Singing in choirs and making music with wind instruments – Is that safe during the SARS-CoV-2 pandemic?

Christian J. Kähler (Prof. Dr.) and Rainer Hain (Dr.)

Institute of Fluid Mechanics and Aerodynamics, University of the Bundeswehr Munich, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany, christian.kaehler@unibw.de

1 Introduction

Singing and making music are wonderful activities that delight many people, whether in a small circle among friends, in church with the community, at festive events or large concerts. In times of SARS-CoV-2, however, the carefree times of making music are also over. Concerts may not take place, in churches singing together is not allowed in many countries and even celebrations in a small circle are prohibited in some places. These restrictions were enforced because at the beginning of March 2020, numerous singers in the USA [1], Germany [2], the Netherlands [3] and France [4] were presumably infected during choir rehearsals. Due to the correlation between singing and infection, a causal connection was suspected, although no such connection has been proven. However, since many musicians work as freelance artists and often live on small incomes, this profession is particularly affected by the enforced rules.

In addition to financial aspects, another major problem for this professional group is that even rehearsals and rehearsals of large orchestras and ensembles are often no longer allowed. However, the perfect interplay of the artists requires a lot of work in the run-up to a concert in order to make it a success and an experience for the audience. It can be assumed that these preparations do not take place in the large halls, but rather in small, unventilated basement rooms of the event buildings. The often limited space on organ galleries in churches or in the orchestra pits of opera houses illustrates the reality of the space situation and the need to develop concepts that allow for safe playing during the pandemic.

At present, it is completely open when and under what circumstances cultural operations can be resumed. The fact is that it is not possible to wear suitable respiratory masks when singing and playing music with wind instruments. Protection against droplet infection must therefore be provided by means of safety distances and flow control methods. However, as long as no reliable information is available on how strongly singers or wind instruments distribute the droplets in their environment and what influence indoor air flows have on the transport of the droplets, it is not possible to establish meaningful distance rules. It is therefore not surprising that until recently the valid demands for distance were partly absurd. On April 27, for example, the Verwaltungs-Berufsgenossenschaft (VBG) demanded a safety distance of 6 m during rehearsals for singing or excessive speaking and for wind instruments of at least 12 m in the wind direction.

Due to this unsatisfactory situation, the aim of this scientific study was to carry out quantitative measurements with experimental methods in order to obtain a reliable database that would allow a more appropriate definition of safety distances. In addition, we wanted to understand which instruments pose a particularly high risk and whether there are ways to reduce the risk. Some key results are shown under: https://youtu.be/BYo3wlWUDDM.

2 Experiments

To answer these questions detailed experimental studies were conducted with a professional singer and vocal coach at the Mozarteum in Salzburg (Marion Spingler), two amateur choir singers, five professional musicians from the orchestra of the Staatstheater am Gärtnerplatz in Munich (Michael Meinel (clarinet), Uta Sasgen (flute), Ursula Ens (oboe), Cornelius Rinderle (bassoon), Michael Herdemerten (trumpet)) and an amateur brass player (Max Schaefer (trumpet, trombone, euphonium)).

For completeness we examined both the spit-like (ballistic) propagation of larger droplets when singing and speaking and the flow-related spreading of small droplets (aerosol) when singing and playing music with wind instruments. For this purpose, the droplets escaping from the mouth and wind instruments during exhalation, as well as the air set in motion, were illuminated with a laser and recorded with digital cameras. The recorded series of images were evaluated with a computer program to quantitatively determine the movement of the flow of air [5]. These quantitative measurements are necessary to determine the volume that can be contaminated by the droplets.

3 At what distance does singing become dangerous?

The experiments clearly show that air is only set in motion in the immediate vicinity of the mouth when singing. In the case of the professional singer, the experiments showed that at a distance of around 0.5 m, almost no air movement can be detected, regardless of how loud the sound was and what pitch was sung. It is therefore unlikely that the virus could spread beyond this limit via the air flow created during singing. Amateur musicians who do not use the diaphragmatic breathing most commonly used by professionals when singing, but rather the natural chest breathing, do not get beyond this range either. By singing a very loud and long sequence of the same tone at about 2 Hz, a slightly wider spread of air movement could be achieved.

