

Executive Summary

Choir rehearsals and related activities including faith-based gatherings, musical performances and other settings likely to involve singing have been identified by epidemiological reports to be connected with the transmission of COVID-19. There is concern that singing in groups conveys a risk of infection with COVID-19 beyond the risk of the gathering of people.

A rapid review of the literature was undertaken for the Adelaide Choral Network with contribution from SA Health to the review of the paper. The aim was to review the emerging scientific evidence regarding steps in the pathway of likely transmission of COVID-19 within choir rehearsals. The review also examines emerging evidence of the likely effectiveness of control measures for singing gatherings. The review was limited by the resources available to the Adelaide Choral Network in September and October of 2020. The findings have informed the development of risk management guidance to South Australian choirs.

This rapid review of the literature regarding risk mitigation for South Australian choirs found singing in choirs **is** associated with an increased risk of transmission of COVID-19, but a combination of risk mitigation strategies, while not completely eliminating risk, will provide the best protection.

Although the routes of transmission of COVID-19 in choir settings are not fully understood there was agreement that the routes include direct person-to-person contact, and indirect transmission through droplet, aerosol and contact with fomites.

Singing in choirs was found to be a higher risk activity because:

- Louder singing and speaking have been associated with increased emissions of airborne particles
- There is an agreed biological mechanism for the emission of the SARS-CoV-2 virus in aerosol and droplet form from the lungs
- Exposure to COVID-19 is possible within the timeframes of typical rehearsals if the environmental conditions encourage it
- Multiple outbreaks of one-to-many transmission (superspreading) in choirs have been described
- Large individual variations in emission of airborne particles have been demonstrated and speculated to play a role in outbreaks within choral singing rehearsals.

This literature review suggests choirs within communities with low COVID-19 prevalence should adopt **multiple control measures** integrated within a **planned risk mitigation strategy** to maximise the safety of choral rehearsals. Fixed risks such as choir members with comorbidities or of older age should be integrated into risk mitigation strategies. Control measures, in addition to hand hygiene and the avoidance of direct contact, that are particularly important for choirs should focus on:

- The **critical role of ventilation** in rehearsal spaces
- **Physical distancing of at least 2m to the front** and 1.5m to the side
- **Environmental cleaning** processes
- An understanding of the effective **use of masks for singers**.

Most of the studies or commentary reviewed were of an observational or theoretical nature or were secondary reporting of research. Therefore the literature regarding COVID-19 can be thought of as emerging and fragmented. Until further primary research specific to choir settings has been undertaken, the precautionary principle suggests that diligent implementation of multiple control measures will provide choirs with the best chance of safely returning to rehearsals and performances.

How does science help us get back to singing together?- An aside on the role of science.

At its simplest, scientific research is defined as a systematic inquiry into a phenomenon for the purpose of establishing knowledge. It differs from public health advice, law and regulation which aim to prevent the spread of a disease or promote healthy practices within a population.

Scientific research is focussed on developing a better understanding of a phenomenon like COVID-19. The technical concept of *validity* within a research project is important because public health actions based on the evidence produced by scientific research will affect the whole population. Study validity can be defined as the extent to which the findings of scientific research will be true in similar populations outside the study. The design and implementation of a research study ideally should maximise validity (Rychetnik et al. 2004). Therefore conducting scientific research can take time, sometimes years. As an added complication, repetition of experiments (*reliability*) is required to be confident of knowledge claims (*evidence*) that might underpin public health action (Rychetnik et al. 2004).

In contrast, public health action to protect populations in the context of a pandemic has to be taken very quickly and within the socio-political culture of a community. Actions are initially based on the best available evidence, which in the case of COVID-19 has been the previous outbreaks of corona viruses, for example, MERS and SARS-CoV-1. Law and regulation are designed to empower public health officials to take quick action to protect the population, which in the case of COVID-19 has been necessary within days of the first reported case. Public health advice is given in a way that promotes action from community members in the best interests of the whole population.

A problem with timing therefore exists. While public health action in a pandemic must be taken quickly to protect the community in the context of incomplete and fragmentary evidence, it is likely to take years to build the scientific evidence base around a pandemic such as COVID-19.

The scientific research surrounding singing and COVID-19 in this review is therefore described as emerging and fragmented, meaning there is not yet agreement on the risks of singing and the effectiveness of control measures. The fields of scientific interest pertinent to singing within a COVID-19 pandemic include:

- epidemiology used to study the characteristics of outbreaks
- virology which examines how viruses live and reproduce
- medical science to better understand the disease, treatment, transmission routes and prevention through vaccines
- physical sciences which further the understanding of the behaviour of airborne particles
- engineering which targets innovative solutions to the problems of, for example, improved ventilation systems for buildings

Over time the findings from scientific research will influence public health actions. Fortunately the pace of research into COVID-19 has been rapid, as this literature review shows. As more evidence accumulates, we will become more confident in making changes to advice concerning singing in groups that, while not completely eliminating risk, will provide an acceptable level of risk for choral singing.

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Introduction

One of the most evocative scenes of the beginning of the COVID-19 pandemic was when Italians took to their balconies to sing in response to the social isolation of lockdown (Corvo et al. 2020; Naunheim et al. 2020). Research is starting to define the benefits of group singing by looking at the improvements in mental wellbeing and social cohesion within our communities when we sing together (Clift et al. 2011; Corvo et al. 2020). But more than that, singing in groups is important to convey who we are as people and how we relate to each other. The important role of the expressive arts in responding to the experience of COVID-19 was expressed by the following observation of Italians singing to one another,

"The antidote of musical solidarity in a time of coronavirus provides a joyful reminder of the deep human will to always find our way back to one another. Even a nationwide quarantine or a deadly pandemic cannot prevent us from connecting and supporting each other through life's darkest hours" (Gupta 2020).

In Adelaide some 8000 singers meet frequently to sing with approximately 80 choirs or singing groups. A recent survey of choirs (May 2020) in Adelaide showed the extent to which singers miss the social, musical and physical benefits of regular singing.

Unfortunately, at least six events of presumed one-to-many (super-spreading) transmission of COViD-19 have been reported within choir rehearsals in 5 countries. Consequently government health departments have recommended restrictions on singing in groups. At the time of writing, Australia is in the very fortunate position of having had no outbreak reported in an Australian choir rehearsal.

The reasons for concern regarding the COVID-19 pandemic include:

- The SARS-CoV-2 virus responsible for COVID-19 is a new pathogen to which most people do not have immunity.
- The virus can be transmitted through multiple routes.
- The virus can be distributed widely through the air in an indoor space.
- The virus can be spread by pre-symptomatic and asymptomatic patients who do not know they are infectious. The incubation period is 5-6 days and can be up to 14 days (Australian Government Department of Health 2020).
- There is a small chance of death - the median case fatality rate amongst countries was 2.3% (Johns Hopkins University and Medicine 2020). For Australians aged $\geq$ 80 years it was 22.3% (COVID-19 National Incident Room Surveillance Team 2020).
- There is an unknown chance of morbidity (future illness) arising from infection. The full range of future conditions that may result from infection with COVID-19 are unknown.

An outbreak in a choir rehearsal in Spain illustrates the problem for choirs well. On 11 September 2020 41 members of the River Troupe Gospel attended a rehearsal leading up to their open-air performance on the 13th September. The choir complied with risk mitigation measures at the rehearsal including temperature checks on arrival, hand washing and physical distancing, and singers wore masks for most of the rehearsal. However, the venue's windows had been closed to avoid moths and mosquitoes, and the air conditioning had been switched on because it was hot. One singer tested positive on the 13th September and all choir members and their close contacts isolated from that date. Thirty of the 41 singers developed COVID-19 (Associated Press 2020).

This rapid review of the literature was undertaken for the Adelaide Choral Network with contribution from SA Health. It aimed to review the emerging scientific evidence regarding steps in the pathway of likely transmission of COVID-19 within choir rehearsals. The review also examines evidence of the likely effectiveness of control measures that might allow a safe return to rehearsals. The findings have informed the development of risk management guidance to choirs in the South Australian context of few active reported cases of COVID-19.

The review was limited by the resources available to the Adelaide Choral Network in September and October of 2020. Publicly available evidence databases were searched using the search strategy outlined in Appendix 2. Only journal articles in the public domain were included. The review was largely limited to papers published in 2020. A total of 103 journal articles were identified using the search strategy and through the references of those articles. Eighteen of these related directly to singing in groups.

The review was structured around the questions in Table 1 derived from areas discussed by Professor Jonathon Reid, School of Chemistry, University of Bristol in a podcast on his research into the risks of singing (Davis et al. 28 July 2020). The scope of the literature review was agreed with Adelaide Choral Network to focus on risk mitigation strategies specific to singing in groups, and therefore does not explore areas relevant to the general population, for example, hand hygiene.

Table 1: Review Questions

1.	What quantity of aerosol and droplet is emitted from singers in comparison to speaking and breathing?
2.	What is the infectious potential of aerosol and droplets emitted from singers?
3.	What is the infectious potential of fomites[1] in choral rehearsal settings?
4.	Under what circumstances have people become infected with COVID-19 during choral rehearsals?
5.	What aspects of indoor ventilation are effective in preventing infection with COVID-19 in choral rehearsals?
6.	How effective are cleaning protocols in preventing viral persistence on fomites[1] in choral rehearsals
7.	What is the consensus for safe physical distancing in the choral rehearsal setting?
8.	What is the evidence for the effectiveness of masks in singing settings?

[1] A fomite is an inanimate object that, when contaminated with or exposed to infectious agents (such as bacteria or viruses), can transfer disease to a new host.

Summary of Evidence

The following sections summarize the research evidence relating to each question in Table 1. Although every attempt has been made to clearly synthesize and explain scientific information, no attempt has been made to express scientific concepts in plain language in the recognition that many choral singers also have significant professional experience in the sciences.

Severe Acute Respiratory Syndrome Corona virus 2 (SARS-CoV-2) is the virus which causes Corona Virus Disease 2019 (COVID-19). The term SARS-CoV-2 is used when referring to the virus. Otherwise COVID-19 is used. The SARS-CoV-2 virus is between 60 and 140nm in diameter (0.06-0.14 µm). It is in the family of coronaviruses that include SARS-CoV-1, the Middle East respiratory virus (MERS) and rhinovirus, and can infect humans and other mammals. The virus can enter the host body (person who gets the disease) by binding to a cell. The host cells can react with protective responses that may lead to pneumonia and in some cases severe acute respiratory distress syndrome (Astuti et al. 2020; Vuorinen 2020). The term virion is only used in this review when a distinction was made between the virion (entire infectious virus particle consisting of an outer shell and an inner core of nucleic acid) and viral nucleic acid. Otherwise the term virus is used.

Recognized transmission routes for COVID-19 include *direct contact* between people, *and indirect contact* with the virus in airborne particles and on contaminated surfaces (Santarpia et al. 2020; Spahn et al. 2020). Direct contact is defined by the World Health Organisation (WHO) as a direct body-surface-to-body-surface contact between an infected person and a susceptible person, with physical transfer of microorganisms. Indirect contact is defined by the WHO as transmission involving contact of a susceptible person with a contaminated intermediate object that carries and transfers the microorganisms (World Health Organisation 2014). Avoidance of direct physical contact and good hand hygiene are well accepted control measures in the prevention of COVID-19 transmission (Vardoulakis et al. 2020) and as such, are addressed in the risk guidance for singers and will not be considered in detail in this review.

