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# Statement of Work: Aerosol Generation from Playing Band Instruments, Singing and Performing and Risk of Infectious Disease Transmission

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## Background

The significance of viral transmission via inhalation of small airborne respiratory droplets (also commonly referred to as 'aerosols') has been intensely discussed in the context of the SARS-CoV-2/COVID-19 (severe acute respiratory syndrome coronavirus-2/coronavirus disease 2019) pandemic (Morawska and Cao 2020; Lewis 2020). Other commonly accepted modes of viral transmission are via larger respiratory droplets (which fall close to where they are expired) and direct contact with contaminated surfaces (fomites).

While evidence for airborne transmission of COVID-19 is incomplete, several hospital-based studies have performed air-sampling for SARS-COV-2 (Ong et al. 2020; Guo et al. 2020; Chia et al. 2020; Ding et al. 2020; Jiang et al. 2020; Liu et al. 2020; Santarpia et al. 2020). Four of these studies found several positive samples for SARS-CoV-2 genome (RNA) in air using polymerase chain reaction (PCR) testing, two found very small numbers of positive samples, and only one found no positive air samples. This evidence at least demonstrates a *potential* risk for airborne transmission of SARS-CoV-2.

Because of this potential risk from infection via droplets and aerosols as illustrated in the above studies and others that are rapidly forthcoming, many activities that occurred prior to the pandemic will have to be modified to reduce risk of infection, especially those that have the potential to generate virus-containing particles. These activities include things like singing and playing musical instruments. While singing has been implicated in several outbreaks (Hong Kong Karaoke 2020; Skagit Valley Choir 2020), there have been no reports yet implicating the playing of instruments. However, the potential is likely. In one study, the number of particles emitted while playing plastic blowing horns used by sports fans was 658 x $10^3$ #/L compared to 3.7 x $10^3$ #/L for shouting. The majority of these particles were between 0.5 and 5 μm in

diameter (Lai et al. 2011), small enough to remain airborne long enough to be transported far from the initial source.

The singing episodes plus the published data on plastic horn playing suggest that further investigation is warranted into the possibility of infectious aerosol generated from playing band instruments. Concern has been expressed specifically regarding wind and brass instruments because the sound is produced by a controlled flow of exhaled air accompanied with a source of vibration; an often-used method for producing small particles is a vibrating surface. For woodwinds, the flow is modulated by reeds on the mouthpieces. But other instruments as trumpets and flutes the flow is not impeded (Music Making Risk 2020). A study is needed to better understand aerosol production in instrument playing so that professional musicians and students of music can resume playing in rehearsal and public spaces in a manner that is safe for the nearby musicians as well as any listeners. A description of the proposed methods to be used in this study is the focus of this Statement of Work.

## Methods

The goal of this project is to provide measurements and risk modelling estimates in a timely manner to better understand particle emissions from playing band instruments. To accomplish this goal, we propose the following four activities:

1. Flow imaging studies to qualitatively document the emission and particulate plume through photography and lasers
2. Chamber studies to measure particle generation rates from the following activities:
    a. 5 woodwinds – Flute, Clarinet, Oboe, Saxophone, Bassoon
    b. 4 brass – French Horn, Trumpet, Trombone, Tuba
    c. The 4 vocal ranges – Soprano, Alto, Tenor, Bass
    d. Musical Theatre – Talking, Monologue, Singing, Dancing (Male and Female Actors)
    e. Elementary – Male and Female in Grades 3-5 (Contingent upon Human Subject Approval by Internal Review Board, IRB)
    f. Aerobic Simulation (Marching Band, Show Choir, Dance, etc.)

3. Field rehearsal studies measuring concentrations in a rehearsal room with multiple players the University of Colorado Boulder (contingent upon IRB and campus approval)
4. Modelling of risk of transmission using the Wells-Riley Model (Noakes and Sleigh 2009; Nicas et al. 2005)

## Flow Imaging

Qualitative imaging will be used to estimate the emission of >1-micron aerosols from playing the flute, clarinet, and trumpet. These studies will take place in our 38 $m^3$ aerosol testing chamber. A musician will enter the chamber using appropriate social distancing, masks, gloves and other lab protocols as needed for maintaining a clean, infection-free environment. A flute, clarinet, and trumpet player will be initially recruited for the study. Once in the chamber the player will initiate a set series of notes at both a soft and loud volume. Initially, schlieren imaging will be used to see the warm exhalations from the musician through the instrument and get an overall understanding of relative airflows from the instrument bell, fingerholes, fipples and the musician's nose and mouth. Next, laser light sheets will be placed perpendicular to the principal flows; micron and larger droplets scatter the laser light, and these images will be recorded with a high-speed video camera. These recordings will then be used to align the laser sheets in the plane of the principal flows so that the particles travel along the sheet. These resulting data have the potential to be analyzed for velocity fields, but in any case, should qualitatively indicate the direction and magnitude of the particle-laden jet motion. In the event that insufficient aerosols for imaging are emitted, stage fog in the area of the musician will be used instead.