The low spread of air movement is not surprising, since singing does not expel a large volume of air in jerks like coughing or sneezing [6, 7]. Rather, the art of singing is to move as little air as possible and still produce a beautiful and powerful sound. This requires to make the room in front of the singer vibrate through resonance without losing too much air. Experiments have shown that even when singing a low tone lasting almost 12 seconds, only about half a liter of air is exhaled. For high notes ½ liter of air was moved in just under 5 seconds, but to produce high notes the air is often inhaled, so that in this case the risk of aerosol or droplet spreading is low. But even when exhaling for high tones, the flow velocity is comparatively low, because the mouth opening tends to increase with increasing pitch and thus the flow velocity decreases accordingly. Technically speaking, strong air movements during singing can be regarded as unwanted losses that singers try to avoid, since sound propagation does not require airflow. An air flow is only required to produce a tone. When warming up and singing in, this can be different and therefore caution is advised. These preparations should not be carried out in a large group without further safety precautions.

In order to prove that the air in front of the mouth is hardly moved at all, one can hold a burning candle in front of the mouth, then sing or speak and at the same time slowly and calmly remove the flame from the mouth [8]. As soon as the flame stops flickering, the distance is determined at which the flow movement is also negligible. The same experiment can of course be performed with wind instruments. It is important to note that the very loud and accentuated speaking of special sounds, which could be described as blowing and spitting sounds, influence the air over a wider range. However, experiments have shown that even these sounds do not cause the air to be swirled much further than 1 m. However, it is possible that larger droplets are spat on even further before they fall to the ground due to their mass. Therefore, some protection mechanisms for droplet and flow control may be advisable, as explained below.

4. Recommendations for protection when singing

4.1 Safety distance

Even though the experiments show that the propagation of aerosol and droplets during singing is relatively small, in our opinion a safety distance of at least 1.5 m must be maintained in a choir. This is necessary to provide effective protection against droplet infection even if other people cough without following the hygiene label (cough into the crook of your arm and turn away from other people). In the case of a simple whooping cough, the droplets can be transported over one metre, and in the case of a long-lasting chesty cough even over 2 metres. The authors have already proven this in another study [9, 10]. For this reason, strict adherence to the hygiene label is very important when singing. If there is no singing in between, we recommend wearing a mouth and nose protector or even better a particle-filtering breathing mask.

4.2 Popshield

To effectively limit the ballistic flight of large droplets and to contain the spread of aerosols due to air movement when singing, a popshield can be used in front of the singer. These popshields are very effective in limiting the spread of exhaled air and expelled droplets and therefore increase the safety. Furthermore, they have no influence on sound propagation and sound quality when they are about 0.2 m in front of the mouth. However, if no popshields are used and extreme spitting sounds have to be spoken, then the head should at least be tilted down a little so that the ballistic flying drops come faster to the ground and are not spat into the head area of the persons in front. But even if this is not done, the risk of infection from these large drops is rather low if the persons are positioned correctly, because in the worst case they would hit the back of the person's head in front of them, where they vaporize. Conversations in which you look your partner directly in the face are much more risky with regard to a droplet infection than a constellation like in a choir. Therefore you should be more careful during conversations in the breaks and wear a mask.

4.3 Staggered arrangement

To increase the distance to the person directly in front, a staggered arrangement of the singers is always recommended from a fluid mechanic point of view if the choir consists of several rows. This arrangement is also recommended to the public in churches in order to protect others and themselves from droplet infection. If the churches are well attended and the safety distances can no longer be maintained, then only N95/FFP2/KN95 or better particle filtering face masks help as self and external protection [9, 10].

4.4 Social behaviour and droplet evaporation

In reports that cite singing as an explanation for the infection of large parts of a choir [1, 2, 3, 4], it should be questioned whether social behaviour is not the actual origin of the infection. If particularly sociable people greet other choir members with hugs and kisses, have a lively conversation during the break, have dinner in a convivial atmosphere after the rehearsal or drink a wine with each other before saying goodbye heartily, it can be assumed that this social behaviour is more critical in the case of an infection than the singing itself. The musicians we asked have confirmed that the social behaviour described above is not unusual from their experience.

The fact is that the 1 µm droplets in the aerosol have already completely evaporated after fractions of a second [11, 12]. Droplets with a diameter of 10 µm are completely evaporated after about 1 second (at 50% relative humidity) and very large droplets sink quickly to the ground and evaporate [13, 14, 15]. It is very important to realize that those experiments, in which the ability of viruses to reproduce in aerosols was studied, were carried out in a laboratory condition that is completely unrealistic in practice [16]. There the rate of evaporation was in equilibrium with the rate of condensation. These conditions may apply in the steam bath, the shower and in some kitchens without proper steam extraction and therefore in some tiny restaurants, but not in our natural environment. Numerical studies in which the dispersion of droplets in the room was analyzed suggest that the droplets can spread over the whole room and cause infections [17]. However, the assumption that the droplets do not evaporate is wrong and therefore, the results are misleading. Even studies that have simulated particle dispersion when jogging and cycling do not consider the effect of evaporation and therefore may massively unsettle the population [18].

