

Update: Bioaerosol Emissions and Exposures in the Performing Arts: A Scientific Roadmap for a Safer Return from COVID19

NASM - 20 May 2021

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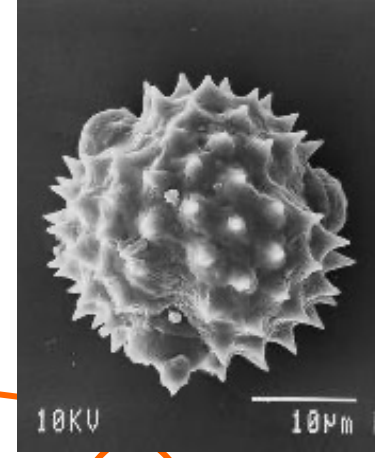
Why don't we have more answers here?

- 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



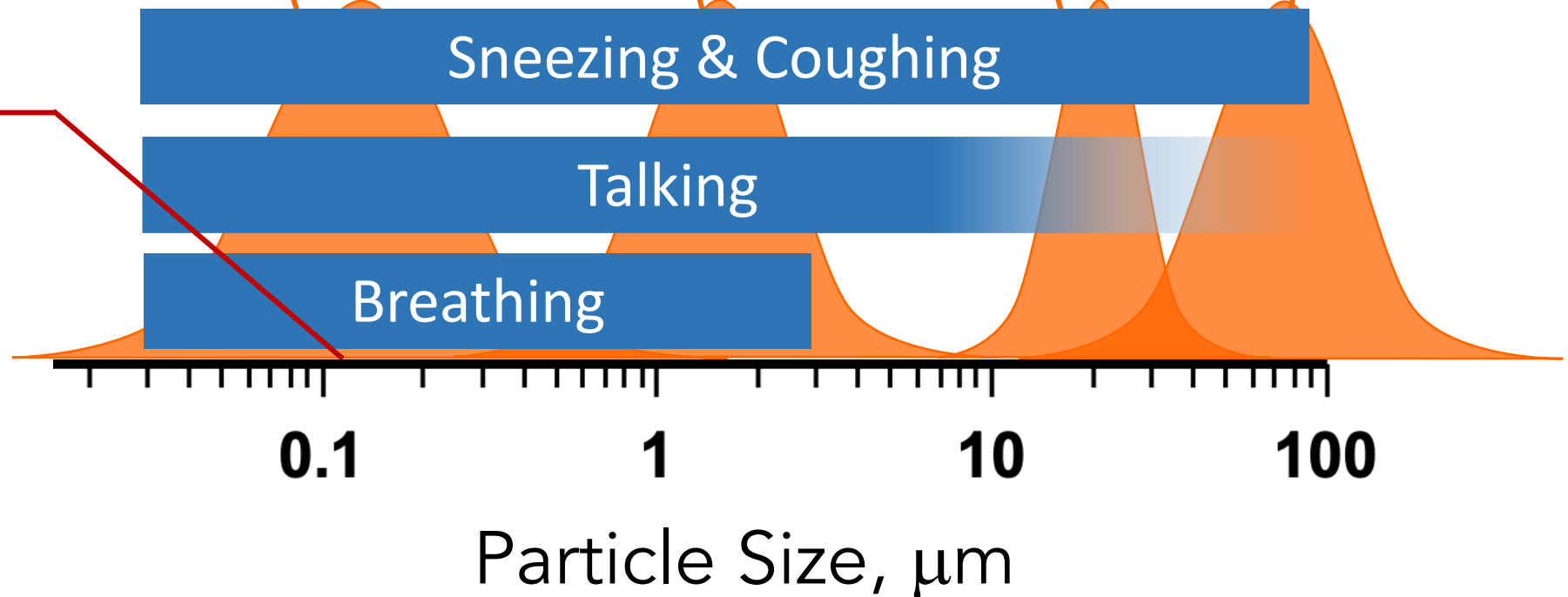
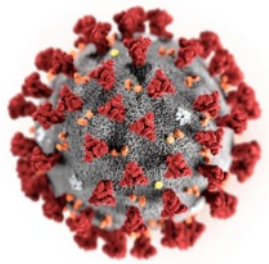
Smoke

Inhaler

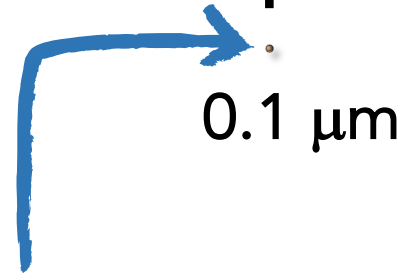
Pollen

Flour Dust

Musical and Vocal Arts?



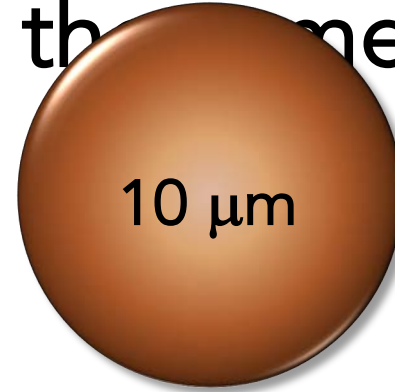
Human bioaerosol spans a huge size range (and not all particles behave the same)