Airborne particles in this review means any particles in the air of any size including aerosols, droplets, airborne viruses, moulds and pollens (Koch 2020). There was general agreement that aerosols are particles of a diameter ≤ 5-10µm (Anderson et al. 2020; Chong et al. 2020; Corriea et al. 2020; Fenelly 2020; Gregson et al. 2020; Tang et al. 2020). This review adopts the WHO definition of ≤5µm for *aerosol particles* (World Health Organisation 2014). There was some disagreement about the smallest size of droplets but general agreement that particles ≥ 20µm were droplets (Alsved et al. 2020; Anderson et al. 2020; Anfinrud et al. 2020; Chong et al. 2020; Corriea et al. 2020; Kohanski et al. 2020; Tang et al. 2020). This review adopts the WHO definition of ≥5-10µm diameter for *droplet particles* (World Health Organisation 2014). Aerosols travel straight out horizontally (Chong et al. 2020), remain airborne indefinitely (Fenelly 2020), and behave like a cloud (Kohanski et al. 2020). Droplets leave the body and drop in a curved trajectory to the floor with their trajectory depending on their size (Chong et al. 2020; Koch 2020). The different behaviour of aerosols and droplets has implications for mitigation strategies. For further discussion of airborne particle behaviour see Appendix 1.

It is now accepted that aerosol as well as the historically described droplet route play a part in infection with COVID-19, and this review assumes aerosols as a mode of transmission (Chong et al. 2020; Corriea et al. 2020; De Olivera 2020; Fenelly 2020).

Choir rehearsal or reference to the choral setting in this review means any singing gathering where ≥2 people sing together in a static, grouped arrangement. Settings include community and religious situations as well as many other occasions where singing in groups occurs. The findings of the review may also be relevant to forms of singing combined with acting, for example, music theatre and opera, or where singing is combined with instrumental groups, for example, bands, jazz ensembles and chamber music.

1. What quantity of aerosol and droplet is emitted from singers in comparison to speaking and breathing?

Major finding

- Louder singing or speaking was associated with increased emission of aerosol and droplet sized particles
- Individual variability in the quantity of airborne particles emitted is high. Some individuals are described as super-emitters because they can consistently emit a very large quantity of airborne particles.

Gaps in knowledge

- Large experimental studies of the quantities of aerosol and droplet emitted from singers and groups of singers
- Research on the airborne particle emissions associated with different types of phonation used in singing

Implications

- Risk guidelines should include the risks associated with the volume of singing and, if appropriate, the use of amplification to avoid the need for loud singing
- It is recommended that Lydia Morawska (QUT) and Con Doolan (UNSW) be contacted regarding further information about mathematical modelling of choral rehearsals and performances, and further evaluation of existing research using mathematical models

This section describes the differences in airborne particle emission between singing, speaking and breathing, and summarises the literature on airborne particle research and singing. Review of the literature on airborne particles indicated a complex relationship between the quantity of aerosol and droplet and the environment into which airborne particles are emitted. This is summarized in Appendix 1. The major finding was that increased volume for both singing and speaking generated higher airborne particle concentrations than breathing. Also important was the consistent finding of individual variability in the quantity of aerosol emitted. Research in this area was noted to be emerging and therefore it was difficult make conclusive statements.

Five studies of airborne particle behaviour were conducted on singers (Alsved et al. 2020; Bahl et al. 2020; Echternach et al. 2020; Gregson et al. 2020; Mürbe et al. 2020). In addition a brief report by Becher et al using the schlieren method of visualising the spreading of air, and a study by Kähler and Hain examined singing as well as other instruments. The latter two studies were considered methodologically weaker because the reports focussed more on wind and brass instruments and lacked detail on singing (Becher et al. 2020; Kähler, CJ et al. 2020a). Comparison of studies was difficult due to the use of different measurements of airborne particles. Measurements included the count of particles, the rate at which they were emitted, the distribution of particle diameters, the concentration of particles and the mass concentration. Gregson et al's study is the strongest study methodology due to the large number and variety of singers, and is preferred here.

Gregson et al confirmed the two known modes of distribution of particles of different diameters, one emitted from the lower lung with a lower median particle size and one from the laryngeal area with a higher median size (Morawska et al. 2009). Singing and speaking were noted to generate airborne particle sizes that were larger than those generated by breathing, (Gregson et al. 2020) consistent with theories about the role of vocalisation in fluid film bursts.

Volume

There was consistent agreement that louder volumes of both singing and speaking produced more aerosol and droplet than softer vocalisations (Alsved et al. 2020; Anfinrud et al. 2020; Asadi et al. 2019; Becher et al. 2020; Echternach et al. 2020; Gregson et al. 2020; Koch 2020; Mürbe et al. 2020; Spahn et al. 2020). Gregson et al's study showed that at 50-60dB (quietest) the mass concentration emitted from singing, speaking and breathing were not significantly different. The change in mass concentration for both speaking and singing showed steep increases with increased volume. At 90-100dB (loudest), singing had a slightly but significantly increased mass concentration in comparison to speaking at the same volume (Gregson et al. 2020). Combined with the extended nature of singing vocalisation, it could therefore be expected that aerosol and droplets emitted during choral rehearsals would be closer to the upper limits found in Gregson et al's research.

Smaller studies of singers found a highest to lowest rate of aerosol particle emission (per second) from loud singing to softer singing to speaking to breathing (Alsved et al. 2020; Mürbe et al. 2020) (Table 2).

Table 2: Aerosol particles/second emitted

	Breathing	Normal talking	Loud talking	Normal singing	Loud singing	Loud singing with exaggerated diction
(Alsved et al. 2020)		270 (120-1380)	570 (180-1760)	690 (320-2870)	980 (390-2870)	1480 (200-1150)
(Mürbe et al. 2020)	4.71-84.76			753.4-6093.14		

Several other studies reported on airborne particle emissions associated with speaking (Asadi et al. 2019, 2020b; Kohanski et al. 2020; Morawska et al. 2009; Stadnytskyi et al. 2020) Morawska (Queensland University of Technology) has a substantial authorship on respiratory particle behaviour spanning ten years. She showed in 2009 that speaking generated more airborne particle mass concentration than breathing (Morawska et al. 2009), consistent with Asadi et al. (2019).

Individual variability in emissions

Three studies identified a high level of Individual variability in emissions (Asadi et al. 2019; Gregson et al. 2020; Stadnytskyi et al. 2020). This is interesting because authors have theorised about the ability of some individuals to be super-spreaders (Althouse et al. 2020; Miller et al. 2020). A small number of individuals were found in studies to generate airborne particles at a rate 100 times (Stadnytskyi et al. 2020) to 1000 times (Gregson et al. 2020) higher than the median. Individual variation was specific to the activity, for example, breathing, speaking or singing (Gregson et al. 2020), and remained constant over several months (Asadi et al. 2019).

Vowels and consonants

Speech and singing are active processes of the respiratory tract which modify the emission of aerosol and droplets. The plosive consonants ‘p’, ‘b’, ‘r’, and ‘t’ in speech and singing were shown to generate a high number of small to large droplets (Alsved et al. 2020), aerosol (Asadi et al. 2020b) and airborne spread (Becher et al. 2020). Spoken ‘t’ and ‘f’ (Figure 1) generated fast average initial velocities (Bahl et al. 2020; Giovanni et al. 2020). Disyllabic words in speech including plosive consonants, for example, ‘gaga’ were noted to yield more airborne particles (0.5-20 µm) than voiceless fricatives, for example ‘s’, ‘h’, ‘f’ ‘th’ (Asadi et al. 2020b; Stadnytskyi et al. 2020). This finding was consistent with Alsved’s work showing that loud singing with exaggerated diction produced the highest aerosol content (Alsved et al. 2020).

Of the vowels in Asadi’s study of speech, ‘i’ as in ‘heed’ had a higher particle emission than other vowels (Asadi et al. 2020b). Echternach et al investigated sung phrases and found that sung melody on a vowel only (without consonants) produced aerosol that travelled less distance than singing of full-text (Echternach et al. 2020).

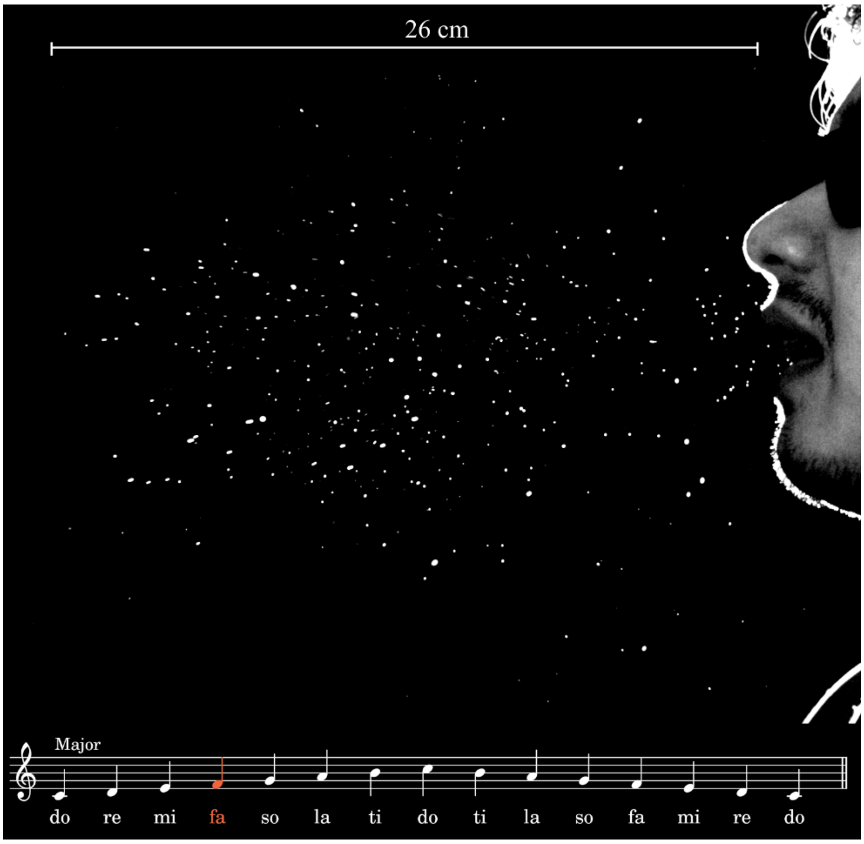

Figure 1: Flow visualisation of aerosols and droplets emitted during singing ‘fa’.

Note: Reproduced from Bahl, P, de Silva, C, Battacharjee, S, Stone, H, Doolan, C, Chughtai, AA and MacIntyre, CR. 2020 Droplets and aerosols generated by singing and the risk of coronavirus disease 2019 for choirs. Brief report. Clinical Infectious Diseases, https://doi.org/10.1093/cid/ciaa1241 with permission from Professor Con Doolan.

Velocity of emission

Bahl et al in an Australian study have shown the maximum velocity of emission of particles from a singer to be approximately 6 metres/second, similar to speech (Bahl et al. 2020). By 15cm from the singer's mouth, 75% of particles were moving less than 0.5m/s, and equally distributed in all directions. The authors conclude these particles are following the ambient airflow pattern at these speeds (Bahl et al. 2020). For coughing, particles were moving at an initial fast speed (50% moving at 6m/s) in comparison to speaking (15% moving at 6m/s) (Bahl et al. 2020). Velocity of emission is connected to the distance travelled by droplets. Bourouiba's study demonstrated that although some 60-100 µm droplets could travel up to 6-8m if emitted at high speed via a sneeze or cough, most settled within 2m (Bourouiba et al. 2014). Distance travelled by airborne particles is further discussed in Question 7 of this review, What is the consensus for safe physical distancing for choral rehearsals?