Recently, an interesting study [19] has been published, which has also received great attention in the press. In the study, the probable viral load is theoretically estimated as a function of the droplet size. Assuming that there are 7 million viruses per ml of liquid, the probability of finding a virus in a 3 µm droplet is 0.01%. The probability of finding at least one virus in a 10 µm droplet is 0.37% and for a 50 µm droplet 37%. Considering that the minimum number of infectious virus particles required to cause infection is probably between a few hundred or thousand particles [20, 21], this estimate shows how many droplets need to be inhaled to be highly likely to become infected. As the liquid evaporates in a few seconds, a solid residue remains, consisting of salt, blood cells and possibly viruses. The authors show in [19] that the measurable droplets with a diameter of more than 12 µm remain in the calm air for several minutes. However, this is a well known fact and by no means surprising or worth mentioning in a scientific paper. Then it is measured how fast these solid remains sink in still air. The result is physically known since Stokes (1851) and therefore trivial. In practice this case is completely irrelevant, because particles with a size of a few micrometer move with the flow [5].

At the present state it is clear, that non-evaporated droplets are infectious [16]. Therefore, the focus of our investigations is on the fluid mechanical distribution of these droplets. However, to the best of our knowledge, it has not been scientifically proven whether the solid residues that remain after the liquid phase of the droplets evaporates are infectious. According to [22] there is a possibility that aerosols might be infectious under special circumstances.

Even if the droplets are long-lasting because the humidity is close to 100%, it must also be considered that the viral load of an infected person would be very much diluted in a large room, so that the necessary viral load would usually not be sufficient to infect others. Poor ventilation could cause people in the immediate vicinity to become infected and a fan would be able to infect people in the wake of an infected person, but it is physically not clear how 102 out of 130 people in a group can be infected by these effects, as happened in Amsterdam [3]. A singer of the Amsterdam choir said [3]: "Maybe we were too naive together." "But that wasn't an issue at the time, the danger of the coronavirus. On Tuesday, February 25th, we just had our normal rehearsal". At the choir rehearsals in Germany, where 60 of 80 singers are said to have been infected on March 9, rehearsals were held in a 120 square meter room [2]. This room size is definitely much too small for 80 people to keep the rules of social distance in practice. How large the room volume was, whether the air exchange was sufficient and how high the air humidity was is not known, but it can be guessed that in this case not the singing but the circumstances were very problematic. In the USA case at Mount Vernon Presbyterian Church they claim that they "were making music and trying to keep a certain distance between each other." [1]. It is uncertain, however, how well the rules were followed in early March, when the sense of the pandemic in the USA was only just beginning to develop. The fact is that there is a high correlation between singing and infection. But whether there is also a causal connection between a person singing at a fixed place in the room and dozens of infections in a large radius is questionable. Over the last 25 years, we have scientifically investigated in great detail the generation of aerosols, their transport in laminar, transitional and turbulent flows, turbulent mixing in boundary layer flows and entrainment effects, as well as the evaporation of small droplets, using the most advanced optical laser measurement techniques. We have written numerous recognized publications in all of the above-mentioned fields. Even with this knowledge and the quantitative results discussed in this study, it is not comprehensible to us how, in practice, a single person in a fixed location can infect dozens of people in a distant environment by simply singing, without ever getting close to the other person and in compliance with the rules of distance.

4.5 Ventilation

In addition to adhering to the rules of distance and placement recommendations, it is also very important to ensure good and proper ventilation in the rehearsal rooms in order to minimize the risk of infection from slow room air motions. To ensure this, on the one hand the air exchange rate should be significantly increased in times of a pandemic, on the other hand, with ideal room ventilation, the air should be supplied from below through the floor and be extracted flatly via the ceiling. Sideways air removal can cause the air contaminated with viruses to flow to non-infected persons, which may lead to infection even over longer distances in streamwise direction under unfavourable conditions. For this reason, fans in the rehearse room are also not recommended if they transport the air at low speed (less than 0.3 m/s) from person to person. With increasing speed, this danger is reduced because the exhaled air volume is diluted by a cross-flow, and strongly turbulent flow motions, thus reducing the viral load, but speeds greater than 0.3 m/s are perceived as unpleasant.