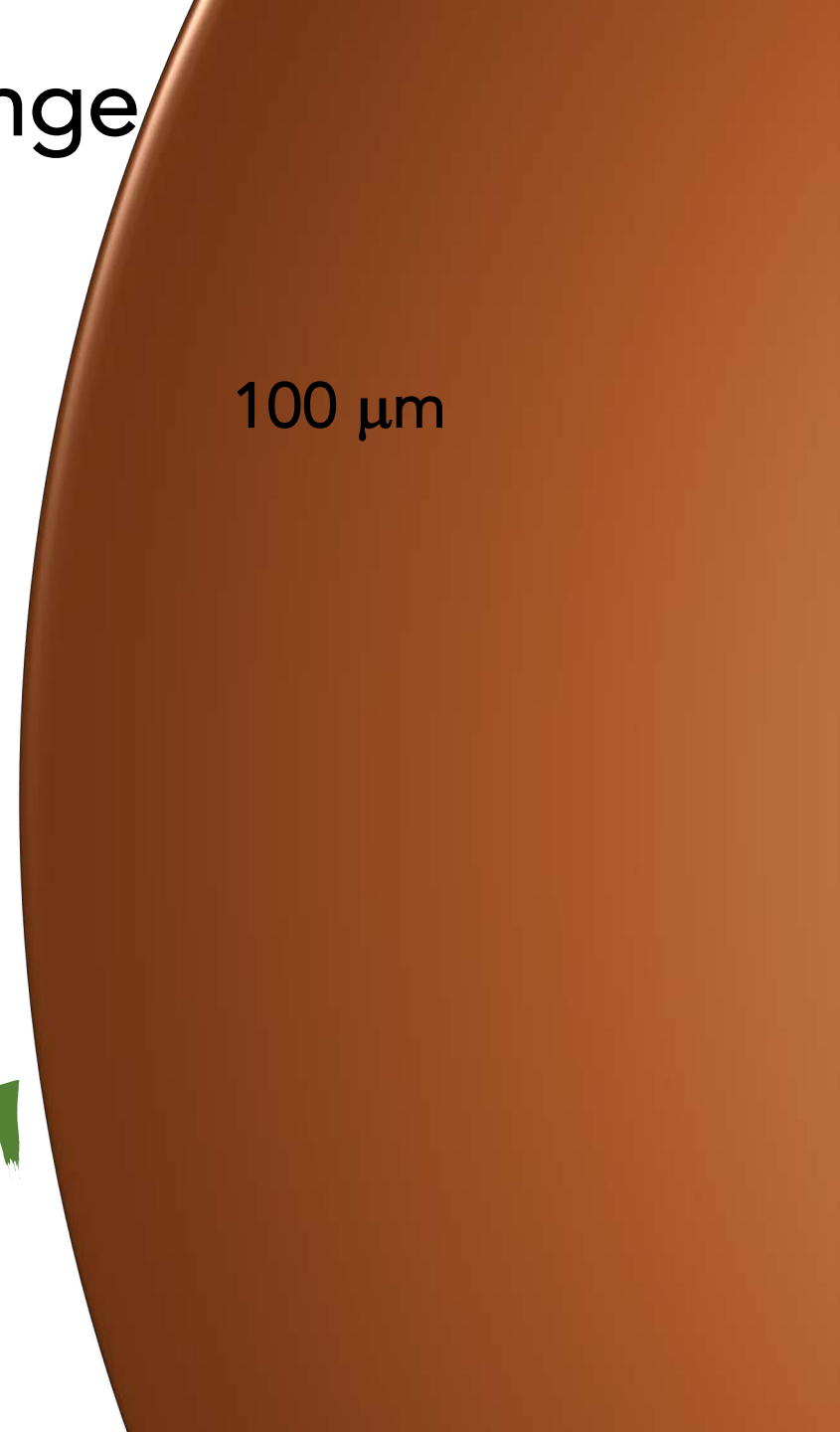
0.1 μm



1 μm



10 μm



100 μm

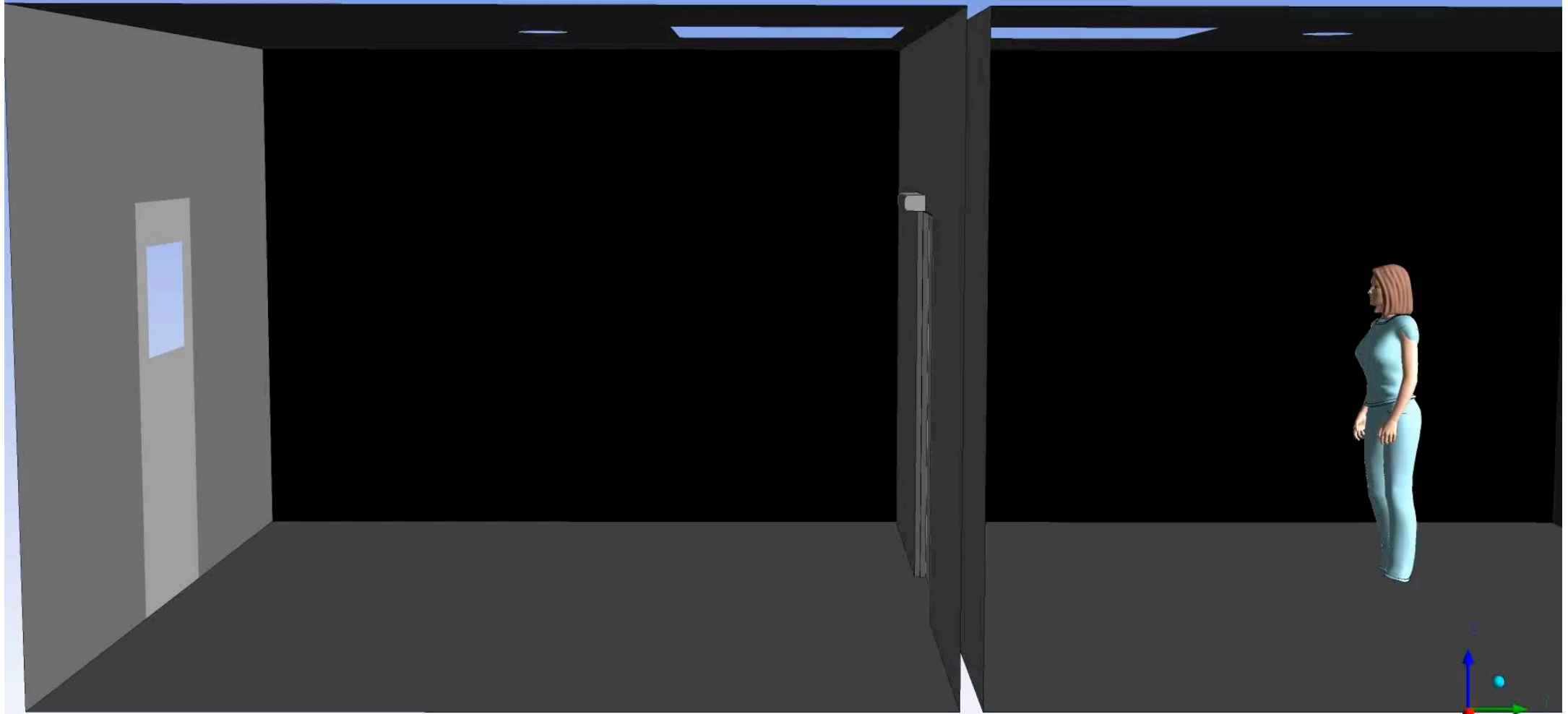
If this particle were
the size of a baseball