Pitch

There was a suggestion that higher pitched singing increased aerosol emissions and the author attributed this to possible increased sound pressure (amount of air released per time unit) used to generate sounds at higher pitches (Alsved et al. 2020).

Gender

There was a lack of agreement between the two studies regarding the effect of singer gender on airborne particle emission. Murbe et al in their smaller study found that females produced more aerosol but Gregson et al found no difference between genders (Gregson et al. 2020; Mürbe et al. 2020).

Other characteristics

A number of other characteristics were examined in single studies.

- Gregson et al found no difference in aerosol production between genres of singing including opera, music theatre, choral , gospel, rock, jazz, pop, soul and actor with singing (Gregson et al. 2020).
- Body mass index and measurement of peak expiratory flow also did not associate with changes in aerosol emission (Gregson et al. 2020).
- There was no difference between the four spoken languages tested by Asadi in 2019 (Asadi et al. 2019).
- One study found that professional singers generated twice as much aerosol than amateur (Alsved et al. 2020).
- Spahn et al raised the issue of increased phlegm production while singing as a possible issue for increased infectiousness (Spahn et al. 2020)

2. What is the infectious potential of aerosol and droplets emitted from singers?

Major finding

- Both droplet and aerosol sized particles are big enough to carry the SARS-CoV-2 virion
- There is an agreed biological mechanism for emission of the SARS-CoV-2 virion in aerosol and droplet form from the lungs
- Theoretical modelling shows that exposure to COVID-19 is possible within the timeframes of typical rehearsals if the environmental conditions encourage it
- Theoretical modelling suggests that increased room volume dilutes the concentration of virus

Gaps in knowledge

- Information to establish the minimum infectious dose of SARS-CoV-2 in choral settings
- Information about the detection of virions within aerosol in real-life settings is needed to establish its infectious potential

Implications

- Risk mitigation cannot rely solely on a directive to unwell people not to attend rehearsals
- Effective ventilation of rehearsal venues is of critical importance
- Larger rehearsal rooms may reduce the exposure of singers to infected aerosols
- Rapid testing for COVID-19, when available, may be useful to choirs to lower the risk of individuals who don't know they are infectious attending rehearsals

This section summarizes information about the infective potential of airborne SARS-CoV-2. No studies specific to choirs or singing gatherings could be found. Therefore a general overview of the biology of infection, estimates of the amount of virus in airborne particles, survival time of the virus in the air and minimum infectious dose is provided. The consideration of airborne particles deposited on surfaces follows in the next section. The main finding was that a plausible biological mechanism for infection could be theorized but more research was needed to confirm theories of transmission and the minimum infectious dose.

Brief summary of the biology of the virus

The SARS-CoV-2 virus is made up of a positive sense non-segmented RNA genome within an envelope. A crown of spikes on the envelope gives it its name. The virus is between 60 and 140nm in diameter (0.05-0.14 µm). It is in the family of coronaviruses that include SARS-CoV-1, the Middle East respiratory virus (MERS) and rhinovirus, and can infect humans and other mammals. The virus can enter the host body (person who gets the disease) by binding to a cell. The host cells can react with protective responses that may lead to pneumonia and in some cases Severe Acute Respiratory Distress Syndrome (Astuti et al. 2020; Vuorinen 2020).

Production of airborne particles

The viral load is said to be higher in the lungs than the upper respiratory tract (Tang et al. 2020). Airborne particles consisting of secretions from the lungs are hypothesized to form primarily through a 'fluid-film burst' inside the small airways of the lungs. Asadi provides the following explanation which is consistent with other authors' understanding (Asadi et al. 2019; Buonanno et al. 2020; Mürbe et al. 2020; O'Keeffe 2020)

'During exhalation the elastic walls of the respiratory bronchioles contract, and the mucosal fluid on the lumen surface forms a continuous film that can completely fill the airway. During the subsequent inhalation, the bronchioles expand and the film ruptures, yielding particles that are drawn into the alveoli and subsequently exhaled.'

Asadi identifies a similar mechanism which occurs in the region of the larynx when the vocal folds open and close during vocalisation (Asadi et al. 2019). Therefore breathing, and vocalisation involving the larynx are agreed to be plausible routes of dissemination of the virus into the environment (Tang et al. 2020). Although coughing and sneezing release higher numbers of airborne particles, breathing and speaking are more extended activities and therefore critical routes for virus emission (Tang et al. 2020). Similarly singing in the context of a choral rehearsal is an extended activity capable of large emissions of infectious airborne particles in small amount of time (Asadi et al. 2019).

Estimates of virus in airborne particles

The viral load of airborne particles has not been definitively established (Asadi et al. 2020a). However, there is research on some issues bearing on viral load that are pertinent to infection through airborne particles generated by a singer.

Aerosol particles of approximately 1µm are big enough to carry virus pathogens such as SARS-CoV-2, and have been noted to carry other infectious diseases, for example, measles (50-500nm sized particles) or influenza virus (100nm-1 µm sized) (Asadi et al. 2019). Aerosol particles are also small enough to deposit virus lower into the respiratory tract of the host (person who gets the disease) (Asadi et al. 2019; Chong et al. 2020; Fenelly 2020; Kohanski et al. 2020). Concentrations of SARS-CoV-2 virus RNA within the range of 1-8690 RNA copies/m^3 (Chia et al. 2020; Liu et al. 2020; Ong et al. 2020) have been found in aerosols in hospital environments, with the concentration varying by location in the hospital. Kohanski et al reported that SARS-CoV-2 viral RNA has been detected most frequently in in airborne particles sized >4µm diameter, although they have also been found in particles as small as 1µm diameter (Kohanski et al. 2020).

Aerosol emission may be increased in symptomatic individuals possibly through sneezing and coughing (Kohanski et al. 2020), although sneezing has been shown to emit a higher percentage of large droplets in comparison to coughing (Kohanski et al. 2020). It is therefore plausible that an increased airborne particle emission from an infected speaker (Bax et al. 2020) or singer may actually pose a higher risk of infection.

A challenge in this emerging evidence is the use of different methods for measuring viral load, making comparison between studies difficult. A preliminary observation of the average viral load of SARS-CoV-2 in oral fluid was 7 000 000 virion/ml but noting that some individuals have been reported to have a viral load of 100 times more (Tang et al. 2020). Viral shedding for other coronaviruses has been measured at 32 600 virions/hour and for SARS-CoV-2 is estimated by mathematical modelling to be similar to that rate (Kolinski et al. 2020). Kolinski and Schneider have modelled estimated infectious concentrations in air of 109 virions/m^3 for a 300m^3 room and 814 virion/m^3 in a 40m^3 room by analysing 20 super-spreading events involving 200 infected and 1000 exposed people (Kolinski et al. 2020). Lower aerosol concentration measurements of 1- 113 SARS-CoV-2 virus/m^3 were found in a Chinese study of hospital areas (Liu et al. 2020).

Survival times of virus

Aerosol persists in the air before settling, increasing the risk of inhalation (Asadi et al. 2019; De Olivera 2020). Survival times for SARS-CoV-2 virus in aerosol ranged from 90 minutes in an experimental situation to 16 hours (Corriea et al. 2020; Tang et al. 2020). The classic calculations by Wells of the life-time of respiratory aerosols which have been used to guide public health practice are suggested to be underestimates (Chong et al. 2020).

Infectivity

The extent of human susceptibility to COVID-19 and the minimum infectious dose of SARS-CoV-2 has not been well described (Karimzadeh et al. 2020; Stadnytskyi et al. 2020). One study using computational fluid mechanics and human physiology concluded that the nasopharynx is where most infection will occur through the lodgement of particles of 2.5-19 µm (Basu 2020). Preliminary work on the minimum infectious dose using mathematical models has been undertaken by several research groups (Basu 2020; De Olivera 2020; Kolinski et al. 2020; Mürbe et al. 2020; Tang et al. 2020; Vuorinen 2020). The use of different methods of measurement was a challenge to comparison of studies. In research using computational fluid dynamics the minimum infectious dose was estimated at 100 virions (Basu 2020; Karimzadeh et al. 2020). Theoretical exposures modelled for one infectious person in two rooms sized $300m^3$ and $40m^3$ by Kolinski et al were 14 and 108 virions/hour respectively (Kolinski et al. 2020). It could be concluded from theoretical modelling that receiving an infectious dose indoors via airborne particles would be easy but that room volume would assist dilution.

Using Wölfel et al's estimated viral load of 7 000 000/ml (reported by Stadnytski et al) Mürbe et al suggest that 1 minute of loud speaking would generate 1000 virion-containing aerosol particles that remain airborne for more than 8 minutes (Mürbe et al. 2020). De Oliveira et al extended the mathematical modelling reported previously by adding SARS-CoV-2 viral load into a model of evaporation, settling and droplet size distributions to predict changes to the liquid mass of airborne particles emitted and the viral load over time. They found that aerosol resulting from 30 seconds of continuous speech had a 1 hr settling time and could deliver a viable viral dose 10 times higher than a short cough (De Olivera 2020). The model also showed that it took only a few seconds to reach 2m in distance with a viral dose above the minimum required for infection (De Olivera 2020). The range of exposure required to inhale around 100 aerosol particles was modelled by Vuorinen et al to be between 1 second and 1 hour (Vuorinen 2020).

To complicate matters, Wölfel et al's work, reported by Tang concluded a 37% probability that a 50µm droplet prior to dehydration will contain at least one virion, reducing to 0.37% for a 10 µm particle (Tang et al. 2020). Further, Ong reports that most virus estimates are made using viral RNA rather than the virion (the whole virus) (Ong et al. 2020).

To be confident of the circumstances of infection by airborne particles, theoretical models, real-life measurements and detailed observations of outbreaks are all needed. It is concluded that enough information has been reported to presume that aerosol and droplet infection has probably occurred in outbreaks during choir rehearsals and should be an underlying assumption of mitigation strategies. Further research to understand the minimum infection dose specific to singing in rehearsals would be valuable, but these results suggest an infectious dose of virus could easily be delivered in a 2 hour rehearsal if environmental conditions encouraging transmission existed.

Pre-symptomatic and symptomatic transmission

Consideration of the minimum infection dose is important because transmission from pre-symptomatic and asymptomatic people has been agreed by several authors to have probably taken place in choral settings (Hamner 2020; O'Keeffe 2020). Pre-symptomatic transmission occurs during the incubation period of an infected person and asymptomatic transmission occurs when an infected person has no symptoms (O'Keeffe 2020). Heneghan examined 21 outbreaks reporting the percentage of asymptomatic individuals to be between 5-80% (Heneghan et al. 2020). The most infectious time period for COVID-19 is agreed to be from two days before to seven days after onset of symptoms (Hamner 2020). It is therefore concluded that risk mitigation for choirs should not rely solely on a direction to not attend rehearsals when unwell. Pre-symptomatic and asymptomatic singers may not realise they are infectious. Rapid testing for active COVID-19 may be a strategy to lower the risk of a pre-symptomatic or asymptomatic singers attending a singing gathering.