4.6 Convection

There is another point to consider: An ascending convection flow usually forms around and above the warm bodies of people, as the air heated by the skin and the air exhaled is lighter than the air in the surrounding area. This effect also speaks in favour of extracting the room air through the ceiling.

4.7 Room size

The size of the rooms is also important as already mentioned. If the rooms are sufficiently high, then a longer dwell time of the droplets above the persons will cause the droplets to evaporate if the humidity is not extremely high (this is ensured by fresh air supply). Even if the viruses would remain infectious without droplets, the risk of infection will be further reduced due to mixing in the upper air layers of the rooms, provided the ceiling height is sufficient. For safe music operation, therefore, not only the rules of distance and placement are important, but also the air conditioning and room size.

5 How dangerous are wind instruments?

5.1 Brass instruments

Experiments with a trumpet, a trombone and a euphonium showed that the smaller the instrument's bell, the deeper the tone and the more impulsive the tone sequence, the larger the moving air area in front of the instruments. Overall, however, the area set in motion is also in this case smaller than 0.5 m. These results are also understandable in terms of fluid mechanics. The actual tone is mostly produced in brass instruments by stimulating the slightly pre-tensioned lips, through which the air flows, to vibrate. The design of the instruments then only changes the timbre and volume of the tone. Just as with singing, the aim of brass instruments is not to blow out as much air as possible in a short time, as is the case with coughing and sneezing, but to allow the lips to vibrate as relaxed as possible according to the desired pitch. The more successful this is, the cleaner and clearer the tone will sound.

However, we still recommend keeping a safety distance of at least 1.5 m and arranging a staggered positioning of the musicians to protect themselves from droplet infection through coughing. It is also important to consider the advices given below.

5.2 Woodwinds and flutes

With a clarinet, an oboe and a bassoon, larger flow movements can be produced than with the brass instruments examined. This is due to the smaller blowing openings and the lower flow resistance due to the straight design. Especially low and long-lasting tones can lead to flow movements in the range around 1 m for the clarinet and oboe and above 1 m for the bassoon. However, these instruments do not blow the air horizontally to other people, which is advantageous with regard to the safety distances.
An even greater range could be achieved with a transverse flute for long, low notes. With this instrument, the air is quickly blown over the arched mouth plate with the actual blow hole with the mouth slightly open. This allows the air to enter the room almost as a free jet. However, due to the curvature of the mouth hole plate, the air is deflected downwards until it separates due to an aerodynamic effect called the Coandă effect. Since the air is not slowed down by the flow resistance of the instrument, the risk of infection emanating from this instrument is much greater than from any other instrument examined. From the point of view of occupational health and safety, it would therefore make sense to position the flutes in the front row during rehearsals or concerts. However, as this is not desired flow control methods are required to contain the spread of droplets and the transportation of aerosol by air motion.

5.3 Which protective measures are effective?

In order to effectively limit the ballistic flight of large droplets and to contain the spread of aerosols due to air movement, it is advisable to attach a very thin and tightly woven silk or paper towel in front of the opening of the bell. A dense popscreen such as that used in front of studio microphones is also very suitable. These are sold commercially right away with a flexible arm and a clamp for attachment. However, care should be taken to ensure that they can be disinfected well after use without damaging the material. If very large droplets should fly ballistically, they can be effectively intercepted with these simple protective measures. The propagation of the aerosol is also effectively hindered, as the spread of the exhaled air is prevented. The principle is the same as for the very simple mouth-and-nose protection, which prevents the spread of the exhaled air when coughing due to the flow resistance [9, 10]. Basically, the flow resistance of the material causes a fast and directed air movement to be converted into a slow and undirected air movement.

If the protection is located at a distance of about 0.1–0.2 m downstream of the instrument's bell (trumpet, clarinet, oboe, bassoon) or the blowhole of the flute, neither the flow resistance when making music nor the sound propagation is affected and therefore neither the sound experience, as the experiments show. Behind the trombone and the euphonium no ballistic liquid leakage in the form of large droplets was observed. This is physically understandable due to the flow resistance caused by the length and design of the instruments and the low flow velocity in the tubes. In this case the liquid is collected in the instrument and then released in a controlled manner. Here too, of course, hygiene must be observed. As soap is said to be harmful for SARS-CoV-2, it might be advisable to empty the condensed water into a bowl with some detergent or dishwashing liquid.

