Minnesota Orchestra Principal Trombone Douglas Wright is filmed on the Orchestra Hall stage as part of the orchestra's aerosol-transmission research study in partnership with scientists at the University of Minnesota.

Travis Anderson

Studying Safer Concerts

Orchestras and scientists are joining forces to study the spread of the coronavirus so they can bring back live music—safely. These collaborations are part of the innovative approaches orchestras are taking on multiple fronts during the pandemic. Results from the scientific studies suggest mitigation strategies, safety protocols, and even new ways to present concerts.

by Michele C. Hollow

Imagine feeling safer performing onstage than shopping at a local supermarket or taking public transportation. That's a comparison recently made by Stefan N. Willich, professor and director of the Institute for Social Medicine, Epidemiology, and Health Economics at Charité University Medical Center in Berlin, Germany. Willich is also a conductor and founder of the World Doctors Orchestra, based in Berlin. Willich is highly aware that COVID-19 cases are on the rise in Germany, here in the United States, and around the world. Despite the widespread increase, he remains optimistic and believes that with proper measures in place, in-person

This article reports on several recent studies of how coronavirus aerosols are transmitted by orchestral musicians in concert halls and other spaces, as well as various interventions to prevent the spread of the virus. Some of the studies have been completed, while others are ongoing. Scientists are continuing to learn more about the coronavirus, and study findings noted in this article do not constitute safety recommendations from *Symphony* magazine or the League of American Orchestras.

concerts can safely return. His confidence stems from a German study issued in May 2020 focusing on research between musicians and scientists; the study noted that restrictions put in place in Germany since March 2020 had "achieved a sharp decline of infections." These restrictions include mask wearing, following recommendations for general safeguards, stage plans for various instruments, cleaning, and ventilation.

In the United States, orchestras are taking action and reaching out to scientists at leading universities to determine how to keep musicians, staff, and audiences safe at performances, whether indoors or out. These collaborations between scientists and orchestras are part of the new, highly proactive approaches orchestras are taking to keep the music going during the pandemic. "We have to think in new ways and on all fronts in fighting this disease," says John Mangum, executive director and CEO of the Houston Symphony. "And you can find the answers in science. It's a great first step."

Brandon Martin/Rice University

Houston Symphony flutist Kathryn Ladner (left) plays her instrument as part of the orchestra's aerosol-research study with Rice University researchers Vivek Boominathan, Ankit Raghuram, and Sean Farrell.

The Houston Symphony and students from Rice University's Shepherd School of Music partnered with Rice University scientists to figure out how to resume their events so everyone onstage, in the audience, and behind the scenes stays safe. The 2020-21 concert schedule at the Houston Symphony's website comes with a caveat that due to the pandemic, programs are subject to change. It's the kind of increasingly familiar proviso that most orchestras and concert halls are posting during the pandemic. Orchestras have to pivot quickly now, and so do audiences: rising infection rates and new restrictions on gatherings in mid-November meant that many orchestras had to cancel or significantly rethink holiday concerts that were just a few weeks away. It is likely that some references to in-person future concerts in this article will have changed since press time.

"The more answers and the more studies we're looking at that tell us the same information, the safer we feel," Mangum says. "We're building a body of evidence." One of the biggest pieces of evidence relates to how far a wind or brass player's breath travels when they perform. Several studies between orchestras and scientists have shown that the airflow of particles from these instruments don't travel as far as previously thought. "That was one of the things we looked at," Mangum says. "Scientists at Rice University have been studying how air particles are spread during a symphonic concert, thus giving orchestras a road map to reopening safely." Most of the Houston study concluded this past summer. Researchers are still compiling data and looking at HVAC (heating, ventilation, and air conditioning) systems.

The crux of the problem is that when aerosols are exhaled from a person infected with COVID-19, the virus rides on those aerosols and can land on nearby surfaces or be inhaled by another person. Aerosol research is essential in getting musicians back to rehearsing and performing safely. In addition to quantifying the aerosol risks, an important goal of the studies covered in this article is to examine how to reduce transmission through a variety of mitigation strategies—even as none of these recommendations can be considered definitive, given that knowledge continues to increase about how the coronavirus spreads.