3. What is the infectious potential of fomites in choral rehearsal settings?

Major finding

- Virus transmission occurs through multiple routes including direct contact with people, and indirect contact with contaminated surfaces and aerosols
- Shared food at rehearsals may be contaminated with virus either during preparation or shared consumption
- Oral-faecal transmission of COVID-19 is possible

Gaps in knowledge

- The independent importance of each form of indirect transmission in choral settings has not been established
- Research on the infectivity of COVID-19 via fomites

Implications

- Risk mitigation guidance should acknowledge direct and indirect transmission routes
- Shared food should not be consumed at singing gatherings
- Cleaning protocols should include toilets

This section summarizes research pertaining to the risk of transmission of COVID-19 through contact with surfaces contaminated with the SARS-CoV-2 virus. Surfaces present in choral settings may include furniture, musical scores, stands, microphones and toilet areas. Contamination may occur by direct deposition of the virus on a surface by an infected person or by settling of contaminated airborne particles onto a surface. Exposure may occur by finger contact with the contaminated surface (fomite) and subsequent contact with the face (Azuma et al. 2020). Direct person-to-person contact is recognized to be a route of transmission for COVID-19 (Santarpia et al. 2020) and is not discussed further in this review. No studies specific to choirs or singing gathering settings could be found. The major finding was that contact with contaminated surfaces (fomites) is a plausible route of infection with COVID-19 during choral rehearsals.

Environmental contamination of surfaces with SARS-CoV-2 RNA (also known as viral nucleic acid) has been reported frequently (Chia et al. 2020; Kanamori 2020 ; National Collaborating Centre for Methods and Tools 2020; Ong et al. 2020; Santarpia et al. 2020). Detection of viral RNA indicates the presence of the virus but is not its viability or infectiousness. Surfaces including hospital tables, bed rails, floors and ventilation grates have been shown to be contaminated with SARS-CoV-2 RNA. (Chia et al. 2020; National Collaborating Centre for Methods and Tools 2020; Ong et al. 2020; Santarpia et al. 2020; Tang et al. 2020). There was a correlation between the level of contamination and the intensity of symptoms in people with COVID-19 occupying the space (Chia et al. 2020; Ong et al. 2020).

In a laboratory setting SARS-CoV-2 survived on surfaces up to 72 hours with concentrations of virus reducing over time (Corriea et al. 2020; van Doremalen et al. 2020). In a review of several studies of SARS-CoV-2 persistence on fomites Azuma et al reported survival of SARS-CoV-2 on dry inanimate surfaces to be between 1 and 7 days, with the presence of proteins found in human sputum increasing the period of survival (Azuma et al. 2020). SARS-CoV-2 has been found to remain more stable on plastic and stainless steel than porous materials such as cotton (Kraay et al. 2020; van Doremalen et al. 2020). Notably no viable SARS-CoV-2 was measured on cardboard after 24 hours in one study (van Doremalen et al. 2020), which may have some application to musical scores.

There was disagreement about the contribution of fomite transmission where multiple routes of infection are suspected (Brurberg 2020; Kanamori 2020 ; Kraay et al. 2020; National Collaborating Centre for Methods and Tools 2020; Ong et al. 2020; Santarpia et al. 2020). Environmental sampling that detects virions (the complete form of the virus) rather than just the viral RNA will further establish the infective potential of fomites in COVID-19.

Food is a possible route of indirect transmission through touching of contaminated food followed by touching of the face. Although no observations of indirect transmission of SARS-CoV-2 through touching contaminated food have been made, other viruses have been demonstrated to transmit through food. In addition, food packaging has the potential to act as a fomite (Duda-Chodak et al. 2020; Jefferson et al. 2020).

COVID-19 has the potential to be transmitted through the oro-faecal route as SARS-CoV-2 is excreted in urine and faeces (Corriea et al. 2020; Jefferson et al. 2020; Ong et al. 2020; Santarpia et al. 2020; Vardoulakis et al. 2020). Viral RNA has been detected in toilets in hospital settings (Tang et al. 2020). Koch reported Li's fluid dynamics work on flushing toilets, predicting high emissions at 35 and 70 seconds after flush of between 1500-2700 droplets, with strong upward droplet velocity of up to 15ft/s (Koch 2020). There are obvious implications for 'lids down'.

4. Under what circumstances have people become infected with COVID-19 during choral rehearsals?

Major finding

- It should be assumed, due to observations of the outbreaks, that choral singing does pose a risk of infection with COVID-19
- Populations at risk of more severe outcomes after infection with COVID-19 included older age groups and people with co-morbid conditions
- Transmission can occur through contact with people who have asymptomatic or pre-symptomatic disease
- Settings with higher risk of one-to-many transmission (super-spreading) included those with large groups of singers in poorly ventilated rehearsal venues

Gaps in knowledge

- Research is needed on the degree of additional risk due to choral singing in comparison with a gathering in the same space of the same size where there was extended loud non-singing vocalisation
- Evaluation of the role of rapid testing for COVID-19 positive status in choristers is needed

Implications

- Risk mitigation for choirs should be planned and diligently implemented
- Risk mitigation cannot rely solely on advice to symptomatic singers to stay home
- Risk mitigation cannot rely solely on the number of reported positive cases in the community
- Risk mitigation for large choirs should include control measures to limit the number of singers at a rehearsal where possible through for example increasing the use of sectional rehearsing in small groups
- Risk mitigation should include control measures that maximise the effective ventilation of rehearsal spaces
- Choirs should be alert to the probable increased risks of COVID-19 in autumn 2021 in South Australia

This section summarises what can be learnt from the reports of outbreaks of COVID-19 in community settings relating to choir rehearsals or singing. Many of the outbreaks occurred early in the pandemic but provide valuable information about the likely outcomes of failure to implement risk mitigation strategies. A public health approach has been used, focussing on what is known about the risk factors within transmission events, the populations affected and environments where transmission took place. The major finding was that in environmental conditions encouraging transmission, choir rehearsals pose a risk of infection with COVID-19 to singers, with particular concern about one-to-many transmission events.

COVID-19 has a basic reproductive number of 2.5 (average number of contacts infected by an individual with COVID-19) with most people experiencing asymptomatic or mild disease (Petersen et al. 2020). The incubation period is usually 5-6 days but can range from 1-14 days, and maximum infectivity is associated with symptom onset (COVID-19 National Incident Room Surveillance Team 2020). The median case fatality rate amongst countries is 2.3% (Johns Hopkins University and Medicine 2020) rising to 22.3% for Australians aged $\geq$ 80 years (COVID-19 National Incident Room Surveillance Team 2020).

Many community-based settings have been associated with a COVID-19 transmission events. The most frequently reported community-based transmission events have been within households (Leclerc 2020). Community settings that have been particularly reported to be associated with a one-to-many (superspreading) transmission have included meat-processing plants, prisons, faith-based meetings, bars and restaurants, cruise ships and worker accommodation (Leclerc 2020). Large transmission events with serious mortality have occurred in hospitals and aged care settings (non-community) and these settings are not considered in this review (Furuse et al. 2020; Leclerc 2020).

Choir rehearsals were reported to be associated with occurrences of the transmission of COVID-19 in France (Charlotte N 2020), Washington State, USA (Alberta COVID-19 Scientific Group 2020; Hamner 2020; Miller et al. 2020; O'Keeffe 2020), Netherlands (O'Keeffe 2020), Germany (O'Keeffe 2020) and most recently (September 2020) in Spain (Associated Press 2020). In Michigan, USA (O'Keeffe 2020) and Japan (Furuse et al. 2020; O'Keeffe 2020) transmission of COVID-19 occurred at performances involving singing. The majority of these events occurred in the period from 1 January to mid- April 2020.

There was no research establishing that singing at a choral rehearsal caused infection with COVID-19. This means the risks associated with singing cannot be separated from the other characteristics of the transmission event. It is not expected that there will be any research using randomisation and control groups to establish a causative link. Therefore observational research provides the basis for drawing guarded conclusions about the risks of singing in gatherings.

Thorough reporting of early transmission events was found for two events of choral singing (Charlotte N 2020; Hamner 2020). The findings from two rapid reviews of the risks of choral singing (Alberta COVID-19 Scientific Group 2020; Naunheim et al. 2020) are included below, along with information from less detailed reports of choral singing (Furuse et al. 2020; O'Keeffe 2020; Wei et al. 2020) when available.

Characteristics of the transmission events involving choirs included:

- Large choirs. (Choir participants in research reported here numbered 20 in one French choir (Charlotte N 2020), 27 in a second French choir (Charlotte N 2020), 30 in a Japanese musical group (Furuse et al. 2020)), 61 in the Skagit Valley outbreak (Hamner 2020; Miller et al. 2020), 80 in a Berlin choir (O'Keeffe 2020) and 130 in an Amsterdam choir (O'Keeffe 2020))
- Presence of asymptomatic/presymptomatic COVID-19 positive singer(s)(Charlotte N 2020)
- Older attendees with reported median age of 69 at one outbreak (Hamner 2020), and mean of 66.9 at another (Charlotte N 2020)
- High attack rates ranging from 53.3% to 86.7% (Charlotte N 2020; O'Keeffe 2020)
- Severe outcomes including hospitalization and between two and nine deaths as a result of an outbreak (Charlotte N 2020; Hamner 2020; O'Keeffe 2020)
- A choir practice just prior to reports of exponential growth of cases in the community (Charlotte N 2020; Hamner 2020)
- Poorly ventilated rehearsal spaces (Charlotte N 2020; Furuse et al. 2020; O'Keeffe 2020; Spahn et al. 2020)
- Indoor rehearsals (Charlotte N 2020; Hamner 2020; O'Keeffe 2020)
- Lack of physical distancing (Charlotte N 2020; Furuse et al. 2020; Hamner 2020; O'Keeffe 2020)

Other reported outbreaks where singing was likely to have, or reported to have, taken place included American summer camps (Blaisdell et al. 2020; Szablewski et al. 2020), faith-based settings (James et al. 2020; Leclerc 2020; Pung et al. 2020; Yong et al. 2020), a large family gathering (Ghinai et al. 2020), karaoke parties (Furuse et al. 2020; Leclerc 2020) and musical performances (Furuse et al. 2020). Characteristics of these gatherings included:

- Large numbers of participants involved in singing (Attendees numbered 92 at an Arkansas, USA church (James et al. 2020), 227 in a Singapore church (Pung et al. 2020), 243 cases within 7 outbreaks in Singapore of which 2 outbreaks involved singing (Wei et al. 2020), 597 at a camp in Georgia, USA (Szablewski et al. 2020), 1006 at a camp in Maine, USA (Blaisdell et al. 2020), and 5000 cases linked to a South Korean church (O'Keeffe 2020). Leclerc reported 15 religious events where the media cluster size was 23 participants (Leclerc 2020) and Yong in a case-finding and contact tracing study reported on 28 cases from two Singapore churches (Yong et al. 2020))
- Presence of asymptomatic/presymptomatic COVID-19 positive singers
- High attack rates ranging from 38% to 78% (James et al. 2020; Szablewski et al. 2020)
- Three deaths and seven hospitalisations in one report of 35 confirmed cases (James et al. 2020)
- A poorly ventilated gathering space (Szablewski et al. 2020)
- Use of indoor gathering spaces (Blaisdell et al. 2020; O'Keeffe 2020; Szablewski et al. 2020)
- Lack of physical distancing (James et al. 2020; O'Keeffe 2020)

One summer camp of 1006 attendees successfully controlled outbreaks using pre-camp quarantining of the attendees and their parents, frequent testing prior to and during the camp, cohort quarantining, isolation of three asymptomatic cases detected and quarantine of their contacts (Blaisdell et al. 2020). There is some hope that control of outbreaks can be achieved even in very large gatherings.