Then this particle would be
the size of a baseball stadium

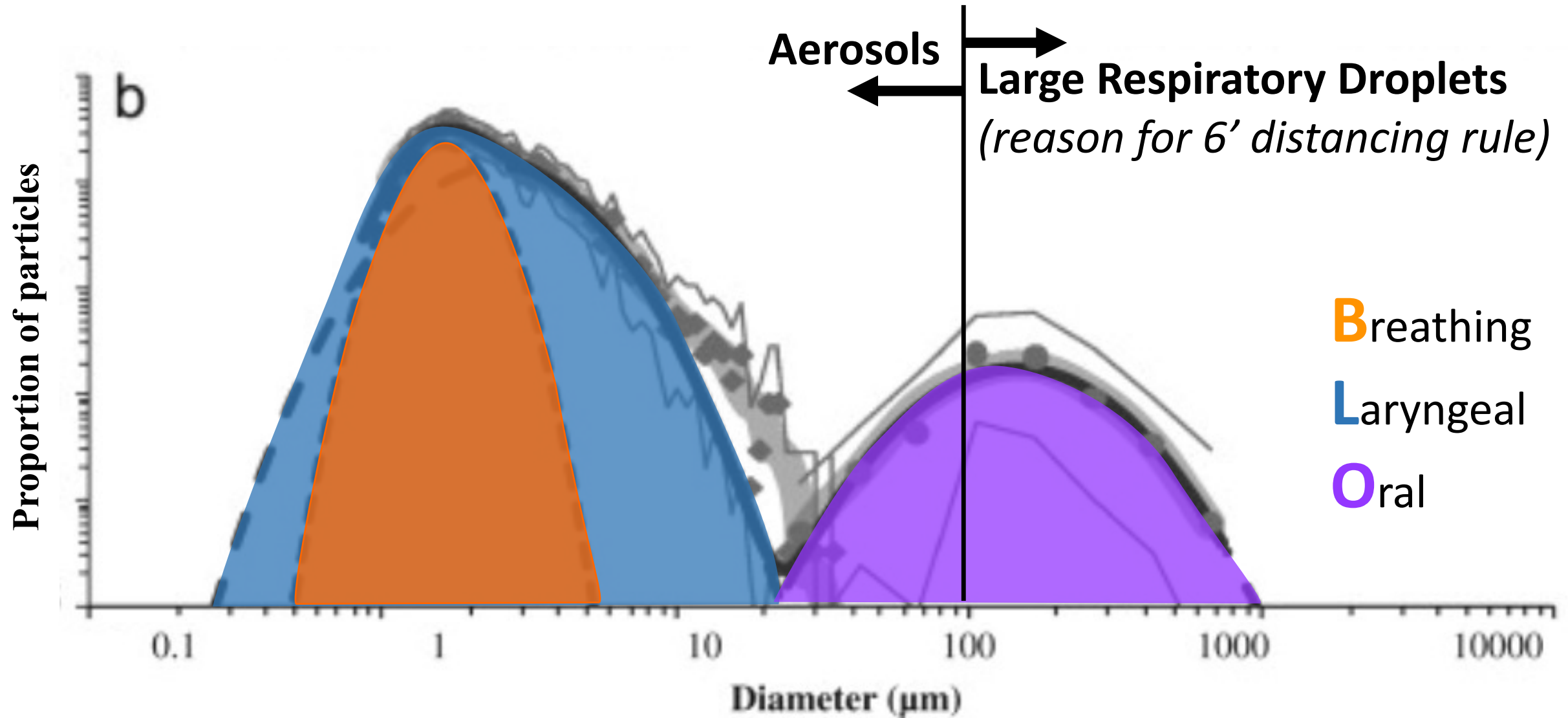


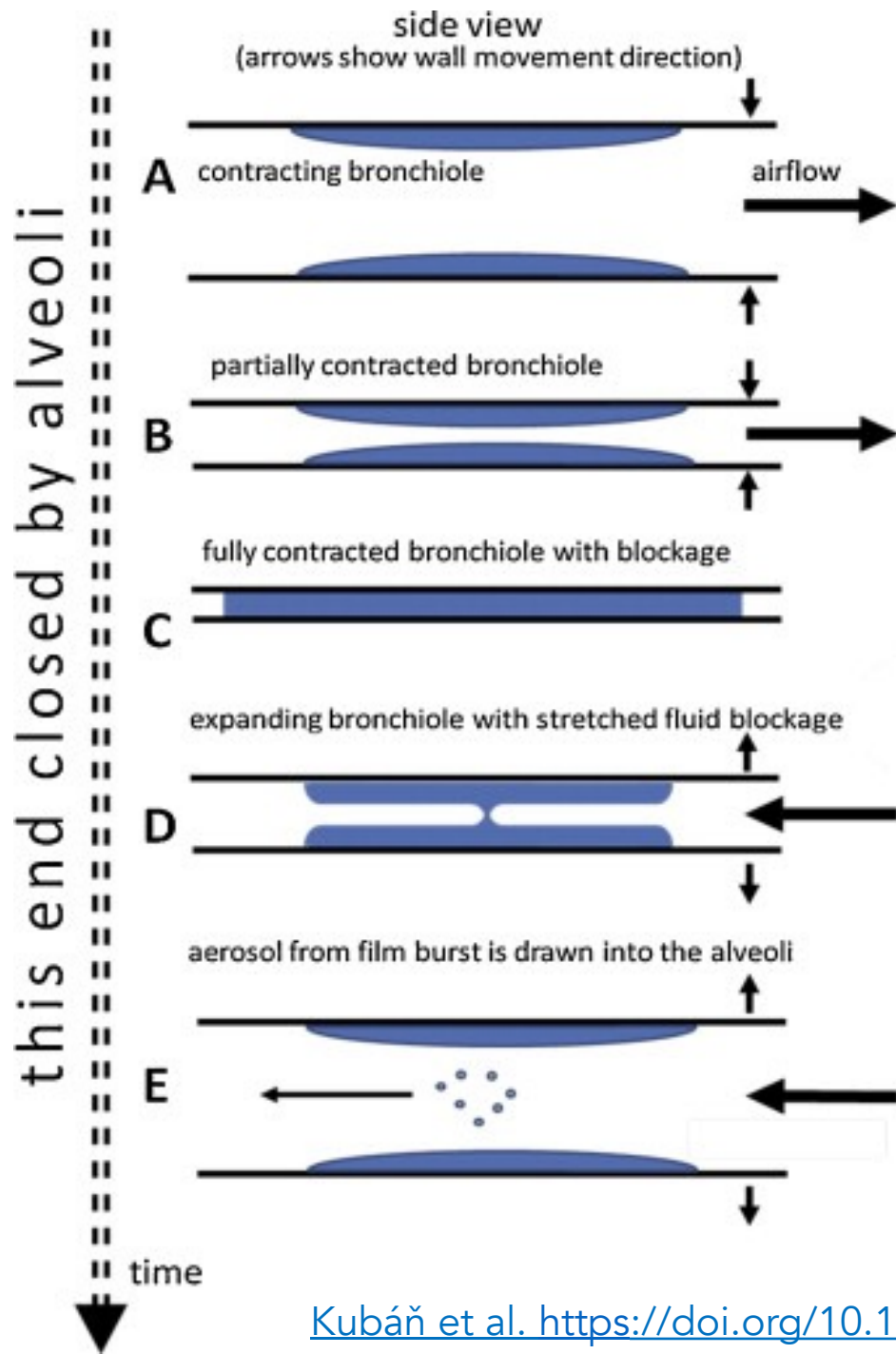
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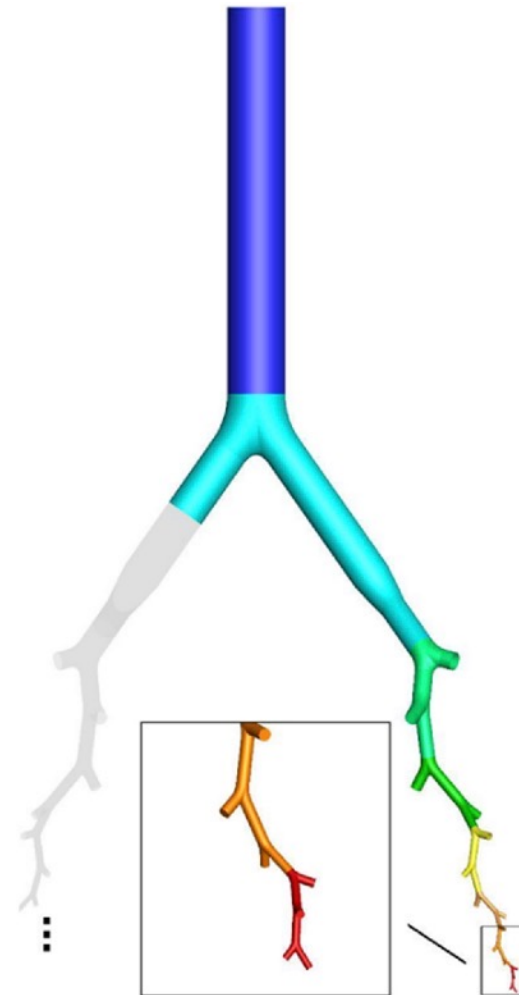
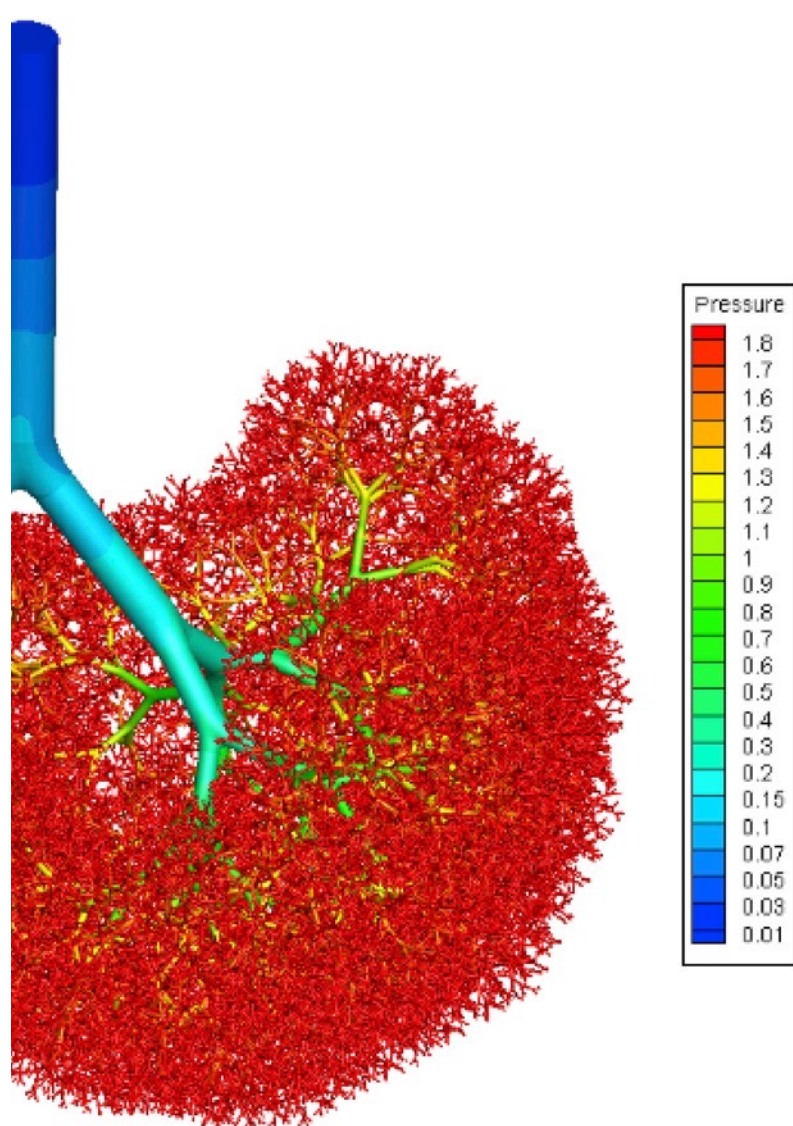
Size of Bioaerosols from the Human Respiratory Tract





Breathing mode:
Wall collapse & film separation
within compliant bronchioles

Breathing: Many Opportunities for Tube Collapse & Separation

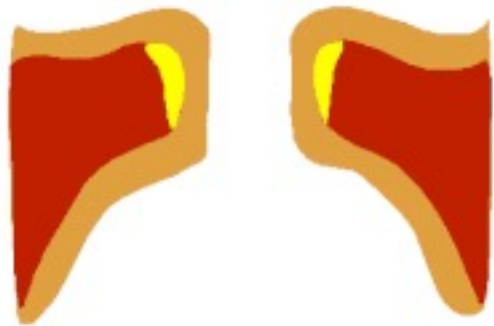


Generation	Number per generation	Diameter (cm)
0	1	1.8
1	2	1.22
2	4	0.83
3	8	0.56
4	16	0.45
5	32	0.35
6	64	0.28
7	128	0.23
8	256	0.186
9	512	0.154
10	1024	0.13
11	2048	0.109
12	4096	0.095
13	8192	0.082
14	16384	0.074
15	32768	0.066
16	65536	0.06
18	260,000	0.05

Laryngeal mode:
Vibration (100-300 Hz) of your
vocal cords sheds particles



Top view



Side view
(slow motion)

Oral Mode:
Saliva from tongue & lip
movement (large droplets)