Orchestras are working with scientists to determine how to keep musicians, staff, and audiences safe.

Making the Invisible Visible

Mangum co-wrote a proposal for the Houston Symphony/Rice University study, which is entitled "TunesFlow: Studying Aerosol Flow Spread for Wind Instruments and Singing," with Ashok Veeraraghavan and Ashutosh Sabharwal, electrical and computer engineering professors at Rice University, and Robert Yekovich, dean of the Shepherd School of Music at Rice University. With funding secured by Rice University's COVID-19 Research Fund Oversight and Review Committee, "we thought the results of the study would help not just the Houston Symphony, but orchestras around the country," Mangum says.

The researchers at Rice looked at the direction and distance air particles travel from instruments and singers. The scientists also studied how long these particles remained in the air. They tracked these

Visit the League of American Orchestras' website for regularly updated information about the pandemic, including federal financial assistance; resources on communications, governance, and fundraising; and links to the Centers for Disease Control. https://bit.ly/leaguecovidresources

Brandon Martin/Rice Universit

Houston Symphony Principal Oboe Jonathan Fischer plays his instrument as part of the orchestra's air-visualization research study conducted by Rice University researchers. Instruments in the experiments included flute, oboe, clarinet, bassoon, horn, trombone, trumpet, and tuba.

air particles using Schlieren photography, an imaging system that monitors airflow that's impossible to see with the naked eye. "It's like looking at a fire and the images behind it," Veeraraghavan explains. "Those images seem to shimmer and move. Schlieren photography makes the invisible visible." They did this by photographing musicians playing their instruments. The camera captures the airflow of the air particles emitted from the holes on the instruments' keys and from the bell when air exits the instrument.

"The more answers and the more studies we're looking at that tell us the same information, the safer we feel," says John Mangum, the Houston Symphony's executive director and CEO.

The scientists found that airflow didn't travel as far as they originally suspected. Even the flute, one of the riskiest instruments due to a larger amount of airflow than other instruments, had an airflow of under three feet. The study noted that the outcomes were "quite surprising and point to other factors that we need to pay attention to other than just social distancing," especially ventilation. Nevertheless, researchers were careful to note that the standard social distancing guidelines of 2 meters are "always important" and that this distancing onstage can "reduce the risk, especially from macro-droplets and directly expelled spray."

"What we didn't take into account," Veeraraghavan says, "was that air exhaled from humans is warmer than the air around us in a concert hall. That warm air rises. Our intent is to remove those air particles with ventilation systems that clean the air." The study noted, "It is clear from our data that room air currents (driven by ventilation) have a major effect on the flow of this exudate air. In particular, the airflow direction in some cases could be the opposite of the exudate direction because of room air currents driven primarily by ventilation…. It's important to have good ventilation … to increase air circulation as much as possible and increase the rate of air exchanges per hour to as high a rate as possible."

Based on the Houston Symphony/Rice University study, several safety measures were put in place in Jones Hall, where the Houston Symphony performs. At press time, in-person concerts were back, and the 2,900-seat concert hall was open for only 150 season subscribers to attend hour-long performances. In what has become standard operating procedure at orchestras open for in-person concerts, Houston concerts have no intermission, to minimize audience movement such as getting up to go to the restroom. No food, drinks, or printed programs or tickets are available. This way crowds won't congregate in the lobby, and everything is touchless. Patrons scan their tickets on their cell phones upon entry, programs are online, and masks are mandatory.

In Houston, musicians are tested for COVID-19 two days before the first rehearsal and string and percussion players must wear masks on stage. Woodwind and brass players also wear masks and take them off when they're performing. The study's initial findings were released in October. Based on those findings, musicians now sit at a minimum of six feet apart from one another, and the number of musicians on stage has decreased to about 40 musicians. "We also have livestreaming of our concerts on 8 p.m. on Saturdays," Mangum says. "Some people prefer watching at home and others want to be here. All 150 seats sell out. They understand the precautions we've put in place." Going forward, Mangum, says, "We hope to be able to increase the size of our in-person audiences. A lot depends on when a vaccine will be available."