Groups at risk of poor outcomes

An exhaustive review of the literature regarding COVID-19 disease progression in different population groups was out of the scope of this review. However, as choirs include people of all ages and health status, a summary of people at risk of severe outcomes from COVID-19 infection is provided.

People at higher risk of poor outcome from COVID-19 disease are agreed to include (Irish Health Information and Quality Authority 2020):

- People aged > 70 years
- People aged > 65 years with chronic medical conditions
- People with compromised immune systems (for example, cancer)
- Aboriginal and Torres Strait Islander people aged > 50 years with one or more medical conditions (Hatcher et al. 2020)
- People with two or more medical conditions regardless of age, and especially if poorly controlled or severe.

Medical conditions associated with high risk of poor outcome include organ transplant, immune suppressive therapy, bone marrow transplant within two years and blood cancers. People undergoing chemotherapy or radiotherapy are also considered at higher risk of serious outcomes (Irish Health Information and Quality Authority 2020).

Medical conditions considered to be of moderate risk for more serious outcomes included: chronic renal disease, heart disease, chronic lung disease, a non-blood cancer, severe obesity, chronic liver disease, neurological conditions including stroke or dementia and poorly controlled hypertension (Irish Health Information and Quality Authority 2020).

Other risk factors may include smoking, male sex, obesity, ethnicity and experience of poverty (Hatcher et al. 2020; Irish Health Information and Quality Authority 2020; Jordan 2020).

Disability

Only one commentary raised the needs of people with a disability who may experience worse health outcomes if infected with COVID-19, as well as the secondary effect of difficulty accessing health services (Armitage et al. 2020). Adelaide has several notable choirs with members who have a disability.

Children

Children appear to be less affected by COVID-19 (Götzinger et al. 2020; Li, X et al. 2020). The prevalence of COVID-19 was <5% in children younger than 18 years (Jordan 2020). An American study of hospitalizations in children with COVID-19 found a higher rate of admissions for children from Hispanic and African-American cultural backgrounds. Hospitalizations were also increased for children with obesity, chronic lung disease, and those aged <2 years with a history of prematurity (Kim et al. 2020). Children have been found to have prolonged faecal shedding with implications for control measures such as hand hygiene and environmental cleaning (Li, X et al. 2020; Rajapakse et al. 2020).

Children were advised to follow the same control measures as adults including hand hygiene, physical distancing and wearing of masks (American Academy of Pediatrics 2020). It was noted that closures of schools had not been found to assist very much with outbreak control (Viner et al. 2020).

A new multisystem inflammatory syndrome with similarities to Kawasaki syndrome has been associated with COVID-19 in children. Although rare, it was associated with heart problems and is potentially fatal (Ahmed et al. 2020).

Care to ensure that secondary effects of control measures on children are minimised was advised (American Academy of Pediatrics 2020), for example physical distancing has been noted to reduce adolescents' face-to-face contact at a time when developmentally they have an increased need for peer interaction (Orben et al. 2020).

Climate

Based on current observations it was expected that waves of COVID-19 will peak in the winter season of temperate climates during low temperatures (Naunheim et al. 2020; Van Damme et al. 2020; Vardoulakis et al. 2020). Tropical climates may experience more continuous outbreaks through the seasons as has been observed in Ecuador and Brazil (Van Damme et al. 2020). There is some support for increased survival of the virus at relative humidities of <50% (Anderson et al. 2020; Corriea et al. 2020; Koch 2020).

5. What aspects of indoor ventilation are effective in preventing infection during choral rehearsals?

Major finding

- Effective ventilation has been shown to be a plausible and probably important control measure for removing infected aerosols from a space
- Ineffective ventilation was implicated in outbreaks in choral rehearsals
- Outdoor spaces provide effective ventilation due to maximum dilution of infected aerosol
- The air changes per hour (ac/h) were a useful indicator of effective ventilation
- Fresh air input to ventilation systems was important in the dilution of aerosols
- Effective ventilation, whether natural or mechanical comprised airflow directed away from singers to an external outlet
- Filtration systems that decontaminate air can be incorporated into ventilation systems

Gaps in knowledge

- Research on portable air cleaners suited to choirs
- Studies of the effectiveness of ventilation in churches and other large venue spaces would benefit choirs

Implications

- Ventilation of rehearsal rooms is a crucial control measure for choirs
- Choir management should understand the effectiveness of ventilation systems in rehearsal venues including during heating and air conditioning modes
- If relying on open windows and doors to ventilate a rehearsal venue, choir management should aim for fresh air to flow in a direction past individual singers directly to the outlet.

This section summarizes the literature about the use of ventilation to prevent aerosol build-up in indoor venues. Ventilation refers to air flow through buildings which may be by mechanical means or through natural forces (Li et al. 2007). The major finding was that effective ventilation in indoor rehearsal venues has the potential to mitigate against indirect transmission from aerosols.

Ventilation has been theorised to play conflicting roles in indoor environments. In circumstances of poor air exchange (low replacement of indoor air with fresh air) it has been shown to have assisted in the contamination of indoor spaces with COVID-19 by moving aerosols greater distances within a venue (Azimuddin et al. 2020; Corriea et al. 2020; Koch 2020; Kohanski et al. 2020; Li, Y et al. 2020). However, there was agreement that air conditioning could be operated so that aerosol build-up would be minimised (Azimuddin et al. 2020; Corriea et al. 2020; Kolinski et al. 2020). For example, Somsen et al showed that with effective ventilation of a room, the number of airborne particles can be halved in 30 seconds, but this could take up to 1-4 minutes with poor ventilation and 5 min with no ventilation (Somsen et al. 2020).

There were no experimental studies of ventilation systems as preventive measures in choral rehearsal rooms. However two studies used mathematical modelling to assess the risks of one-to-many (superspreading) events associated with the known characteristics of outbreaks in choir rehearsals (Hartmann et al. 2020; Miller et al. 2020). Hartmann et al used the Berlin Philharmonic Choir rehearsal and concert venues to model aerosol concentrations after a rehearsal of two 30 minute sessions separated by a room ventilation break of 15 minutes. It was concluded that use of a large rehearsal room and reducing the number of singers would decrease the build-up in concentration of potentially infectious aerosol (Hartmann et al. 2020). Window opening was found to be unreliable in achieving good ventilation in comparison to mechanical ventilation (Hartmann et al. 2020). In a more sophisticated study, Miller et al used the outbreak at a choir rehearsal in Washington to model the effect of ventilation conditions, density of occupants and duration of exposure on risk of transmission. The authors concluded it was likely these characteristics were associated with a one-to-many (superspreading) event (Miller et al. 2020). A carbon dioxide traffic light monitoring system for the effectiveness of ventilation was recommended for choir rehearsals and other singing gatherings (Miller et al. 2020; Spahn et al. 2020). In addition, it was recommended that ventilation systems have a warning sign about the shut-down of fresh air supply if the heating or cooling was turned off while the room was occupied (Miller et al. 2020). It was noted that at the rates of emission theorised in the Washington choir outbreak, current American standards of ventilation would only allow for a rehearsal of 30min for an infection risk level below 10% (Miller et al. 2020).

The technical nature of building ventilation, heating and cooling systems may mean it is advisable for choir management to consult an expert in air conditioning and heating about their rehearsal venue. Characteristics of ventilation systems reported in the literature that may assist choir management to discuss their particular rehearsal venue follow.

Types of ventilation

Two types of ventilation were identified. In ‘displacement ventilation’ the air enters the room near the floor at a low flow rate and is removed near the ceiling. This form is more effective at removing aerosol build-up such as would occur in a choral rehearsal. In ‘mixing ventilation’ the air enters the room near the ceiling at a high flow rate and mixes with the used air. This form of ventilation focuses more on diluting the concentration of airborne particles (Blocken et al. 2020).

If a recirculation mode is used by ventilation systems the air should be filtered and decontaminated before being recirculated into the room (Blocken et al. 2020).

Intake of air

Air-conditioning systems can be set up to maximise the intake of fresh air (Hayashi et al. 2020). It was recommended that 24-hour air-conditioning be used for rehearsal venues. Alternatively starting the air conditioning system several hours early and ensuring it is not turned off until the room is not in use was an option (Hayashi et al. 2020; Melikov et al. 2020). Similarly heating systems should maximise intake of fresh air (Hayashi et al. 2020). Hayashi et al in their discussion of the ventilation of theatres and karaoke venues found that these venues should be treated as high density with the maximum intake of fresh air, effective filtration and management of temperature and relative humidity. Additional benefit may be achieved by the use of air purifiers (Hayashi et al. 2020). Some building ventilation systems may not be able to operate efficiently on maximum intake of outdoor air in which case other means of introducing outdoor air may be used, for example, window installed fans (Melikov et al. 2020).

Direction of airflow

Directing airflow from the inlet to occupants to the outlet was considered to be important (Azimuddin et al. 2020). When using open windows as the main ventilation strategy, air should travel from the open window past individuals to another window or door (Azimuddin et al. 2020; Blocken et al. 2020; Hayashi et al. 2020; Kohanski et al. 2020). There was a suggestion that directing airflow downward rather than upwards or into a mixing pattern would assist aerosols to move away from singer's faces (Azimuddin et al. 2020).

Air change rate

Air change rates are defined as the number of complete changes of air in a room per hour (ac/h). Twelve ac/h is the minimum ventilation rate for hospital isolation rooms (Azimuddin et al. 2020) and provides an upper limit to the rate of air change that might be appropriate for rehearsal venues. Air change rates in the Guangzhou restaurant outbreak were 0.77 and 0.56 air changes per hour and provide an indication of levels of poor building ventilation (Li, Y et al. 2020). For aerobics and martial arts 8-10 ac/h were recommended (Blocken et al. 2020). Spahn et al recommended 4-8 ac/hr for singing and playing instruments (Spahn et al. 2020). Modelling by de Oliveira showed that for one hour of continuous speaking in a poorly ventilated room, the infection risk would be between 0.1-11% for viral loads of 10^8-10^{10} copies/ml which would reduce to 0.03-3% if ten ac/h were delivered by active ventilation (De Olivera 2020). Azuma et al included the occupancy of the room in their recommendations for standards of room ventilation, finding a minimum rate of $30m^3$/h per person to provide protective ventilation (Azuma et al. 2020).

Filtration

Air filters collect particles of different sizes depending on their rating. High efficiency particulate air filters (HEPA) are routinely used in surgical theatres and collect 99.97% of particles >0.3 µm. SARS-CoV-2 is 60-140nm in diameter but most frequently emitted from the body within the larger aerosols ($\leq$5µm) and droplets ($\geq$5-10 µm) (Blocken et al. 2020; Corriea et al. 2020; Hayashi et al. 2020; Koch 2020). HEPA filters are noted to be expensive to run but cheaper to install (Blocken et al. 2020). Maintenance of filters in ventilation systems maximised their performance (Azimuddin et al. 2020; Hayashi et al. 2020).

Another type of filtration system used an electrostatic precipitator to collect charged air particles (Hayashi et al. 2020). One author suggested ventilation that reduced the humidity would effectively decontaminate air based on a finding that the lifetime of airborne particles of 10µm was extended by 30 times on the traditional estimates in 50% humidity (Chong et al. 2020).

Once airborne particles were captured in a filtration system, ultraviolet light (UVC in the range from 315 to 380nm) (Azimuddin et al. 2020; Azuma et al. 2020; Miller et al. 2020; Vardoulakis et al. 2020) and heat of 80-90 degrees celsius (Azimuddin et al. 2020; Azuma et al. 2020) has been used to kill bacteria and viruses. Filtration and sterilization equipment was noted to require significant expertise to install and maintain (Naunheim et al. 2020).

