UPDATE: Bioaerosol Emissions and Exposures in the Performing Arts: A Scientific Roadmap for a Safer Return from COVID-19

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Why don’t we have more answers here?

- For every 1,000 doctors that graduate from US medical schools, we see ~1 new PhD granted in aerosol science.
- There are probably fewer than 5,000 aerosol PhDs actively working in the U.S.
- 80% of those PhDs work outside of academia.
- Probably less than 5% study bioaerosols and public health.
- Not everything you read on the internet is true…
Questions we hope to answer

1. What is the rate (and size) of bioaerosol emitted by performers of varying age and gender when engaging in music, voice, and dance?

2. How effective are active and passive control measures at reducing bioaerosol emissions and exposures?
   - isolation and distancing
   - room ventilation and filtration
   - use of homemade masks, respirators, shields or other barriers

3. Can the risks of co-exposure be reduced to “acceptable levels” using these active and passive controls?
Some Sizes and Sources of Airborne Particles

Flour Dust
Some Sizes and Sources of Airborne Particles

Pollen

Particle Size, $\mu$m
Some Sizes and Sources of Airborne Particles

Particle Size, µm
Some Sizes and Sources of Airborne Particles

Smoke

Particle Size, \( \mu m \)
Some Sizes and Sources of Airborne Particles

- Flour Dust
- Pollen
- Smoke
- Spray

Particle Size, \( \mu m \)

- 0.1
- 1
- 10
- 100
Some Sizes and Sources of Airborne Particles

- Flour Dust
- Pollen
- Smoke
- Spray

Particle Size, µm

- Breathing
- Sneezing & Coughing
- Talking
Human bioaerosol spans a huge size range (and not all particles behave the same)

- 0.1 µm
- 1 µm
- 10 µm
- 100 µm

If this particle were the size of a baseball

Then this particle would be the size of a baseball stadium
CSU Mask and Respirator Testing Program

- Shortage of N95 respirators for healthcare workers across Colorado
- Supply of domestic and international respirators of unknown quality / performance
- On March 25, Colorado Governor Jared Polis asked our lab to provide respirator testing and performance verification for State of Colorado COVID-19 Task Force

Over 300 different mask designs tested as of Dec. 1, 2020
N95 means >95% removal efficiency for particles that flow into the mask.

CSU testing program follows modified* NIOSH protocol for particle collection and “breathability”

“Looks” can be deceiving!

Only CDC/NIOSH can certify masks to bear the “N95” label.

PASS  PASS  FAIL  FAIL

* https://www.cdc.gov/niosh/nptl/respirators/testing/default.html
N95s are great if you can get them (but you can’t) so what about cloth masks?

Anonymous Donor: “Please test these 24 different masks, each made with popular mask material, and make the data publicly available”
Most N95 masks remove ~99% of all particle sizes
Mask4: Only 50% of the 3-micron particles are blocked.
Mask17: Add a MERV13 filter layer to Mask4

Mask4: 2-ply high thread-count cotton

Fraction Collected by Mask

Particle Size, μm

Nordic Pure AC & FURNACE AIR FILTERS

mask

4

17

Mask4: 2-ply high thread-count cotton
**Mask17**: Add a MERV13 filter layer to Mask4

**Mask18**: Wash that fancy mask 3 times

**Mask4**: 2-ply high thread-count cotton
What about “Singer’s Masks”?
http://jv.colostate.edu/masktesting/

Want to learn more? Watch our free webinar on mask design: https://col.st/Wq2Bu
Mask efficacy is determined by four primary factors:

1. **Fit**
   - Does the air flow through the mask or around the mask?

2. **Filtration**
   - How efficient is the mask at removing particles that flow through it?

3. **Breathability**
   - How easy is it to draw air through the mask?

4. **Compliance**
   - Are you doing what was asked of you?
Reducing Bioaerosol Emissions and Exposures in the Performing Arts: A Scientific Roadmap for a Safer Return from COVID19
Experimental Design

- 100 volunteers over 3-6 months (~2/day)
  - Open to ages 12 and up; all genders
  - ~28 singers, actors, dancers
  - ~72 instrumentalists: bassoon, clarinet, euphonium, flute, French horn, trumpet, trombone, saxophone, and possibly others
- Everybody speaks, sings and “does their thing”
  - With and without control technologies in place
    - Masks, bell covers, and screens to be tested
    - “BYOM” approach to testing
- Particle sizes from 0.01 to 100 micrometers
Cameron Peak Fire: August 13 – December 1, 2020

Photo credits: CSU SOURCE, Erik Hardy
SET Facility: A Musical Class 100 Cleanroom
SET Facility: A Musical Class 100 Cleanroom
Low (maybe 10 counts)

Increasing Particle Emissions

High (~1,000)

More (~100)

Low (below background)
Ongoing Instrument Results (particles > 0.3 µm)

Relative Particle Emissions

- highest
- higher
- lower
- below background
Ongoing Instrument Results (particles > 0.3 µm)

Relative Particle Emissions

- highest
- higher
- lower
- below background
Ongoing Instrument Results (particles > 0.3 μm)

Relative Particle Emissions

- highest
- higher
- lower
- below background

Instruments:
- bassoon
- piccolo
- french horn
- oboe
- flute
- saxophone
- clarinet
- voice
- tuba
- trumpet
Ongoing Vocal Results (particles > 0.3 μm)
Ongoing Vocal Results (particles > 0.3 µm)
Ongoing Vocal Results (particles > 0.3 μm)
Ongoing Vocal Results (particles > 0.3 µm)
Ongoing Vocal Results (particles > 0.3 µm)

This person singing happy birthday emitted aerosol equivalent to 22 people all talking at once.
Mask Efficacy for Singing (particles > 0.3 µm)

Wearing a Mask?

Relative Particle Emissions

highest

higher

lower
1. Yes, some instruments produce more aerosol than others. For example: Trumpet, tuba > bassoon, piccolo. 
   But the performer is a major determinant of instrument emissions. Soon we will examine effects like age, sex, and volume level.

2. Bioaerosol emissions can vary massively from one person to the next. “Super-spreaders” are maybe 2-5% of the population.

3. Masks and bell covers appear to be effective. Masks/covers will stop particles larger than 10 microns (bigger droplets) But what about aerosol between 0.3 and 10 um? Masks and bell covers certainly help but we can’t (yet) say by how much with confidence. We’ll know more in 1-2 months.
Thank you to those who made this work possible!

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- National Association of Teachers of Singing
- National Band Association
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