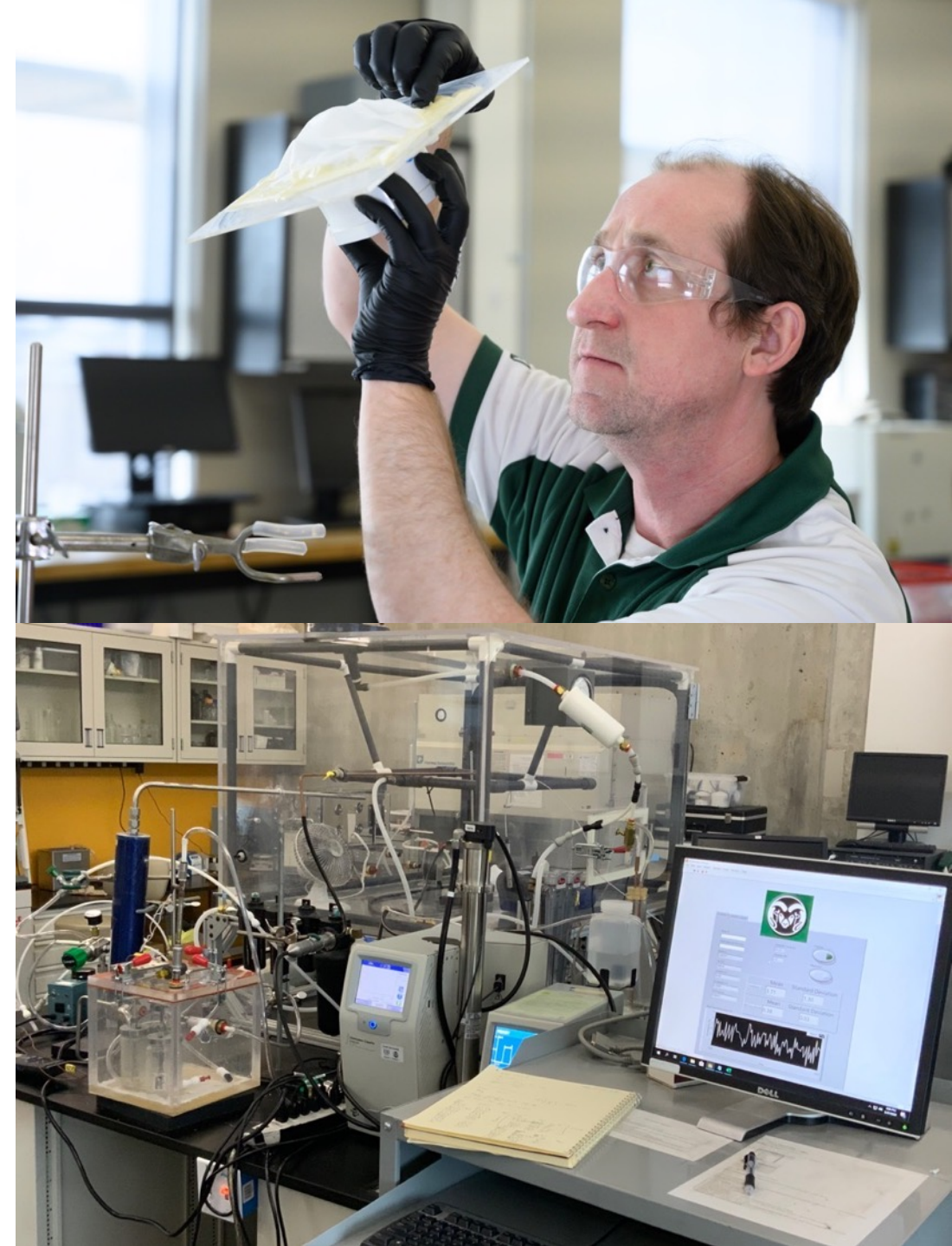


bwilson | photography

Mask Testing Results

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 25th, Colorado Governor Jared Polis asked our lab to provide respirator testing & performance verification for State of Colorado COVID-19 Task Force



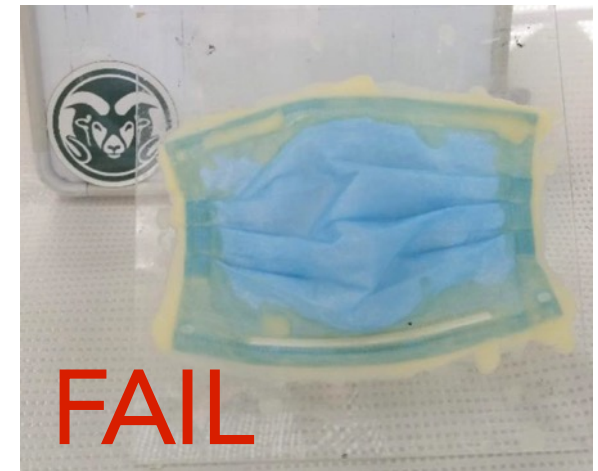
N95 means >95% removal efficiency for particles that flow into the mask

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



* <https://www.cdc.gov/niosh/npptl/respirators/testing/default.html>

N95s are great if
you can get them
- *they are hard to find*-
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

(provided they don't leak air around the edges!)



Fraction Collected by Mask

1.00
0.90
0.75
0.50
0.25
0.10

1

3

10

Particle Size, μm

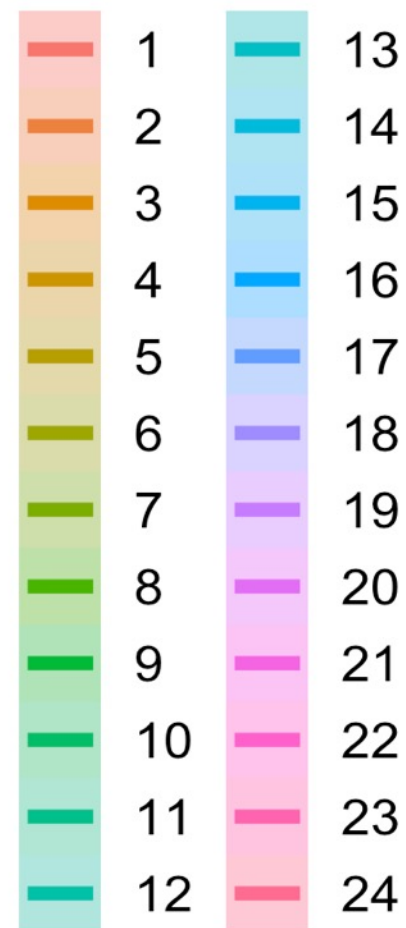
mask

— N95

Fraction Collected by Mask

Particle Size, μm

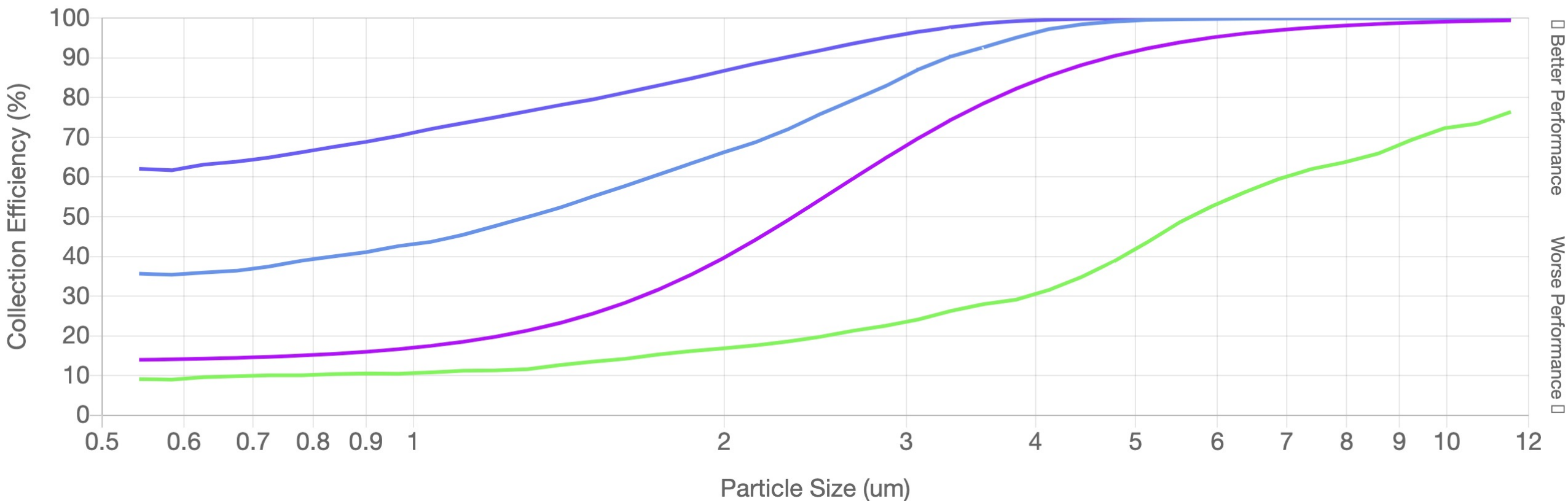
mask



What about “Singer’s Masks”?

<http://jv.colostate.edu/masktesting/>

Cloth Mask Performance



Want to learn more? Watch our free webinar on mask design <https://col.st/Wq2Bu>

Study Confirms Nose Holes Connect to Lungs

Below-the-nose mask wearers shocked by science



Rachael Ann Sand

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Aug 26 · 2 min read ★



Beware the half-maskers. Photo by [Marcel Strauß](#) on [Unsplash](#). Cropped by author.

Source: [medium.com](#)

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

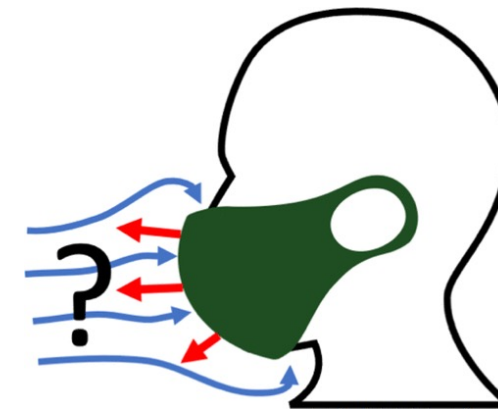
- How easy is it to draw air through the mask?