Other issues identified in the literature included the following.

Outdoor rehearsals

Several authors recommended that choirs investigate rehearsing outdoors as a control measure for mitigating the risk of choral singing (Naunheim et al. 2020; Spahn et al. 2020). Outdoor spaces were theorised to have maximum dilution of infected aerosol, although theoretically, wind may also assist transmission by increasing the distribution of airborne particles or altering evaporation rates (Koch 2020; Qian et al. 2010). Physical distancing should be maintained to prevent infection through droplets (Blocken et al. 2020; Hayashi et al. 2020).

Churches

Spahn et al discuss the ventilation of churches although from the point of view of expert opinion rather than experimental research. The following advice was provided:

> "Singing in religious settings
>
> Congregational singing appears possible if the distancing rule of 2 metres is observed and face masks are worn, since it can be assumed that there is no greater risk of being infected by singing than by speaking. In addition, services usually take place in large to very large spaces.
>
> Church rooms with a ceiling height of 10 metres and more usually have such large volumes of room air that they can be considered comparable to smaller rooms with a powerful ventilation system (air exchange rate 6 ac/h) with regard to the risk of infection. In addition, many church rooms are equipped with modern ventilation systems. Where this is not the case, the air quality and effectiveness of the ventilation can be checked directly on site using the CO_2 traffic light system."

Extreme temperatures

South Australia can experience extreme high temperatures where air conditioning of venues is necessary and low temperatures in winter when heating is used. Strategies for the management of rehearsals during extreme temperatures may include ventilation breaks in rehearsal where the room is aired out and effective operation of the air-conditioning and heating system to maximise fresh air intake (Hayashi et al. 2020). Hayashi et al recommend using strategies to manage the comfort of venue users including blocking solar radiation heat on west facing walls, avoiding meeting in the heat of the day, reducing meeting times and monitoring the health of room occupants (Hayashi et al. 2020). This would be particularly important for singing which is a physically active process.

Fans

The use of fans should assist directional airflow. Moving air with fans without directing air from an intake to an outlet may not assist the clearance of aerosols because of the possibility of extending droplet settling times (Koch 2020), and may actually assist distribution of infectious airborne particles. The World Health Organisation discourages the use of fans for this reason (World Health Organisation 2020). However 24 hour extractor fans in bathrooms and toilets or fans that assist inflow through windows have been reported in the literature to be helpful (Azimuddin et al. 2020; Hayashi et al. 2020).

Portable air cleaning

An opportunity to develop portable air cleaners that may assist choirs with reducing the build up of aerosols produced by singers during rehearsals was noted (Kähler, C et al. 2020; Kohanski et al. 2020; Ontario Medical Advisory Secretariat 2005). Kähler et al have experimentally trialled a portable air cleaner which halved aerosol particles concentrations sized 0.1-0.3µm in 6-15 minutes depending on the rate of air flow in a room of 80m^2. The shape of the room and objects in the room were demonstrated to negatively influence the filtration of all areas of the room, in which circumstance the authors suggest multiple air cleaners (Kähler, C et al. 2020; Ontario Medical Advisory Secretariat 2005).

6. How effective are cleaning protocols in preventing viral persistence on fomites in choral rehearsals?

Major finding

- Effective cleaning protocols are an important component of a risk mitigation strategy
- Training of staff combined with testing of cleaned environments and effective disinfectant products were important factors in successful cleaning protocols

Gaps in knowledge

- All aspects of the evaluation of cleaning protocols merit further research

Implications

- Choir management should have an understanding of the cleaning protocols of venues used for rehearsals and performances
- Choirs should ensure a process for the cleaning of venues before and after rehearsals and performances is undertaken

This section summarizes the literature about environmental cleaning as a control measure for contamination of surfaces with SARS-CoV-2. Few studies evaluating environmental cleaning were found and none were specific to the choral setting. Most studies were undertaken in hospital environments which were higher risk than the general community settings due to treatment of active COVID-19 on the premises. There was agreement that effective cleaning protocols were an important component within risk mitigation strategies for COVID-19 (Kraay et al. 2020; Meyer et al. 2020; Ong et al. 2020; Vardoulakis et al. 2020). This review concludes that environmental cleaning should not be relied upon as the sole risk mitigation for choirs.

A number of issues related to cleaning protocols were raised.

Effectiveness of cleaning protocols

The effectiveness of cleaning protocols in reducing traces of virus on surfaces was evaluated in Liu's study of infection in two Wuhan hospitals. Sanitization of hospital surfaces including toilet areas was shown to reduce virus on surfaces and to prevent aerosolization of virus in toilet areas. (Liu et al. 2020). However, the extent to which surface cleaning protocols in hospital patient's rooms were followed in a Canadian study was found to be on average 63% (Meyer et al. 2020).

Hourly cleaning schedules in office environments were found to be effective in reducing the transmission rate through fomite contact with SARS-CoV-2 (R_0) to below one in comparison to four and eight hourly cleaning schedules (Kraay et al. 2020). Sampling to check the quality of cleaning may be important to ensure cleaning is achieving the aim of irradicating SARS-CoV-2 especially in environments where there was known contamination (Kraay et al. 2020).

A randomised controlled trial by Mitchell et al found that an approach to cleaning which included communication with and training of staff, audits of effectiveness, choice of product and a cleaning technique focussed on minimizing touching of the surface was associated with improved cleaning in hospitals and a reduction in vancomycin-resistant enterococci in hospitals (Kanamori 2020). Such approaches would assist with knowledge and practice gaps in safe preparation, use and storage of cleaning products which have occurred since the onset of COVID-19 in USA (Gharpure et al. 2020).

Substances used to decontaminate virus on fomites

Usual disinfection procedures for fomite surfaces have been noted to vary due to 'the type of disinfectant, it's dilution, contact time, acidity/alkalinity of the product, air temperature, and interfering substances' (Vardoulakis et al. 2020). It was noted that dirt and other organic matter should be removed first (Vardoulakis et al. 2020).

Other methods with potential to deactivate SARS-CoV-2 virus on fomites included heating (Brurberg 2020), ultraviolet irradiation (Brurberg 2020), ozone (Yao et al. 2020) or by decreasing local relative humidity (Yao et al. 2020). Sunlight has been noted to rapidly destroy SARS-CoV-2 on fomites (Azuma et al. 2020).

7. What is the consensus for safe physical distancing in the choral rehearsal setting?

Major finding

- Physical distancing of at least 2m to the front and 1.5m to the side is likely to be an effective control measure for choirs to prevent transmission through droplet emissions.
- Physical distancing is not likely to be effective in controlling aerosol transmission of COVID-19

Gaps in knowledge

- Research to support physical distances of 2m to the front and 1.5m to the side for choral singing

Implications

- Physical distancing is an important control measure for choirs within an integrated risk mitigation strategy
- Conductors should be located at least 2m away from singers

This section summarizes the literature on physical distancing where relevant to the context of choral rehearsals. The determination of safe physical distances was noted in the literature to be used for several purposes in the management of the COVID-19 pandemic including:

- to define a close contact
- to determine a safe distance for health workers in clinical care
- as a part of suppression strategies for outbreaks
- as a preventative measure in the community
  (Irish Health Information and Quality Authority 2020).

Only the latter purpose (preventative) is considered relevant to the choral setting in South Australia, although it may become important to consider suppression of outbreaks in the future. The major finding was that physical distancing was an important control measure aimed at avoidance of droplets. It should be used as part of an integrated risk mitigation strategy (Kamal et al. 2020). Evidence regarding physical distancing as a sole control measure suggested it would not be effective in choral rehearsal settings due to the cloud-like behaviour of aerosols (Bourouiba 2020).

One study examined physical distancing for singers (Echternach et al. 2020) recommending 2- 2.5m to the front and 1.5m to the sides. The study used video photography of e-cigarette emission in laboratory conditions to study aerosol particles sized 250-450nm (Echternach et al. 2020). Spahn et al interpreted Wang et al's research on household transmission to mean a physical distance of 2 metres would be needed for musicians (including singers) to account for movement while playing or singing (Spahn et al. 2020).

Studies critically examining the basis of the 1-2m physical distancing recommendation found it to have originated from outdated research (Bazant et al. 2020; Bourouiba 2020; Jones et al. 2020; Qureshi et al. 2020). Despite this most countries continue to recommend physical distancing of 1-2m for prevention of COVID-19 transmission in general community settings (Irish Health Information and Quality Authority 2020).

Research undertaken in 2020 has established much longer possible travel distances for airborne particles carried by strong airflows (Jones et al. 2020; Qureshi et al. 2020) but a likelihood of lower infection rates with increased distance from the source (Chu et al. 2020). Most reviews of physical distancing cited Bouriouba's research on coughs and sneezes (Azimuddin et al. 2020; Fenelly 2020; Koch 2020; Tang et al. 2020) This study demonstrated that although some 60-100 µm droplets could travel up to 6-8m if emitted at high speed via a sneeze or cough, most settled within 2m (Bourouiba et al. 2014). Chong's research confirmed this by showing that at the start of a cough, most 100µm droplets fallout within 200 milliseconds reaching between 0.1 and 0.7m from the face (Chong et al. 2020). Chu's meta-analysis of physical distancing associated with the transmission of coronaviruses (SARS-CoV-1, MERS and SARS-C0V-2) considered the risk of transmission as physical distancing was increased. It showed a reduction of 82% in risk of transmission at a 1m distance from the source, and every 1m further away doubled the protection (Chu et al. 2020). Coughing, which can be a frequent occurrence in the choral setting, may be responsible for large droplets travelling further than 2m.

In contrast to the larger droplets, particles sized <5µm have been shown to travel further before eventually sedimenting out onto surfaces, behaving like aerosols (Chong et al. 2020; Tang et al. 2020). Two studies investigated the distance travelled by aerosol emissions from singers. Bahl et al found that at 15cm from the mouth 75% of airborne particles were moving at <0.5m/s with aerosol-like behaviour and Echternach showed that aerosols emitted from singing moved up to a distance of 1.36m from the mouth without sedimenting. This review therefore concludes that physical distancing is not likely to be effective in controlling aerosol transmission of COVID-19 in choral rehearsals.

8. What is the evidence for the effectiveness of masks in singing settings?

Major finding

- Masks may provide added protection to singers when used in conjunction with physical distancing, hygiene, and ventilation control measures

Gaps in knowledge

- Evaluation of the benefit of masks as a preventative control measure for choirs in the context of low community prevalence of COVID-19

Implications

- If community transmission of COVID-19 was to increase in South Australia, masks worn by the majority of the choir may be an important control measure
- Masks for congregational singing and other equivalent situations may be a strategy for allowing participation in singing if used in conjunction with physical distancing, hand hygiene and ventilation control measures
- Choir management should have an understanding of the effective use of masks. Singers should experiment with singing in masks

This section summarizes the literature on the effectiveness of masks in a choral setting. The major finding was that masks may provide added protection to singers when used in conjunction with physical distancing, hygiene, and ventilation control measures.

The uses of masks

Masks evaluated in the literature included respirators (for example, the N95 mask), surgical masks (Sommerstein et al. 2020) and non-medical masks of various designs and made from cloth or other textiles (European Centre for Disease Prevention and Control 2020). Masks have been used in infectious disease settings:

- to protect health workers in clinical care
- to protect surgical patients from infections that may be carried by a surgeon
- as an active community-based suppression strategy for outbreaks
- as a general preventative measure in the community.