Jeff Fitlow/Rice University

Houston Symphony Principal Tuba David Kirk participates in the orchestra's Schlieren-imaging study with Rice University researchers.

The Importance of Air Flow

Many orchestras continue to stream concerts online or through their local public television and radio stations. The St. Louis Symphony Orchestra does both. However, nothing compares to in-person concerts. "Despite social distancing and masks, music is still the shortest way from one heart to another," says Music Director Stéphane Denève.

Like many other orchestras, the St. Louis Symphony Orchestra canceled in-person performances due to the pandemic beginning last March. The orchestra returned to Powell Hall in October and has concerts planned through May 2021 with a maximum audience of 150 people. In order to make this season and the next possible, the orchestra teamed up with a group of infectious-disease specialists led by two medical researchers—Stephen Liang and Abigail Carlson of Washington University School of Medicine—to develop concert protocols.

In photo: St. Louis Symphony Orchestra Music Director Stéphane Denève with a nurse at Mercy Hospital, October 2020. After partnering with doctors at Washington University to study ways to return safely to Powell Hall, the orchestra invited healthcare workers to its first socially distanced concerts at the hall this fall.

The St. Louis study, which is ongoing while scientists continue to learn more about the virus, looks at many possible scenarios, from airflow from instruments to social distancing to mask wearing and HVAC systems in the building. The orchestra's leadership "has gone to tremendous lengths to understand and operationalize public health strategies to prevent the transmission of COVID-19," Liang says in an email. "I'm inspired by the passion with which the orchestra has labored to bring music back into all of our lives after all these months."

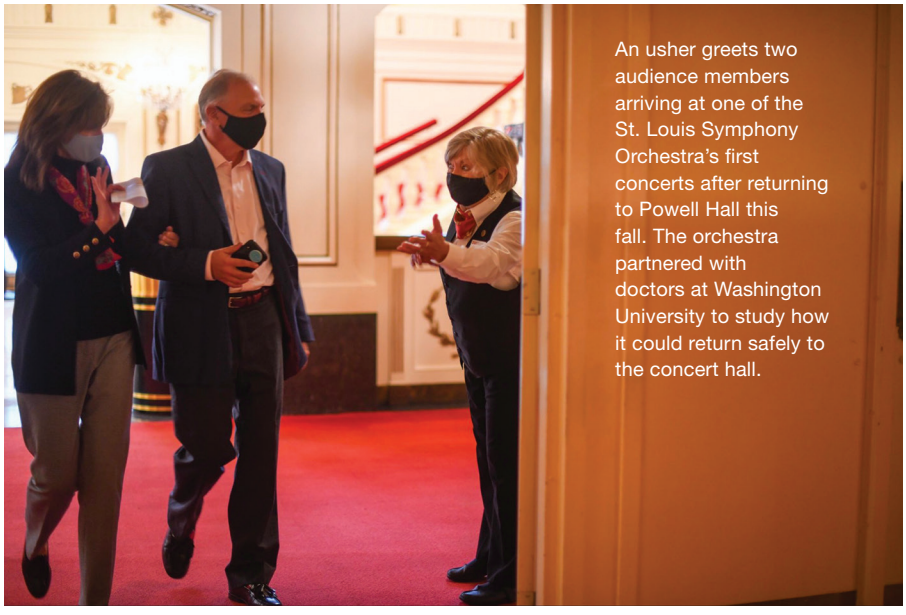
"With all these protocols in place, everyone's on board because it's the future of our business," says Marie-Hélène Bernard, president and CEO of the St. Louis Symphony Orchestra. "We're still learning how the virus behaves, and this study allows us to bring back live music."

Results from the study changed the way St. Louis Symphony Orchestra concerts are performed. Just like other concert halls presenting live music, now-familiar safety protocols will be in place at Powell Hall, among them: no food or drinks, everyone wears masks, concert times average between 60 and 75 minutes without an intermission, and halls are sanitized prior to each performance. On stage, plexiglass barriers separate rows of woodwind and brass players to ensure the airflow from those musicians is directed upward to the return filtration system.