4. Compliance

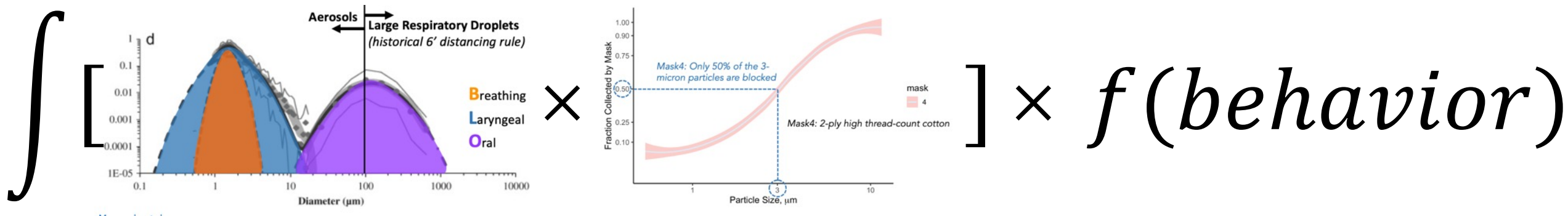
- Are you doing what was asked of you?

Quantitative Protection Factors for Common Masks and Face Coverings

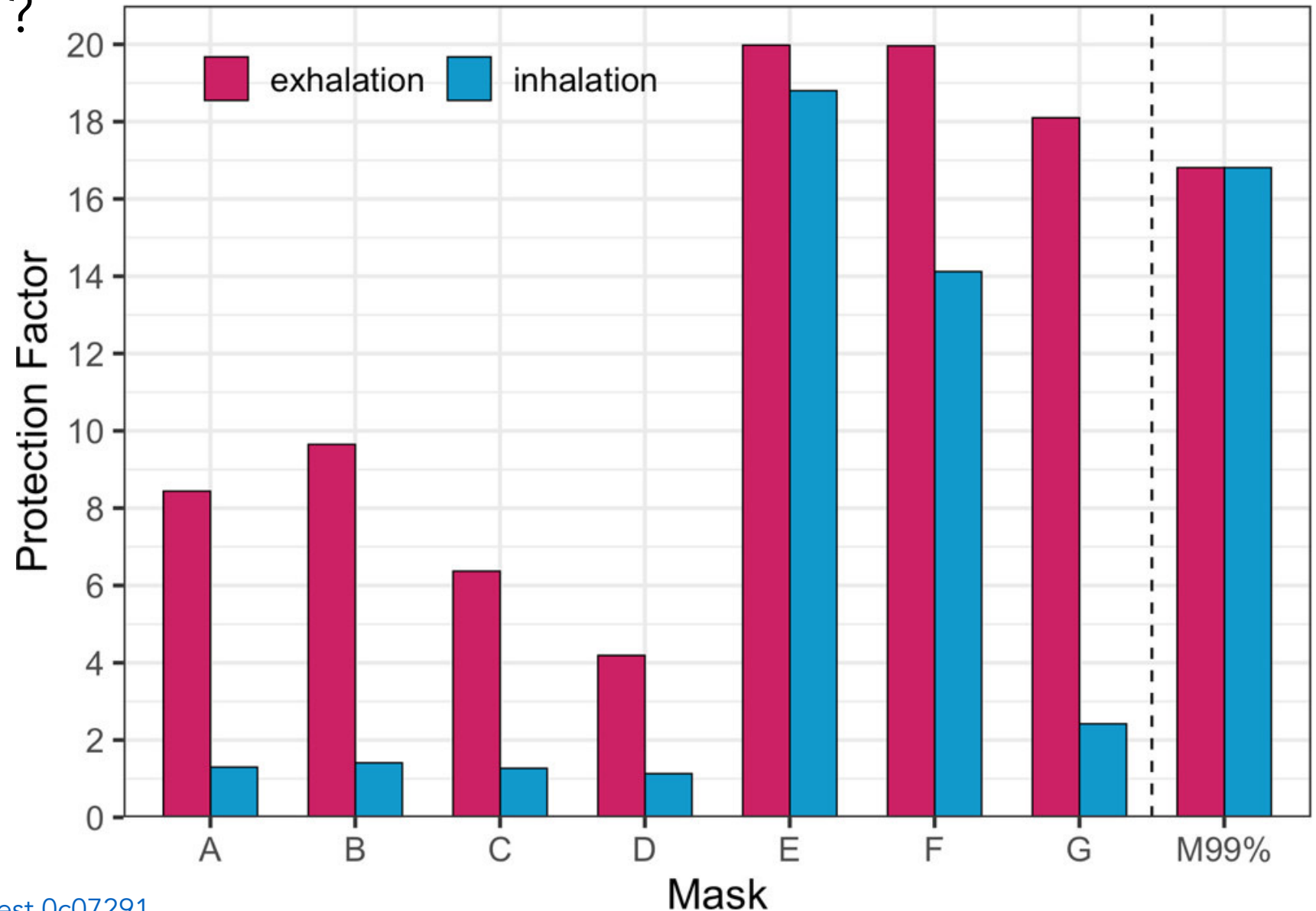
David Leith, Christian L'Orange, and John Volckens*



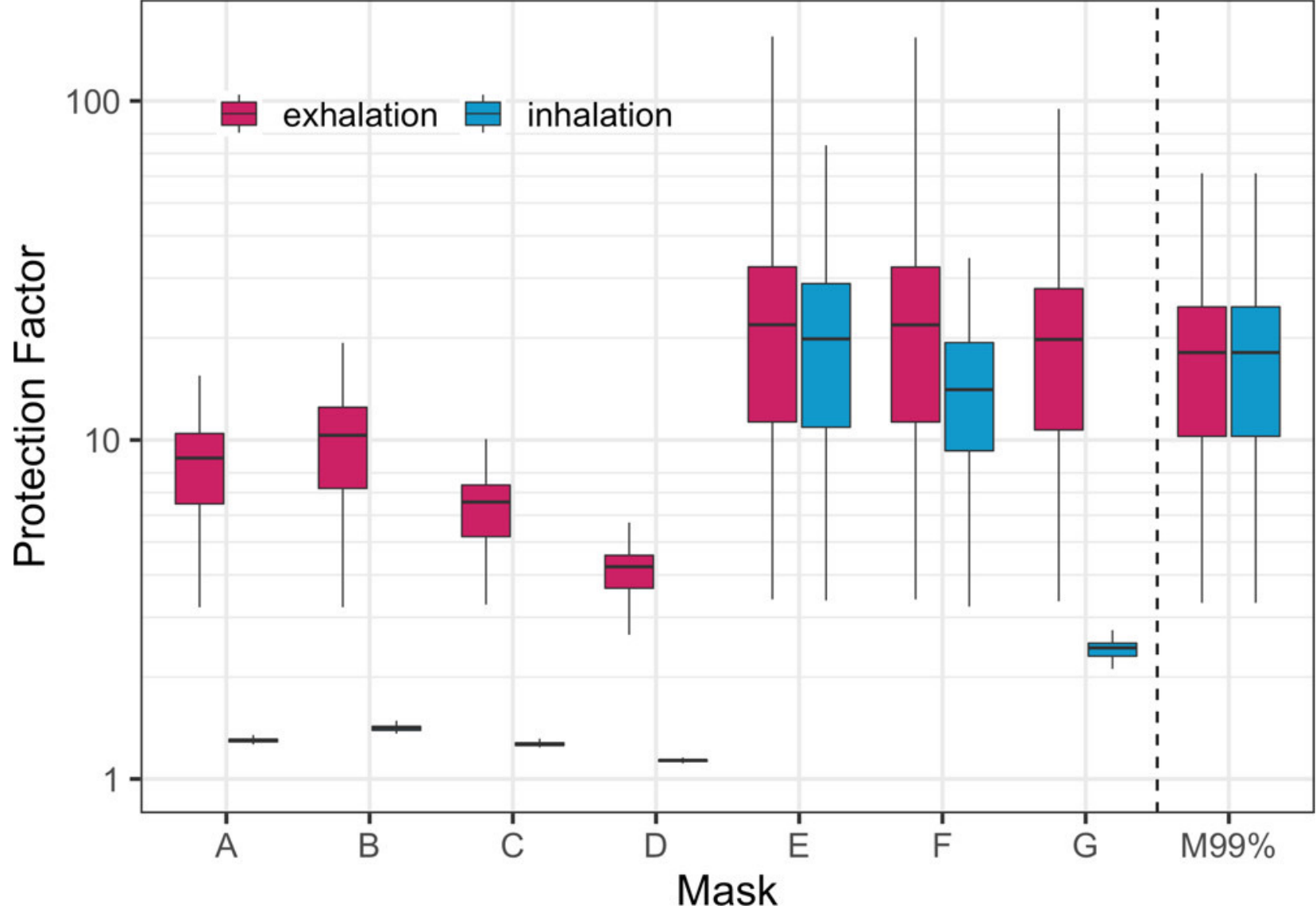
$$\text{Protection Factor (PF)} = \frac{\text{Mass of aerosol flowing towards the mask}}{\text{Mass of aerosol that gets past the mask}} = \frac{\dot{M}_{in}}{\dot{M}_{out}}$$



Protection Factor tells you: "By how much is your exposure (or your release of aerosol) reduced from wearing this mask"?



Real-World: Vary the key factors that control Protection Factor



These results account for variation in breathing rates, mask leakage (fit), time spent talking, etc.

<https://smt.d.colostate.edu/>



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CSU Aerosol Emissions Study

Reducing Bioaerosol Emissions and Exposures in the Performing Arts: A Scientific Roadmap for a Safer Return from COVID19

Take Home Messages

- You were right to apply the precautionary principle in 2020 and that choice saved lives.
- Brass instruments emit more aerosol than woodwinds.
- Singing emits more aerosol than speaking.
- Men emit more aerosol than women.
 - *This difference can be explained by physiology.*
- Adults emit more aerosol than children.
 - *This difference can also be explained by physiology.*
- Masks and bell covers help...when used appropriately.
- In the absence of "herd immunity" a layered strategy will be needed.