In the first setting, the mask needs to prevent ideally all infectious airborne particles from entering the wearer’s respiratory system. In contrast, surgical and non-medical masks used in the latter settings are designed to contain most airborne particle emissions from the wearer to behind the mask or to the wearer’s local area (Kähler, CJ et al. 2020b). The effectiveness of masks in the latter two settings is dependent on the percentage of the population wearing masks.

Mask use for singers

There was one study examining the use of masks while singing. The authors showed that a surgical facemask reduced the amount of aerosol and droplets produced by loud singing to the level of speaking (Alsved et al. 2020). In addition Bahl et al and Spahn et al have recommended mask wearing for singers based on their research (Bahl et al. 2020) and review of the literature (Spahn et al. 2020). Spahn et al also recommended masks for keyboard and string players based on research that masks confer some protection in non-musical settings (Spahn et al. 2020).

Effectiveness of masks in a low prevalence prevention setting

In general, masks were considered to be an effective component of risk management strategies that successfully limited transmission of COVID-19 (Cheng et al. 2020; Chu et al. 2020; European Centre for Disease Prevention and Control 2020; Ollila et al. 2020; Sommerstein et al. 2020; Tang et al. 2020). It was not always clear in research studies whether the evaluation was targeting mask use aimed at protecting the wearer or the community. However, two findings of this literature lent support to the idea that masks may be useful for South Australian choirs in some circumstances.

Firstly the mandated or high use of face masks has been consistently noted in countries with successful suppression of COVID-19 or other airborne diseases (Azimuddin et al. 2020; Cheng et al. 2020; European Centre for Disease Prevention and Control 2020; Ollila et al. 2020; Spahn et al. 2020). For example, Tian et al (reported by Greenhalgh) found that a mask that is 60% effective at blocking viral emission from the wearer and worn by 60% of the population reduced the transmission rate of COVID-19, resulting in effective community suppression of outbreaks (Greenhalgh 2020). Therefore some protection can be assumed to be conferred on groups of people if enough people wear masks.

Secondly, research on the use of masks in community settings supports a probable protective effect in South Australian conditions. Two large studies of masks worn in a community setting found them to be protective against transmission of corona viruses, although neither were based on studies of COVID-19. Chu's meta-analysis found a strong protective effect associated with mask wearing in community settings (OR 0.56 (95% CI 0.40-0.79)). This was calculated from two Chinese studies and a Vietnamese study where it might be assumed that population densities would be higher than South Australia (Chu et al. 2020). Ollila's meta-analysis of five randomized controlled trials of the use of masks in non-hospital and non-household settings demonstrated a protective effect on the transmission of airborne disease (Ollila et al. 2020).

In addition, a theoretical modelling study by Cheng et al demonstrated that surgical masks were more effective when airborne virus was less abundant in the environment, as is likely to be the case in the low prevalence contexts in South Australia. Cheng et al also showed that the more control measures used in a low viral abundance environment, the more likely each control measure was to be effective in preventing transmission of COVID-19 (Cheng et al. 2020). Therefore, while there was no clear guidance about the benefits of masks in the South Australian context of almost zero cases, face masks may confer benefits to a choir within the context of other control measures. Also face masks worn by singers may become an effective added strategy for South Australian choirs if the community prevalence of COVID-19 rises or singing is considered to be a particularly high-risk activity.

The following issues pertinent to the use of masks were raised in the journal literature.

Experimental testing of masks

Masks have been shown by experimental testing to restrict the emission of airborne particles into the environment. Airborne particles of the size of > 1µm from a cough that would normally spread 1.5m were restricted effectively by a surgical mask (Kähler, CJ et al. 2020b). The authors concluded that wearing a simple mask was very useful in protecting others from aerosol and droplets emitted in coughing, sneezing and vocalisation (Kähler, CJ et al. 2020b).

Evaluation of textiles used in masks

Characteristics of an effective mask included a good filtration efficiency and low breathing resistance. The mask should also be hypoallergenic, comfortable, washable and affordable (Beesoon et al. 2020). There were several reported mechanisms of filtration by a textile reported:

- Gravity sedimentation and inertial impaction (bumping into fabric and becoming stuck) for particles >10µm
- Diffusion and mechanical interception by filter fabrics for particles <10µm
- Electrostatic attraction and binding to fibres for aerosols 0.1-1 µm.

(Beesoon et al. 2020)

Tests on a range of textiles showed variation in their filtration efficiency (Beesoon et al. 2020; Kähler, CJ et al. 2020b). Konda et al (in Beesoon et al) stated that tightly woven cotton fabrics filtered particles <300nm to 82% efficiency and 98% for particles >300nm (Beesoon et al. 2020). Kähler reported vacuum cleaner bag material to have excellent filtration for particles of >0.3µm (Kähler, CJ et al. 2020b). Microfiber was found by another study to have a collection efficiency of 90% in contrast to multilayered cotton which tested at 70% (Koch 2020). When multiple layers of different textiles were used filtration efficiencies for particles of 10nm-10µm diameter increased to over 80% (Beesoon et al. 2020). The SARS-CoV-2 virus is 60-140nm, and therefore partial protection of the non-mask wearer from COVID-19 may be conferred by masks. It was noted that care should be taken not to use materials in masks that might cause lung damage if inhaled regularly (Kähler, CJ et al. 2020b).

The surgical mask, in comparison with other textiles, performed better in its ability to filter two types of bacteria sized 23nm and 0.95-1.25 µm. Surgical masks had a mean filtration efficiency of 89.52%, higher than cotton mix (70.24%), linen (61.67%) and cotton T-shirt material (50.85%) (Beesoon et al. 2020). Surgical masks also demonstrated an efficiency three times higher than homemade masks for preventing dispersion of aerosol and droplets (Beesoon et al. 2020), although Blocken et al in their study cautioned that surgical masks with a coarse pore structure failed to block 80% of aerosols >1µm. This improved to 20% when specific filter material was incorporated into the mask (Blocken et al. 2020). Therefore it may be important to understand the quality of the surgical mask used.

Areas of future exploration to enhance face masks included

- Enhancing water repellence
- Use of an antimicrobial layer
- Use of a cationic charge to enhance filtration
  (Beesoon et al. 2020)

Procedures for correct mask use

A correctly fitted face mask was noted to cover the full face from the bridge of the nose to below the chin (European Centre for Disease Prevention and Control 2020). Leakage of airborne particles from the sides of masks or from poorly fitted masks was demonstrated in experimental testing (Kähler, CJ et al. 2020b). It was noted in studies where surgical and non-medical masks were worn to protect others, that they did not necessarily confer a high degree of protection on the wearer. This was attributed to the type of mask or the incorrect fitting and removal of the mask (European Centre for Disease Prevention and Control 2020; Fenelly 2020; Kähler, CJ et al. 2020b; Sommerstein et al. 2020). The use of any mask was found to prevent the wearer from touching their face frequently which was thought to assist with preventing transmission via the hands (Kähler, CJ et al. 2020b; Sommerstein et al. 2020).

Washable masks were considered decontaminated after washing in 60 degree celsius water. It was recommended that care be taken to avoid touching the mask if possible while wearing it (European Centre for Disease Prevention and Control 2020). Hand sanitization before and after fitting and removing the mask was advised to prevent contamination of the mask. If masks were damaged or wet, it was advised that they be changed (Sommerstein et al. 2020).

Messaging about masks

Clear and consistent messaging from public health officials about the purpose and process of wearing masks has been associated with higher rates of compliance (Fisher et al. 2020). However, there has been debate about the effectiveness of masks in preventing infection with COVID-19 which has led to mixed messages.

Arguments against wearing masks reported in the literature have included:

- People will feel safe and stop diligently using other control measures, for example, physical distancing
- Most people will not fit, wear and remove their mask in a way that minimises transmission (Kähler, CJ et al. 2020b)

Many authors advised that masks are best used in the context of multiple control measures, particularly hand hygiene and physical distancing (Chu et al. 2020; Kähler, CJ et al. 2020b; Ollila et al. 2020; Sommerstein et al. 2020).

Implications for Risk Mitigation

Major finding

- The use of multiple control measures within a planned risk management strategy will provide the best protection from COVID-19 transmission during choir rehearsals.
- The precautionary principle would suggest implementing as many control measures as possible, prioritising effective ventilation, hand hygiene, environmental cleaning and physical distancing.

Gaps in knowledge

- Scientific evaluation of combinations of multiple control measures that would best protect people in the choral singing context

Implications

- If choirs implement fewer control measures, meticulous records of attendance should be kept and choir management should be prepared to make quick contact with SA Health if a singer tests positive. The implementation of QR code attendance records may be facilitate quick investigation of outbreaks.

This section provides information on several aspects of risk mitigation found serendipitously in the process of this review of the literature. No additional search for studies on the process of risk mitigation was undertaken. As such this section should be considered to be expert opinion expressed by the authors of research reviewed here rather than a scientific investigation. The major finding was that the use of multiple control measures within a planned risk management strategy will provide the best protection from COVID-19 transmission during choir rehearsals.

Multiple Control Measures

The use of multiple control measures has been noted to achieve control of outbreaks (Cheng et al. 2020; Kucharski et al. 2020; Qureshi et al. 2020; Vardoulakis et al. 2020). There was a suggestion, although not well demonstrated, that this might be due to an increased effect of each control measure in the presence of multiple control measures (Cheng et al. 2020; Kucharski et al. 2020). Kucharski tested combinations of control measures and found that self-isolation, household quarantine, physical distancing and 100% contact tracing was much more effective at reducing transmission rates than combinations with fewer control measures (Kucharski et al. 2020). Cheng et al in their evaluation of the effectiveness of face masks showed that the more control measures used in a low viral abundance environment, the more likely each control measure was to be effective in preventing transmission of COVID-19 (Cheng et al. 2020). Conversely, the absence of two or more control measures has been noted in the outbreaks occurring in choirs (Charlotte N 2020; Furuse et al. 2020; O'Keeffe 2020).

Responses by governments to outbreaks in choir rehearsals have ranged from complete prohibition of group singing, such as reported by Spahn et al about the State of Berlin, to permission for choral singing under conditions of defined risk mitigation, for example, the State of Rhineland-Palatinate (Spahn et al. 2020). If local outbreaks increase in South Australia, increased diligence in following multiple control measures will assist to manage risk and prevent rehearsals being cancelled unnecessarily.

An integrated risk management strategy

Several papers considered the issue of multiple control measures integrated within a risk management strategy (Blocken et al. 2020; Duckett et al. 2020; Jones et al. 2020; Spahn et al. 2020), with one literature review addressing musical settings (Spahn et al. 2020). In additional commentary in the Lancet, MacIntyre (an Australian epidemiologist) argued for the recognition of integrated multiple control measures in combatting epidemics (MacIntyre 2020). Integration is referred to here as:

- Undertaking a process of risk assessment
- Identifying multiple control measures suitable to a choir's local context
- Documenting control measures in a plan
- Communicating that plan to choir members
- Continuing to implement control measures until the plan is considered outdated
- Responding to new risks
- Reviewing the plan as needed

In addition to the control measures summarized in this review, other control measures with relevance to choral settings raised in the literature included:

- Regular recurring testing for COVID-19 (Duckett et al. 2020; Spahn et al. 2020)
- Ensuring risk management guidance is clearly documented, for example instructions targeting building managers (Blocken et al. 2020; Spahn et al. 2020) .
- Measuring the temperatures of attendees, although this is considered controversial (Spahn et al. 2020)
- Risk assessment questionnaires targeting symptom identification from the past 5-6 days (Spahn et al. 2020)
- Certification of building ventilation systems focussed on their rating and performance (Blocken et al. 2020)

Rapid testing (results available within hours) is especially noted by Spahn et al to have potential for assisting choirs to lower the risk of singers who are asymptomatic but infectious attending a rehearsal (Spahn et al. 2020).

