Music and aerosols: What the research reveals about the performing arts during a pandemic

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1 December 2020

The question of the conditions under which singers and musicians, especially in larger groups, can perform safely before live audiences has become a pressing problem under conditions of the COVID-19 pandemic. Music is essential to human life and culture, but there may be no alternative at present but to restrict access to it. Various scientists and researchers have now looked into the problem.

A University of Colorado Boulder study began with an apparently unassuming, everyday event:

On the evening of March 10, 2020, 61 of the 122 members of the Skagit Valley Chorale met for rehearsals at the Fellowship Hall of a church in Mount Vernon, Skagit County, Washington. At this early date in the pandemic, the Skagit County Health Department had not issued recommendations for widespread closure of large gatherings or public events.

On March 15, the Centers for Disease Control and Prevention (CDC) issued guidance recommending that crowds of 50 people be avoided, and a day later President Donald Trump indicated restrictions needed to go into effect.

Though the director had emailed choral members and suggested that if they were ill they not attend, an individual who had developed cold-like symptoms three days earlier went to the rehearsal. Subsequently, that person (index case, or "patient zero") was tested positive for COVID-19. At the time, there were no cases in Skagit County. Necessary contact precautions were taken to include hand sanitization and avoiding handshakes.

The rehearsal commenced at 6:30 pm and ended at 9 pm that evening. According to the University of Colorado Boulder study submitted to the journal *Indoor Air* on June 15, the heating had been turned up to 20 degrees Celsius, and no exterior doors were opened. It was not known if the furnace exchanged outside air.

Over the next several days, several members of the chorale began experiencing flu-like symptoms. Among the 61 attendees, there were 53 cases in total, of which 33 were confirmed COVID-19 positive and 20 unconfirmed presumed infected cases. The secondary attack rate ranged from 53 to 87 percent.

The authors of the University of Colorado study concluded it was unlikely that fomites or respiratory droplets could have accounted for such an attack rate. The singers had been interviewed and all insisted they had abided by strict contact precautions. Additionally, the index case could not have spent a considerable amount of time near that many people in the limited space of time.

The poor air circulation and high respiratory aerosol emissions generated during singing were the main factors for one of the nation's first super-spreader events. The study was a critical analysis that brought to light the crucial role of aerosol transmission for the transmission of SARS-COV-2 under certain conditions.

A few weeks after the study was posted on medRxiv, the preprint server for health sciences, 239 scientists wrote to the World Health Organization (WHO) and international health authorities arguing it was time to address airborne transmission of the coronavirus. In a letter, published July 6 in the journal *Clinical Infectious Diseases*, they wrote, "There is significant potential for inhalation exposure to viruses in microscopic respiratory droplets (microdroplets) at short to medium distances (up to several meters, or room-scale), and we are advocating for the use of preventive measures to mitigate this route of airborne transmission."

Before this appeal, the WHO and CDC had endorsed contact and respiratory droplets as two primary modes of transmission based on evidence from research conducted a century ago. Prominent in this shift to recognizing aerosol forms of transmission is the weight of evidence conducted under laboratory conditions by a collaboration of international researchers on the mechanism of super-spreading events.

This has received further support from field research in hospitals, as well as video analysis of recognized clusters on public transportation and restaurants, which has shifted recommendations towards mandating mask usage, strict social distancing with limited time allotments and improving indoor air circulation.

With schools shuttered and the performing arts essentially abandoned, the National Federation of State High School Associations, College Band Directors National Association and a coalition of over 125 performing arts organizations joined forces to commission a study on aerosols' impact in various live performances. Their primary intent was to see if mitigation efforts could sufficiently protect the musicians, artists and their audiences from the risks posed by aerosols generated from singing or playing brass and woodwind instruments in concert halls and theaters.

What followed was an unprecedented six-month collaborative effort between Dr. Shelly Miller, co-author of the Skagit County super-spreading event study and mechanical engineering professor at the University of Colorado, and Dr. Jelena Srebric, a professor of mechanical engineering and Acting Associate Dean of research at the University of Maryland, to discern the science of aerosol behind the performing arts. Specifically, they sought to quantify the risks such activities presented and what measures would bring these risks to an acceptable level.