To ensure that liquid that has accumulated in the instrument due to condensation does not escape from the instrument as a liquid film or droplets at high blowing speeds, the liquid should be drained more often than usual. This is important because the danger from these physical effects increases with the amount of liquid. Wind instruments without a liquid outlet should be wiped through as often as possible to avoid these effects.

5.4 Important additional considerations playing indoors

Just as with the singers, the size and height of the rooms must be appropriate for the musicians in the ensemble, the rooms must have adequate ventilation and the flow conditions in the room must be taken into account, as already mentioned in sections 3.5–3.7. If the normal rehearsal room does not meet these requirements, the room should not be used for collective performances. In this case, another room must be found which ensures that music can be played safely.

5.5 How dangerous is playing music outdoors?

Playing music outdoors can be considered largely safe if the rules of distance and placement are followed, unless there is a light and steady cross wind that transports the contaminated air over a greater distance without reducing the viral load by turbulence or greatly stretching the droplet cloud after exhalation. However, there is another very important point to consider. If the music tends to play in the background, for example to create a cosy atmosphere, the music should not be too loud. Loud music causes those people who like to talk to each other to talk very loudly and also brings them closer together. Both is fatal in view of the imminent danger of droplet infection, as the number and size of the droplets that are produced when speaking increases greatly with the volume [23, 24]. In addition, the viral load increases significantly when the distance to an infected person is reduced. Therefore, the organizers must not only keep the safety of the musicians in mind, but also the safety of the audience. And it's not only distances, positioning, air conditioning and room size that count, but also people's behaviour when music is loud. Sociable celebrations, e.g. during carnival or Oktoberfest, but also in discotheques and bars are to be classified as critical with regard to loud music. But also musicians at parties should moderate their volume until the end of the pandemic in order not to induce people to risky behaviour.

6 Summary and conclusion

Our quantitative measurement results show that the dispersion of droplets when singing and making music with wind instruments is in general relatively small. A safety distance of 12 m is therefore completely exaggerated.

However, when singing, the safety distance should in any case be greater than 1.5 m, in order to be largely safe even when people in the vicinity are coughing without observing the rules of hygiene (cough into the crook of your arm and turn away from other people).

In addition, a staggered positioning of the persons is recommended, as this increases the distance to the person in the direction of flow even more.

To be sure that the spread of droplets and aerosol is contained, popscreens are highly recommended when singing.

In our opinion, this popscreen is absolutely necessary for a transverse flute in order to allow safe playing at moderate distances.

For the oboe, clarinet and bassoon we also recommend the use of a popscreen for safety reasons.

According to our measurements, the large brass instruments are not able to influence the flow over a large area and therefore these instruments can be played without protection.

However, we recommend to let out the condensation water more often under consideration of the hygiene standards and to wipe the woodwind instruments as often as possible.

In addition to these protective measures, which each musician can control himself, it is also very important to ensure that the room is sufficiently large, well ventilated and provided with sufficient fresh air. The automatic fresh air supply should be significantly increased compared to the legal requirements in order to keep the virus load in the room low. An open window cannot replace a high-quality automated fresh air supply.

If the findings and recommendations derived from our quantitative measurements are taken into account, then making music in a community should be relatively safe. However, there is of course no absolute certainty that droplet infections or infections by aerosols are completely excluded by these measures. Risk groups and people with relevant previous diseases should therefore protect themselves as well as possible.

We would like to point out that we consider compliance with all recommendations to be important in order to minimize the probability of infection. If individual recommendations cannot be followed, e.g. because no suitable room is available, what should be done? It is better to find another room that meets the requirements or to stop singing in the choir than to do without individual protective measures.

7 Concluding remarks for decision makers

Flow phenomena play a very central role in many areas of the COVID 19 pandemic. These include the generation of virus-laden respiratory droplets in an infected person, the transport of the droplets from the lungs and throat into the atmosphere, their transport through the air and the molecular and turbulent mixing and dilution processes that occur during this process through entrainment, as well as large movements of room air through air conditioning, the evaporation of the droplets on their way to another person, the phenomenon of inhalation and deposition inside the body. The sinking of larger droplets, the wetting of surfaces by droplets and the subsequent evaporation are also research topics in fluid mechanics. Even the efficient prevention of flow propagation by means of breathing masks or a popscreen can only be analysed with a profound knowledge of fluid mechanics. Due to this fact, we recommend to consider fluid mechanics in the current discussion. In addition, fluid mechanics provides quantitative results that can secure and legitimize important political decisions.

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