## Aerosol Emission Studies

Information from the flow visualization study will be used to inform the aerosol sampling design for the chamber study. Similar protocols will be followed. A performer will enter our aerosol testing chamber using appropriate social distancing, masks, gloves and other lab protocols as needed for maintaining a clean, infection-free environment. One performer for each of the 19 research categories listed above (the exception is the children, which will be addressed with IRB approval) will be initially recruited for the study. Once in the chamber, the performer will initiate a set series of notes at both a soft and loud volume. Aerosol instrumentation is

connected to the sampling ports located in the wall of the chamber and a couple of instruments will be placed inside the chamber. Performers will 1st play close to the sampling ports, < 1 meter away and then also 2 m away. This method will also work for our singing performers.

We will measure particles between 12 and 500 nm with a scanning mobility particle sizer, between 500 nm and 20 μm with an aerodynamic particle sizer, and between 60 nm and 1 μm with our ultra-high sensitivity aerosol spectrometer. We will also monitor the chamber air for $CO_2$ and water vapor to better document the physiological parameters of each performer (how much $CO_2$ and water vapor is exhaled). These data will also be used to estimate the emission factor for droplets produced per liter of air exhaled. An ultrasonic spirometer will be used to measure the mean flow volume of breath into the instrument by the performers before and after each experiment. Each experiment will be repeated up to 10 times with each performer to capture the *within variability* of each performer. If the within variability is low, we will add another performer to capture the *between variability* of performers. Note that we are working to limit the total number of individuals entering the chamber for safety reasons, thus the focus on one performer at a time to capture their variability. In between each experiment and prior to any testing the air in the chamber will be purged with particle-free air, and also cleaned using a HEPA air cleaner to reduce the background particle concentrations as low as possible. Surfaces will be disinfected immediately and between experiments following established lab safety protocols at CU Boulder.

In addition to the above measurements, which will provide baseline aerosol emissions information, we will also investigate interventions to reduce potential exposure and risk. These include plastic shields at the end of the instruments or the use of a music stand to block the aerosols, mutes, Win-D-Fender, fabric bell Covers, plastic wrap, operating air cleaners, etc.

## Field Rehearsal Studies

Another goal of this study is to assess the potential impact of aerosol generation in a rehearsal room with multiple performers, in a more realistic scenario. The ability to proceed with this part of the study depends on whether the research team as well as university officials think we can proceed safely. This would be ideal so that we can better understand the impact of dilution ventilation in real practice spaces and also to test the loading of aerosol in a larger space

along with the impact of interventions. Methods similar to those used in the aerosol chamber study will be applied if possible.

### Modelling and Data Analysis

Data analysis will be conducted after every experiment to assess the success of the measurements as the study progresses. Particle size distributions will be generated, and standard aerosol data methods will be used. Emission rates will be estimated using the material-balance method. The Wells-Riley model will also be explored to estimate the probability of infection (P) assuming the instrument player is infected (equation 1):

$$P = 1 - \exp\left(-\frac{Iqpt}{Q}\right) \qquad \text{(equation 1)}$$

Where I = # of infectors, p = pulmonary ventilation rate of a person, q is the quanta generation rate, t is the exposure time interval, and Q is the room ventilation rate with clean air. The quanta are usually estimated epidemiologically from outbreak cases; in this application we would use the particle generation rate and assume roughly 1 virus per particle, and that 0.1% of all viruses are infectious. This modelling would provide opportunities to explore how room ventilation rates would impact infection risk, as well as reducing the generation rate through interventions.

## Summary

The risk of COVID infection from droplets and aerosols generated by playing band instruments could be significant. This study is needed to better understand potential risk and how to mitigate the risk so that musicians can return to playing and music students will be able to continue playing in school bands, practicing and performing.

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