Experimental Design

- 100 volunteers over ~~3~~ 9 months (~2/day)
 - Open to ages 12 and up; all genders
 - ~28 singers, actors, dancers
 - ~72 instrumentalists: bassoon, clarinet, euphonium, flute, oboe, piccolo, saxophone, French horn, trombone, trumpet & tuba
- 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

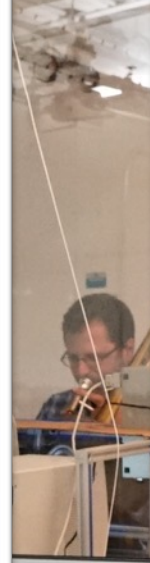
Cameron Peak Fire: August 13 – December 1, 2020



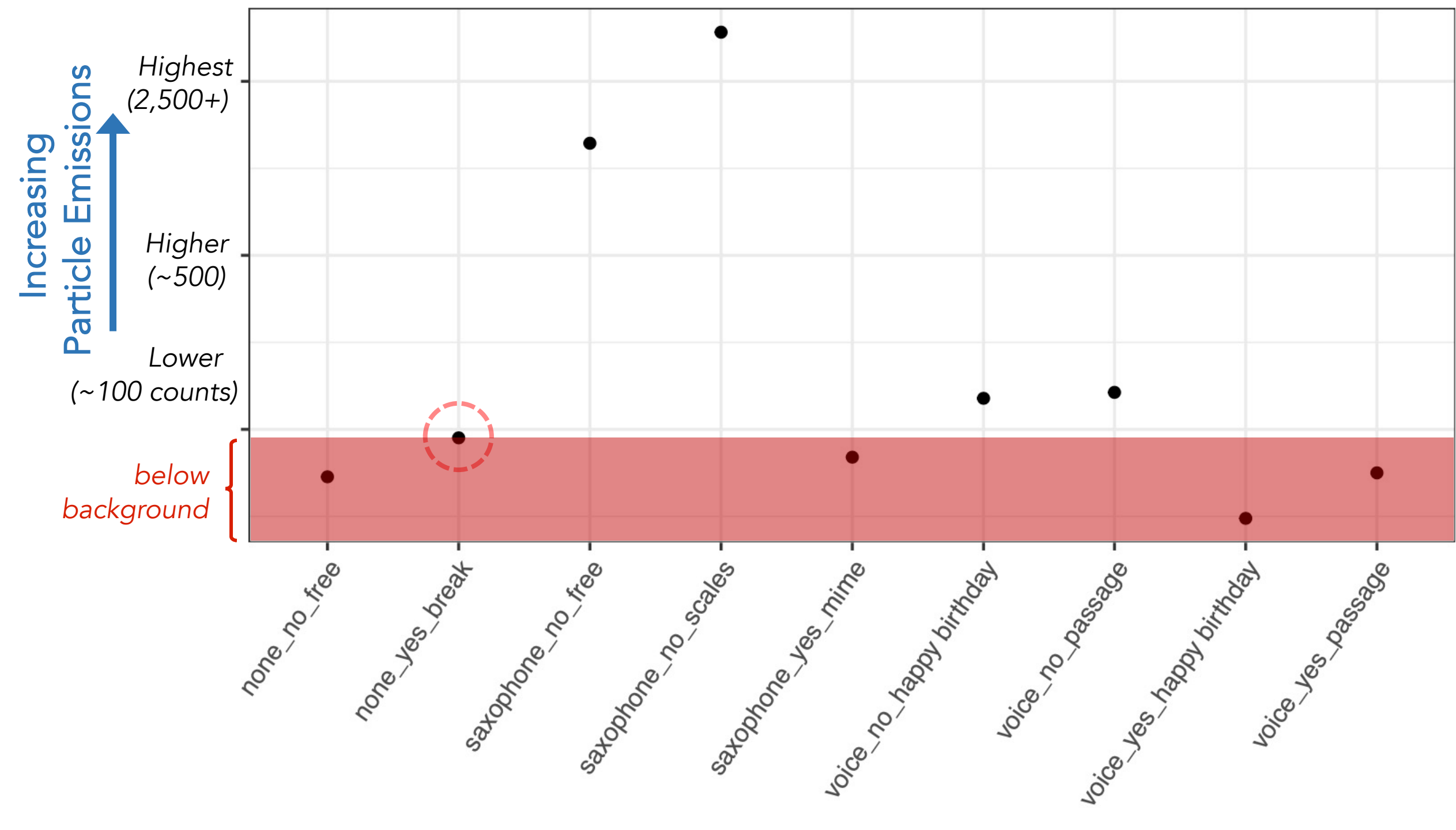
Photo credits: CSU SOURCE, Erik Hardy



SET Facility: A Musical Class 100 Cleanroom



SET Facility: A Musical Class 100 Cleanroom



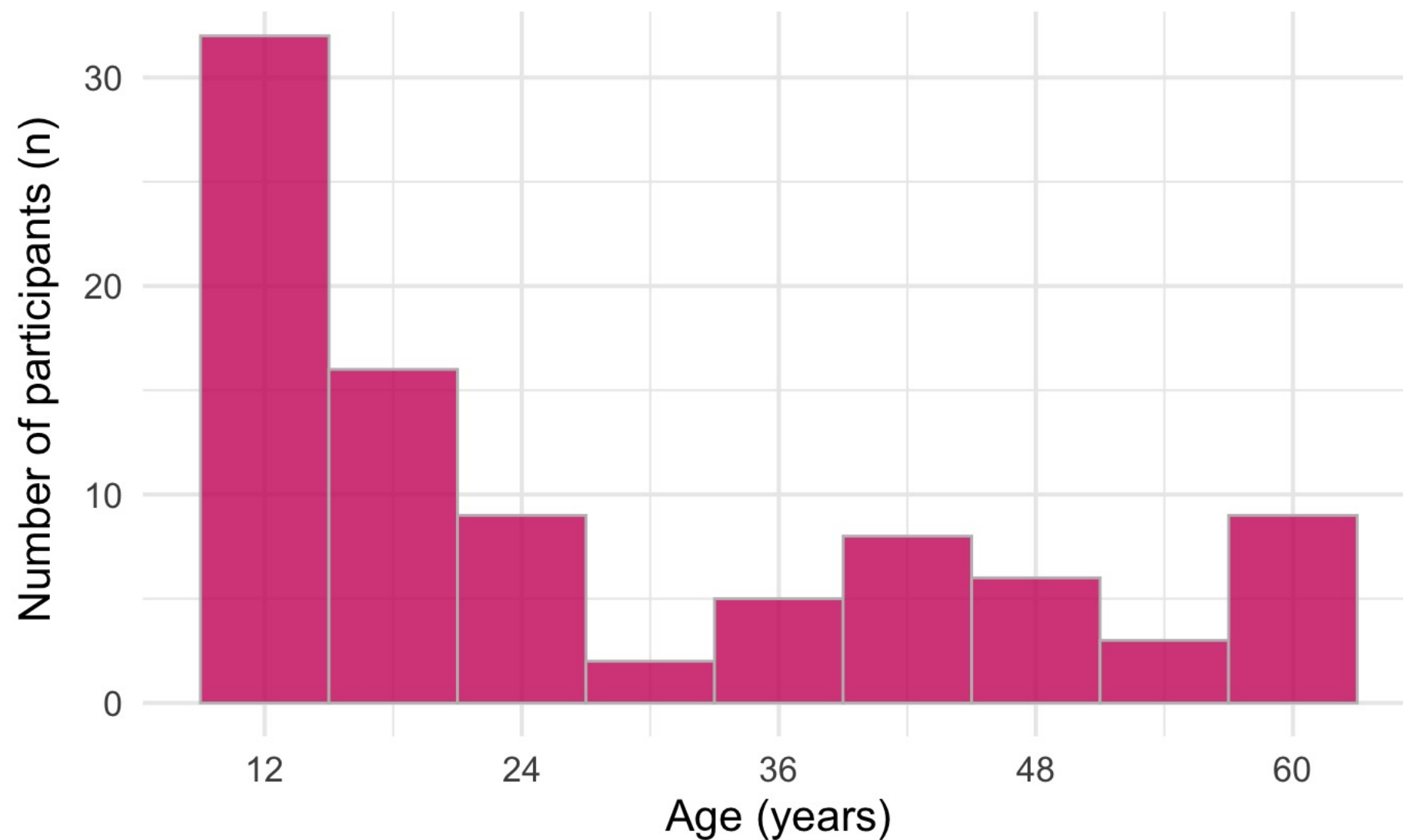
Participants (n) **Age Range (years)** **Female [male] (n)** **Minor [adult] (n)**

90

12-63

42 [45]

40 [50]



Instrument Results

(particles 0.3 - 30 μm)

Instrument Emissions (particles 0.3 - 30 μm)