As their protocol states, "This study was designed to (1) identify

performing arts activities that generate respiratory aerosols including volume, direction, density, (2) estimate the emission rates of respiratory aerosol, (3) model the dispersion of these aerosols, and (4) investigate mitigation strategies." Preliminary results of their studies were released in three phases—July 13, August 6 and November 13—with a final publication forthcoming in December. They defined aerosols simply as solid or liquid particles suspended in a gas.

They wrote in their third summation report that "wind instruments and singing produce aerosols, which vary by instrument as well as intensity. The produced aerosol amount is, on average, similar across all instruments types and singing with the exception of the oboe. Most aerosol is being expelled from the bell of the instruments and from the mouth of the performers. … It appears that if players wear surgical style masks with slits for mouthpiece AND bell covers, aerosol emission is reduced between 60 and 90 percent."

The research indicated that the concentration of aerosol emissions was relatively high for instruments that had straight shapes from mouthpiece to bell (trumpet, clarinet, and oboe). The use of masks and nylon bell coverings all seemed to reduce particle concentrations. Additional general considerations included recommendations that students and teachers should wear well-fitting masks. At the same time, wind players should use masks with a slit through which the mouthpiece can be placed. Once they stopped performing, they were to cover their mouth with a second mask. They endorsed the six-foot separation and limited rehearsals to 30 minutes to clean the room for a minimum of one air change rate per hour (the volume of the room exchanged in one hour) before the next rehearsal.

Interestingly, they strongly discouraged plexiglass partitions or barriers between musicians in concert halls as they would limit the heating, ventilation and air conditioning (HVAC) system's ability to exchange the air in a given space. They noted that dead zones were created where aerosol can concentrate if these partitions are erected. Specifics for HVAC units, filters and high-efficiency particulate air (HEPA) cleaners are cited.

In another study conducted recently by Rice University engineers in collaboration with the Houston Symphony, using high-speed camera to track the movement of exhaled air released by singers and musicians that played wind instruments, researchers found the warm exhaled plume rose toward the ceiling where it joined the air currents in the room. These findings provide additional evidence for well-designed ventilation systems that will predictably direct currents that can exchange room air multiple times each hour.

A comparison between various instruments and voices concisely demonstrates the different concentrations of aerosols they generate in the figure presented. The Y-axis for the two figures is different in scale. The Aerodynamic Particle Sizer spectrometer (APS) measures airborne particles' acceleration ranging in size from 0.5 to 20 microns through a nozzle. The APS concentration measures the number of particles in a volume.

The oboe without a bell cover generates the highest concentration at four particles in a cubic centimeter. However, once the bell is covered, there is a 96 percent reduction in the emission. On the other hand, the flute, because of the angle of the jet stream, has the lowest emission compared to other brass and woodwinds. Similarly, a soprano forces more carbon dioxide to be exhaled than a baritone, therefore probably spreading the virus farther and pushing more out to get that sound. But once masked, the different voices reach a similar low concentration.

Another study conducted by the Metropolitan Orchestra and Princeton looking at exhaled CO2 gas from a singer revealed that the fluid dynamics are influenced by the phonetics which can propel aerosols beyond the established one-meter limit.

These innovative studies provide a unique understanding of the nature of sound and potentially how to mitigate the risks and provide the community at large how it can better protect itself from becoming infected.

Of course, soloists (pianists primarily, but not exclusively) and chamber specialists (especially string quartets) do not face the same risks as larger groups, particularly those including wind instruments. Wigmore Hall in London, for example, continued to organize live concerts, which were streamed online, with socially distanced audiences of some 25 percent capacity, plus a few socially distanced musicians onstage. They recently stopped the audience involvement in response to an uptick in positivity and the general resurgence of the pandemic.

Orchestral and choral groups certainly face greater risks performing, as does the audience in such cases. And anyone who has attended an orchestra performance recognizes the utterly captivating world the ensemble of instruments playing in unison can produce, one that leaves a significant impression that the music lives and breathes. Unfortunately, it seems that such events in the context of a pandemic inform us of even a more dangerous reality at present, thanks to the policies of every nation's ruling elite.

Supplementary material:

The Schlieren Test is optical inhomogeneities in a transparent medium that are not necessarily visible to the human eyes. They help identify flow pathways, which would carry emitted particles. Below are some experiments highlighting these tests:

- Link 1
- Link 2
- Link 3
- Link 4