Air filtration systems are essential in making sure the air is clean, says a growing body of research. The St. Louis Symphony Orchestra's website states, "There will be time reserved between each event to allow for six complete fresh air purges and complete sanitation of that hall. HVAC air filters have been upgraded to maximum efficiency rated MERV-13." MERV stands for Minimum Efficiency Reporting Value. The rating means the filters can catch a high percent of air particles.

"With all these protocols in place," says SLSO President and CEO Marie-Hélène Bernard, "everyone's on board because it's the future of our business. We're still learning how the virus behaves, and this study allows us to bring back live music. We found good news about Powell Hall. It was built in 1925 as a movie theater. The airflow in the building is good because of how the building was constructed."

The St. Louis Symphony Orchestra says concertgoers are returning—but with a substantial adaptation due to the pandemic: the 2,600-seat hall is open to 150 concertgoers. "Our audiences want to be here," Bernard says. "We conducted a survey with Slover Linett, an outside consulting firm, and the results were great. Of the 1,300 people who responded to the survey, we found 32 percent were ready to return. One third were on the fence, and the last one third were in a high-risk group for getting the virus. Of the people who wanted to attend live concerts, the mix included young and old from a variety of backgrounds."



An usher greets two audience members arriving at one of the St. Louis Symphony Orchestra's first concerts after returning to Powell Hall this fall. The orchestra partnered with doctors at Washington University to study how it could return safely to the concert hall.

Dilip Vishwanat

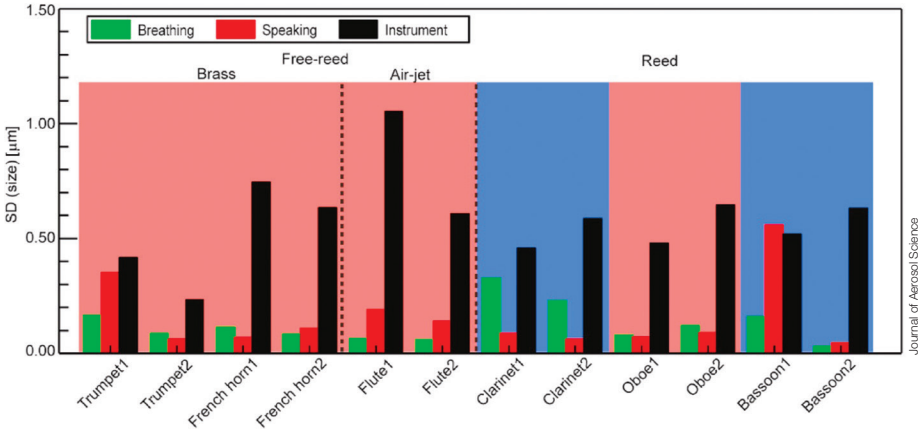
St. Louis Symphony Orchestra Music Director Stéphane Denève greets the audience at a chamber concert at Powell Symphony Hall on October 16, 2020.

Filtration, Aerosol Concentration, and More

The Minnesota Orchestra teamed up for a study with scientists at the University of Minnesota and with Stay Safe Minnesota (a government resource site), Minnesota Department of Health, Minnesota Department of Labor and Industry, Centers for Disease Control and Prevention, and federal Occupational Safety and Health Administration. "We were trying to understand what the situation was and how it was going to affect us," says Mele Willis, the orchestra's artistic operations manager. "At the time we had little knowledge about aerosol emissions."

"Our approach all along has been to take it gradually," says Mele Willis, artistic operations manager at the Minnesota Orchestra. "We want to keep everyone safe."

The study, which concluded November 20, 2020, looked at air particles that came out of brass and woodwind instruments. "When we exhale, air particles come out of our mouths and out of the instruments we play," Willis explains. "We wanted to understand what happens to those air particles when we're performing together. Scientists at the University of Minnesota looked at the aerosol concentration coming from the instruments and at the direction and length of that concentration. None of the air particles went farther than 30 centimeters, which is under one foot." The Minnesota Orchestra's website states that the University of Minnesota aerosol research study indicates that "aerosols from all wind and brass instruments are not directional and do not flow further than 30 centimeters from the instrument before decreasing to the level of ambient air."