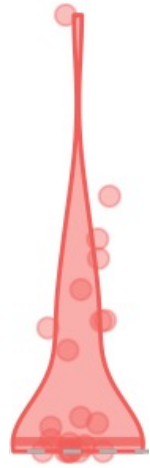
Relative Particle Emissions

highest

higher

lower

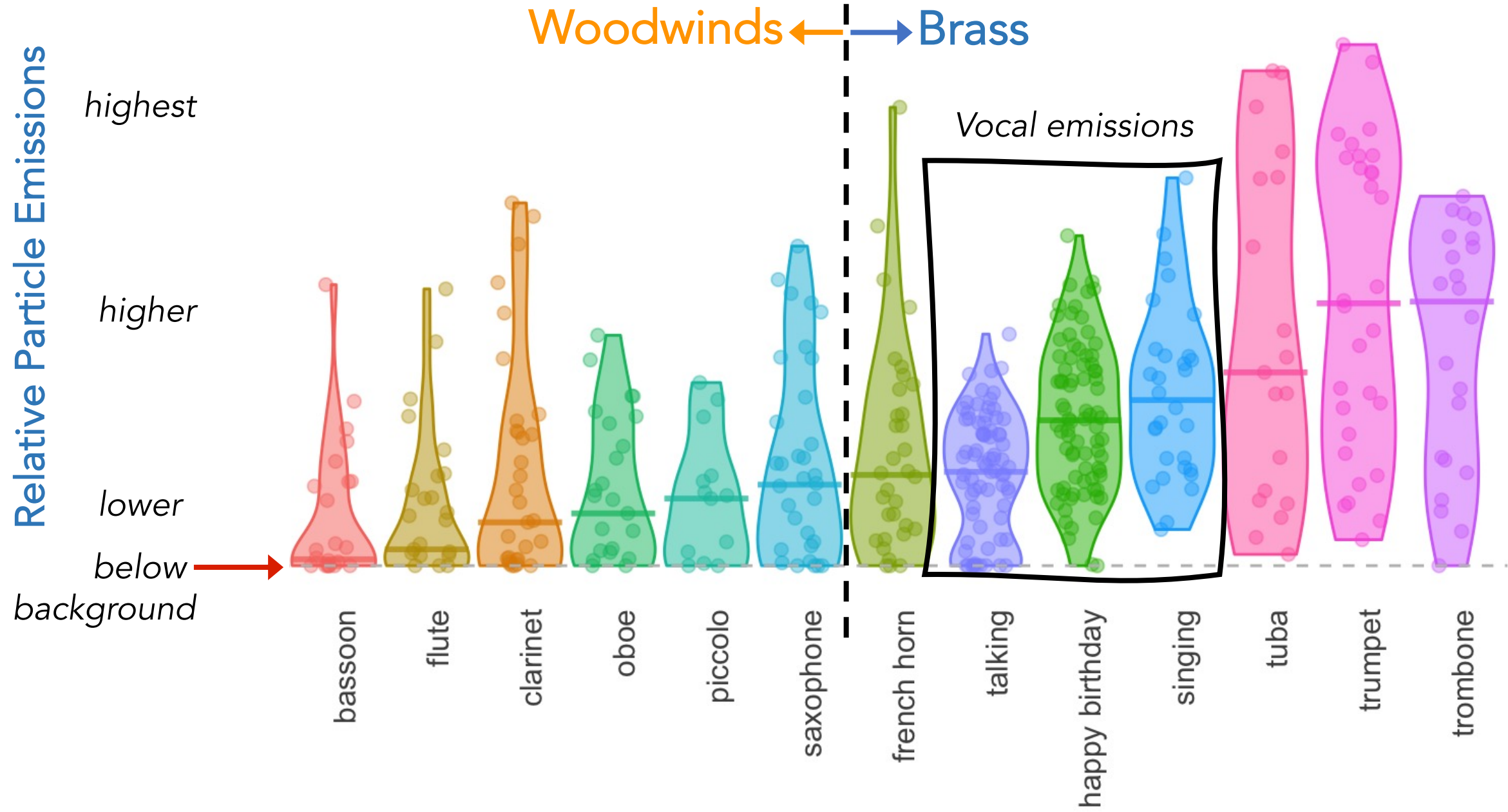
*below
background* →



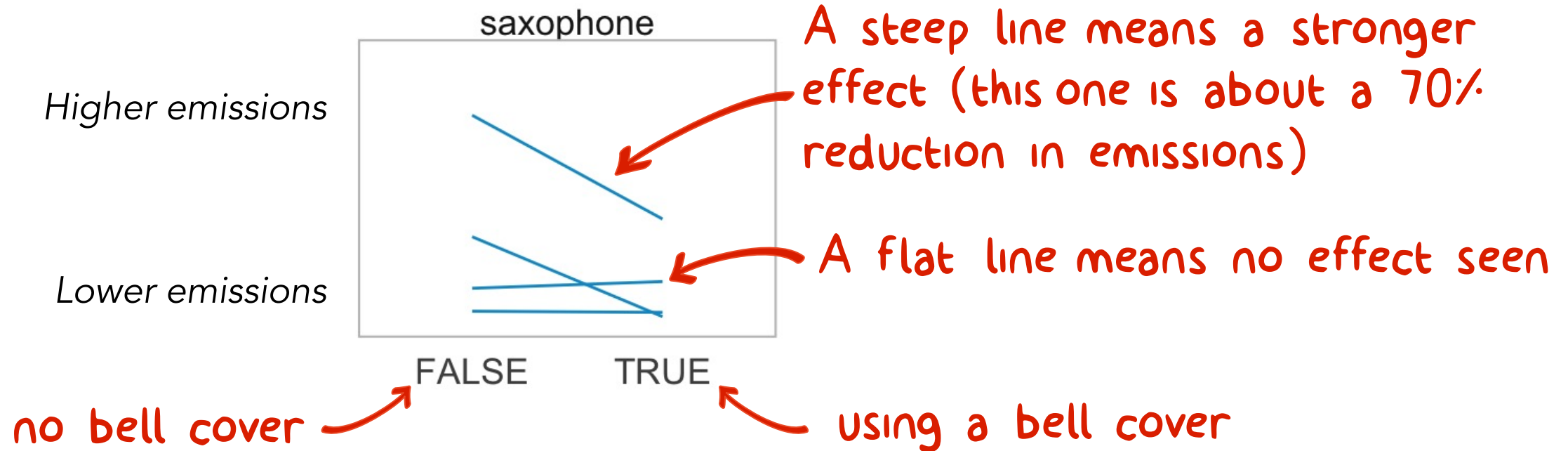
Instrument Emissions (particles 0.3 - 30 μm)



Instrument Emissions (particles 0.3 - 30 μm)

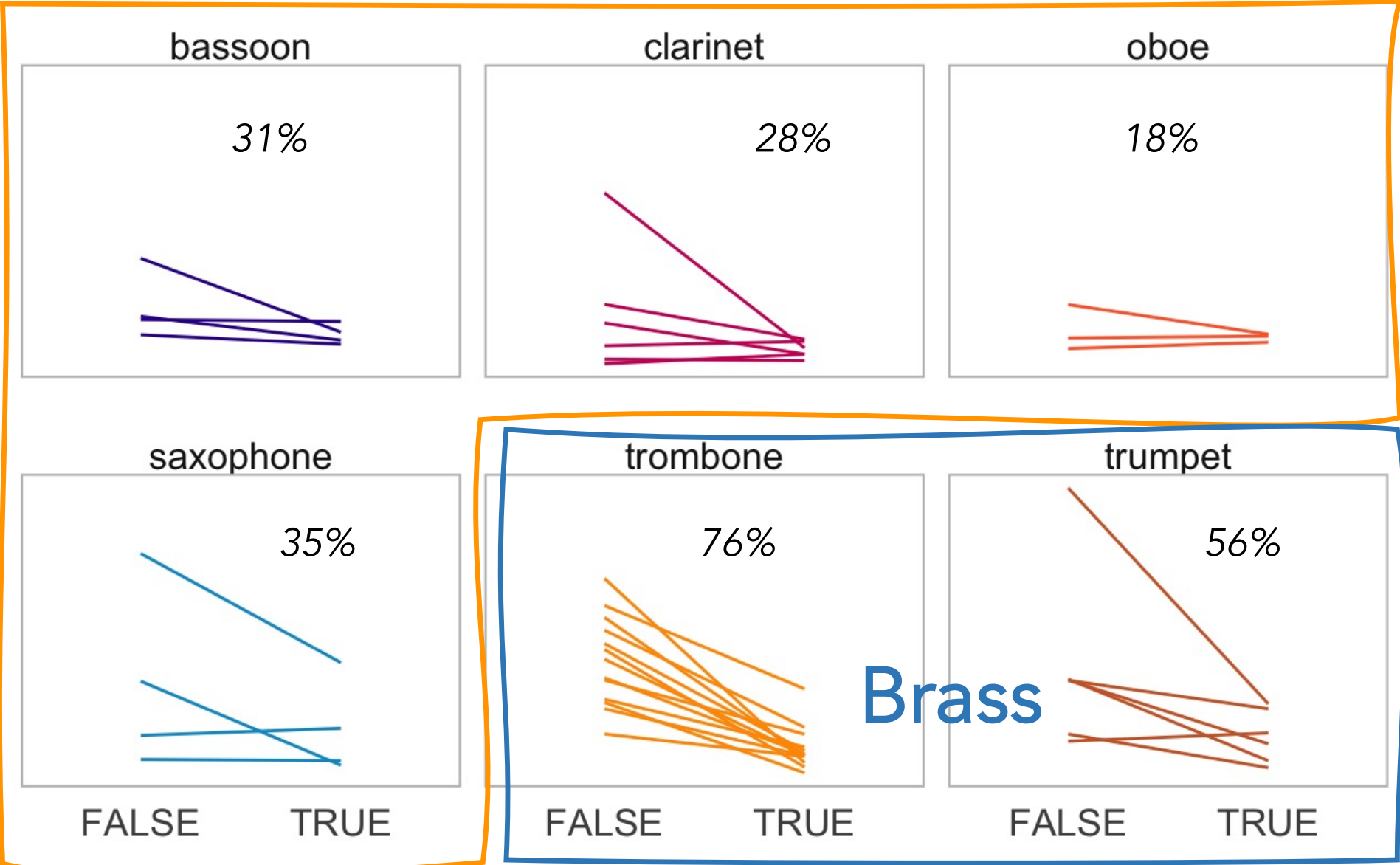


To Bell Cover or Not to Bell Cover?