Figure 2 provides this author's adaption of Jones et al risk schema to the choral setting (Jones et al. 2020). It may serve as a visual reminder of the need to consider multiple control measures integrated within a risk mitigation strategy.

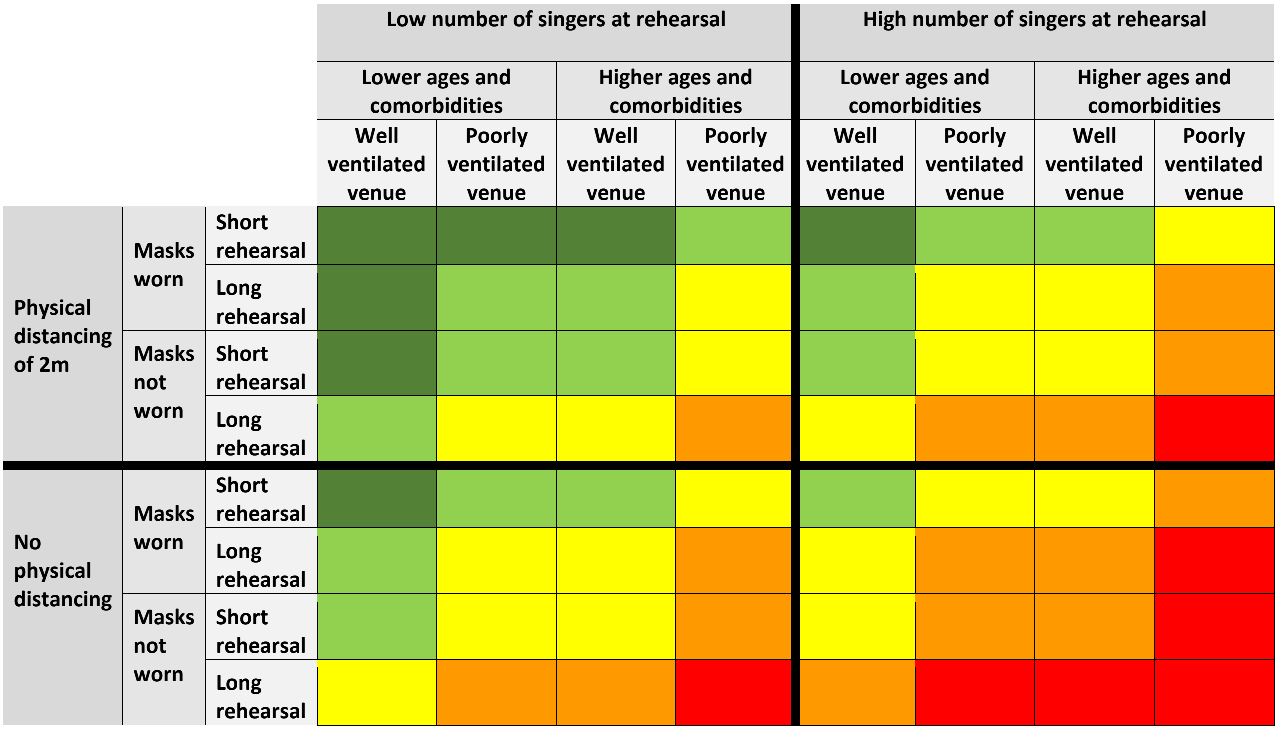

Figure 2: Risk of transmission of COVID-19 in choir rehearsals by control measure

The schema is qualitative and treats each control measure or risk as equal in magnitude which is unlikely to be true. Masks are assumed to be surgical or non-medical rather than respirators. Other risks and controls that may be important, for example rapid testing, are not represented here.

Local context

A modern approach to risk mitigation is said to differentiate control measures on the basis of the risk contexts found in local communities (Duckett et al. 2020; MacIntyre 2020; Spahn et al. 2020). South Australia has a low prevalence of cases, a high testing regime for COVID-19, robust contact tracing and a population with demonstrated adherence to quarantining. Therefore South Australian choirs may feel justified in choosing to implement fewer control measures (in Figure 2). However, the first component of the precautionary principle, 'taking preventive action in the face of uncertainty' (Kriebel et al. 2001; Spahn et al. 2020) would suggest that choir management implement as many control measures as possible to reduce the risk of transmission of COVID-19 in choral rehearsals.

Recommendations

Singing in choirs is a higher risk activity because:

- Louder singing and speaking has been associated with increased emissions of airborne particles
- There is an agreed biological mechanism for emission of the SARS-CoV-2 virus in aerosol and droplet form from the lungs
- Exposure to COVID-19 is possible within the timeframes of typical rehearsals if the environmental conditions encourage it
- Multiple outbreaks of one-to-many transmission (superspreading) in choirs have been described
- Large individual variations in emission of airborne particles have been demonstrated and speculated to play a role in outbreaks within choral singing rehearsals

This literature review suggests choirs within communities with low COVID-19 prevalence should adopt multiple control measures integrated within a planned risk mitigation strategy to maximise the safety of choir rehearsals. Fixed risks such as choir members with comorbidities or of older age should be integrated into risk mitigation strategies. Control measures should focus on:

- The critical role of ventilation in rehearsal spaces. Choir management should understand the effectiveness of ventilation systems in rehearsal venues. This will include maximising air changes per hour and fresh air intake through natural or mechanical ventilation systems.
- Physical distancing of at least 2m to the front and 1.5m to the side. Physical distancing is likely not to be effective in controlling aerosol transmission of COVID-19.
- Environmental cleaning processes. Choir management should have an understanding of the cleaning protocols of venues used for rehearsals and performances, and should include a process for the cleaning of venues before and after rehearsals and performances.
- An understanding of the effective use of masks for singers in combination with ventilation of rehearsal spaces, hand hygiene and physical distancing.

The choral sector should monitor future research in the areas of:

- The relative importance of ventilation in the context of integrated risk mitigation strategies for choirs
- Rapid testing for COVID-19 of singers prior to rehearsals and performances

Conclusion

This rapid review of the literature found singing within choirs **is** associated with an increased risk of transmission of COVID-19, but a combination of risk mitigation strategies will provide the best protection from COVID-19 transmission during choir rehearsals and performances.

The scientific literature surrounding COVID-19 and singing in groups is still emerging. Until further research specific to choir settings has been undertaken, the diligent implementation of multiple control measures integrated within a risk mitigation strategy will provide choirs with the best chance of safely returning to rehearsals and performances.

Appendix 1: Summary of literature on airborne particle behaviour

Aerosols and large droplets behave in different manners after leaving the body due to their size. Understanding these behaviours assists with the development of effective mitigation strategies. Methods for examining airborne particles included temporal and spatial studies using high-speed cameras (Anfinrud et al. 2020; Bahl et al. 2020), and particle counters which have become increasingly sensitive to smaller sized particles over time (Alsved et al. 2020; Asadi et al. 2019; Gregson et al. 2020). This review can make no further comment about the relative merits of methods of investigating airborne particle behaviour.

Observations of the behaviour of aerosols and droplets have shown the following:

- Aerosols (<5µm) travel straight out horizontally (Chong et al. 2020), remain airborne indefinitely (Fenelly 2020), and behave like a cloud (Kohanski et al. 2020). Humans emit a cloud of aerosols every time they breath, speak, sing, cough or sneeze. The aerosols consist of fine particles of liquid from the respiratory tract (Koch 2020).
- Droplets (> 5-10µm) leave the body and drop in a curved trajectory to the floor with their trajectory depending on their size (Chong et al. 2020; Koch 2020). Larger droplets fall sooner because they are heavier and research has shown that they travel <0.5m before falling out of the air (Alsved et al. 2020). Chong showed that droplets <100 µm travel horizontally greater distances than large droplets and are implicated in airborne infections (Chong et al. 2020). As large droplets evaporate to <5 µm they can become aerosolized and behave as such (De Olivera 2020).

There was agreement that most of the airborne particle emission during breathing, talking and singing was aerosol (Anderson et al. 2020). However, droplets, although a smaller percentage of the emission, can contain more virus due to their larger size.

To make it more complicated there is a complex relationship between both aerosols and droplets and the environment they enter (Buonanno et al. 2020; De Olivera 2020; Stadnytskyi et al. 2020; Tang et al. 2020). Humidity, air temperature, airflow, evaporation and emission speed affect the behaviour of both aerosols and droplets (Chong et al. 2020; Koch 2020).

Airflow

In turbulent air larger droplets can remain in the air for longer and be propelled further increasing the physical distancing needed to prevent contact (Bazant et al. 2020), although wind has also been shown to increase evaporation (Koch 2020). It follows and has been shown that in calmer air large droplets will fall to the surface more quickly and in a shorter distance. The direction of air flow from the host to contact with a person is therefore important in more turbulent air. This is consistent with epidemiological studies showing patterns of transmission that follow air flows within a room (Tang et al. 2020).

Evaporation

Evaporation determined by air temperature and humidity effects both aerosol and droplet sized particles with 50% humidity extending airborne particles' lifetime (Chong et al. 2020). Aerosol particles emitted into dry air, shrink more quickly, concentrate their contents (including the virus) and remain airborne for longer due to their smaller size and concentration of matter (Koch 2020; Stadnytskyi et al. 2020). Eventually they will completely dry out and this is thought to reduce the infective potential of the virus (De Olivera 2020; Koch 2020).

A multiphase turbulent puff cloud theory

More recently the traditional view of the interaction between airborne particles and their environment defined by an arbitrary cut-off in particle size between aerosols (<5µm diameter) and droplets (>5µm diameter) has been challenged. Bouriouba's more dynamic proposition for aerosol behaviour is described as the multiphase turbulent puff-cloud theory. Emission of airborne particles from the mouth was found to occur in a microenvironment that trapped aerosol in a moist warm cloud of turbulent gas with its own inner dynamics. This cloud was noted to behave very differently to the traditional view of airborne particles depending on the ambient humidity and air currents. The puff cloud was noted to be capable of being propelled forward up to 7-8m due to its momentum, and evaporation of droplets could be delayed due to the inner dynamics of the puff cloud (Bourouiba 2020). It could be expected using the puff cloud theory that the behaviour of airborne particles might be more like the traditional view of aerosols.

What are the implications of a different theory of airborne particle behaviour for control measures targeting choirs?

The traditional dichotomy of aerosol (<5µm) and droplet (>5-10µm) has been maintained in this review because it is the current recommendation of the World Health Organisation. It is strongly suggested by this review that control measures for both aerosol and droplet mode of transmission be implemented for choir rehearsals. It could be hypothesized that this combination would also be effective for the turbulent puff cloud behaviour of airborne particles by accounting for the further distance travelled by a puff cloud and the aerosol behaviour of particles. Consequently risk management guidance may not change significantly. However, it is very important to the understanding of modes of transmission that research respond to new theories of airborne particle behaviour, such as the puff cloud theory. Development of new theoretical models of risk such as those reported in this review (Basu 2020; Bazant et al. 2020; Buonanno et al. 2020; Chong et al. 2020; De Olivera 2020; Kolinski et al. 2020; Miller et al. 2020; Vuorinen 2020) contribute to the prevention of further outbreaks of COVID-19 through a better understanding of the complex dynamics of airborne particles.

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