Journal of Aerosol Science

As part of the University of Minnesota's aerosol study with Minnesota Orchestra musicians, researchers measured aerosol generation when musicians breathed, spoke, and played their instruments.

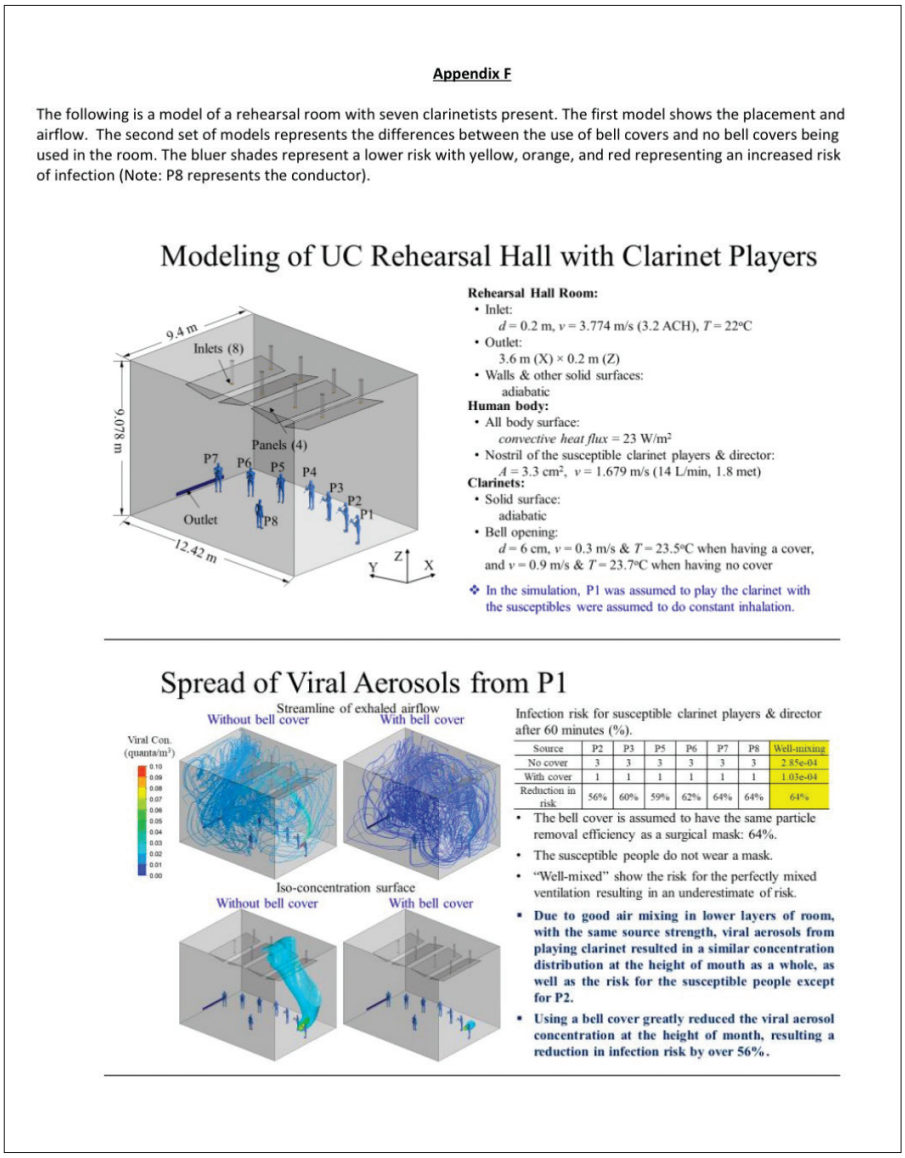
Currently, the orchestra is performing—in ensembles of up to 25 musicians, with health and safety measures in place for the musicians, in programs created for at-home viewing—but not in front of an in-person audience. Minnesota Public Radio broadcasts the orchestra's concerts on Friday nights, while the orchestra's other concerts are streamed on its own website, and some have aired on Minnesota Public TV.

The next step is to bring audiences back. Safety measures are in place, air purifiers are on stage, and the filtration system cleans the air about eight times an hour. Researchers in Minnesota used a computer simulation to study how air moves in the orchestra hall and how it's pulled out and filtered back. "Our approach all along has been to take it gradually," Willis says. "Coronavirus numbers are rising. We want to keep everyone safe. When live concerts return, audience size will be smaller than usual. We're being cautious." Once everything is in place, the musicians hope to return to performing before live audiences.

Bell Covers, Masks with Slits

According to the World Health Organization (WHO), data suggests that children ages 18 and younger represent about 8.5 percent of reported COVID-19 cases and children with pre-existing conditions are at risk. The WHO states that further studies are underway to understand transmission in this age group. Gaining more knowledge about this younger population is important for orchestras—especially youth orchestras—and audiences of all ages.

An aerosol study commissioned by the National Federation of State High School Associations (NFHS), the College Band Directors National Association, and a coalition of more than 125 performing arts organizations including the League of American Orchestras, has generated results that indicate mitigation strategies for reducing the impact of COVID-19 on performing arts activities. These organiza-



The International Coalition of Performing Arts Aerosol Study Report was conducted by researchers at the University of Maryland and the University of Colorado Boulder. This graphic shows various models of airflow in a rehearsal room with seven clarinetists, including differences between the use of bell covers vs. no bell covers as well as relative risks of infection.

tions collaborated with scientists from the University of Colorado Boulder and the University of Maryland.

"We are providing these results to assist in the safer return to performing arts activities," James Weaver, Ed.D., director of Performing Arts and Sports for NFHS, where he oversees student participation, professional development, and awareness of performing arts activities at the nation's more than 19,500 high schools. He is co-chair of the study, which "focuses strictly on the distribution of respiratory aerosol that is generated while playing wind instruments, singing, acting, speaking, dancing, and in a simulated aerobic activity," he says. "The study was designed to identify performing arts activities that generate respiratory aerosol including volume, direction, density, and mitigation strategies."

What surprised Weaver about the study was that the flute didn't produce as many aerosols as he expected it would, and that double-reed instruments break up large droplets into smaller droplets because of the vibration from the reed on these instruments. Smaller droplets can remain suspended longer than larger ones. "These can be dealt with by having the musician wear a surgical mask with a slit in it," he explains. "Everyone should wear a mask whether they're in rehearsal or performing. Putting bell covers on the end of the instrument reduces aerosol emissions between 60 and 90 percent. And improving classroom ventilation and limiting the size and duration of rehearsals makes performing safe."

A safety poster designed for music educators and students in conjunction with the International Coalition of Performing Arts' aerosol study. The study was commissioned by the National Federation of State High School Associations, the College Band Directors National Association, and a coalition of more than 125 performing arts organizations, including the League of American Orchestras.

The study recommends against using plexiglass partitions or barriers between musicians, due to HVAC system design limitations in many schools. "Dead zones," or areas where aerosols can build up, are a concern when these partitions are used. Wearing masks at all times is highly recommended. Some of these findings may seem surprising and counter-intuitive, given, for instance, that we have seen plexiglass partitions frequently used on concert stages during the pandemic. It illustrates that best practices are still emerging as scientific knowledge increases.

The multi-part NFHS aerosol study was still underway at press time, with final results expected to be published in January 2021, and individual orchestras continue to work closely with scientists and health officials in their communities to keep musicians, staff, and audiences safe. In the meantime, though nothing is certain, recent news about several new vaccines has made many in the arts community cautiously hopeful about where we might be by the middle of 2021.

MICHELE C. HOLLOW writes about autism, Alzheimer's, health, and animals. Her byline has appeared in *The New York Times, AARP, The Guardian, Parents,* and other publications.