To Bell Cover or Not
to Bell Cover?

Woodwinds



Higher emissions

Lower emissions

Brass

Use of Bell Cover

- Results suggest that **brass instruments** tend to have higher particle emissions than **woodwinds**...

BUT the “player effect” is likely larger than the “instrument effect” ...

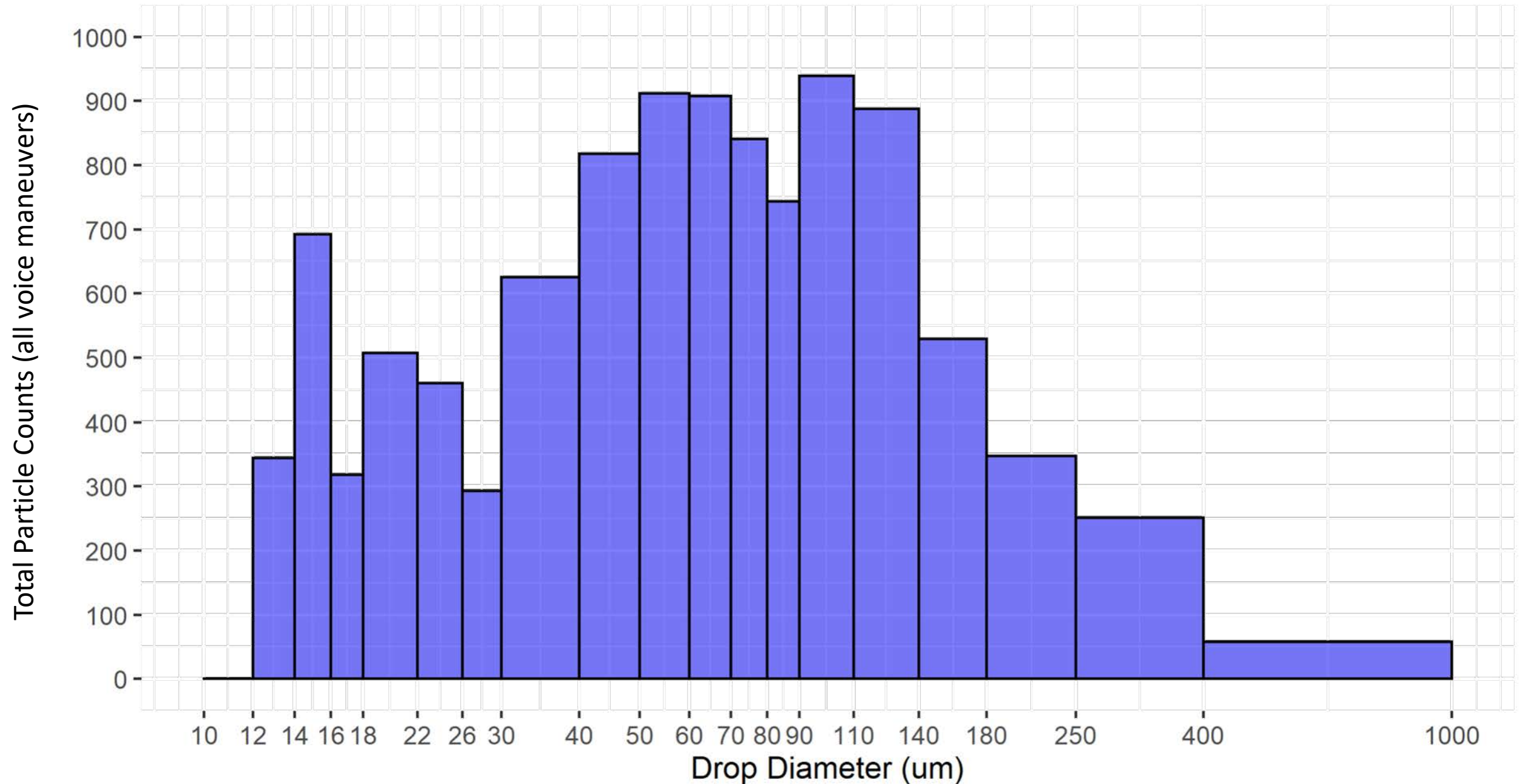
Meaning that almost ALL instruments have the potential for high emissions.

- Bell covers on **brass instruments** (single air exit) make sense.
- Bell covers on **woodwinds** (multiple exit paths for air besides the bell) show mixed results.

Vocal Results

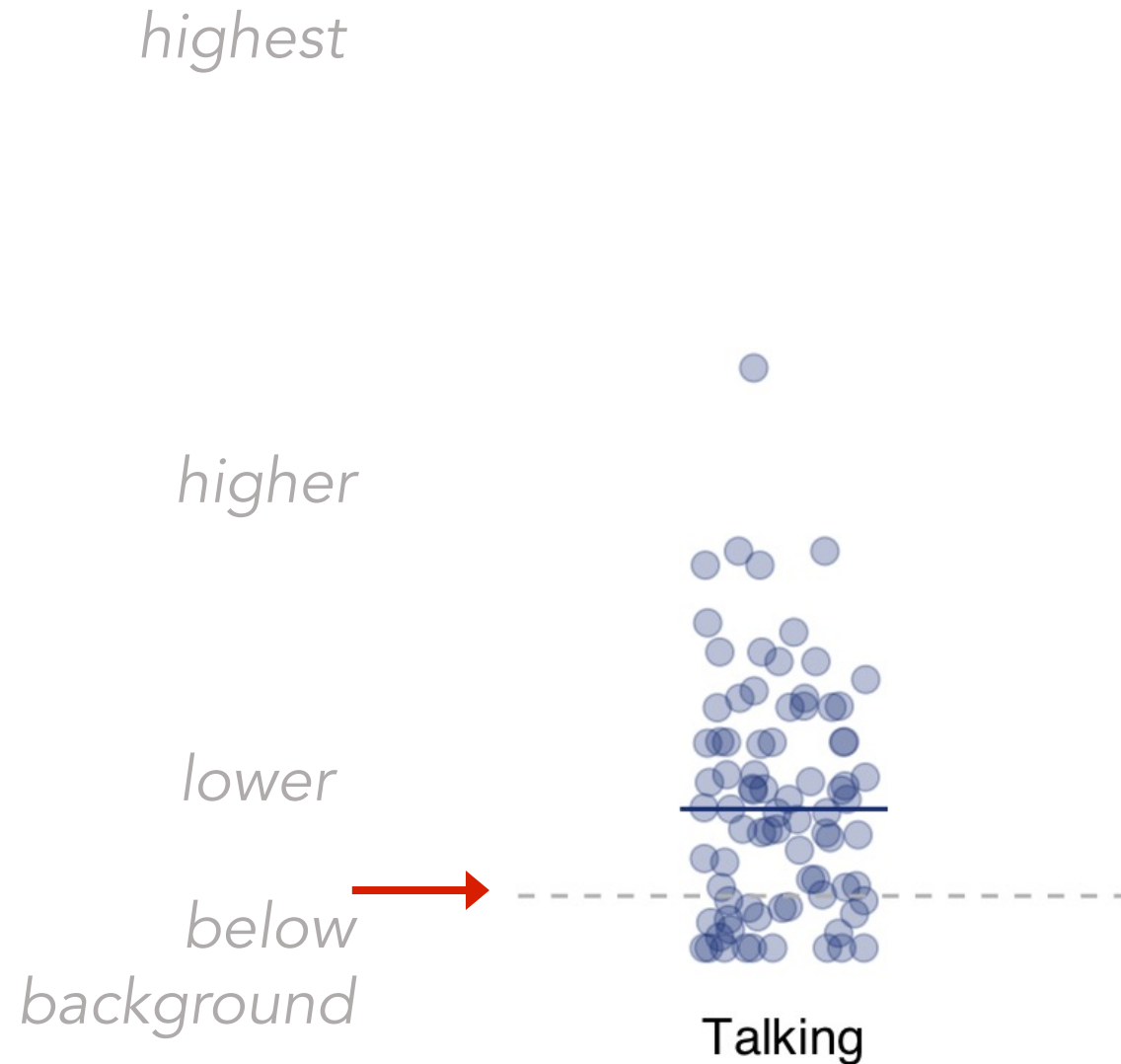
(particles 0.3 - 30 μm)

Note: We “see” lots of big droplets emitted from voice, instruments, too.



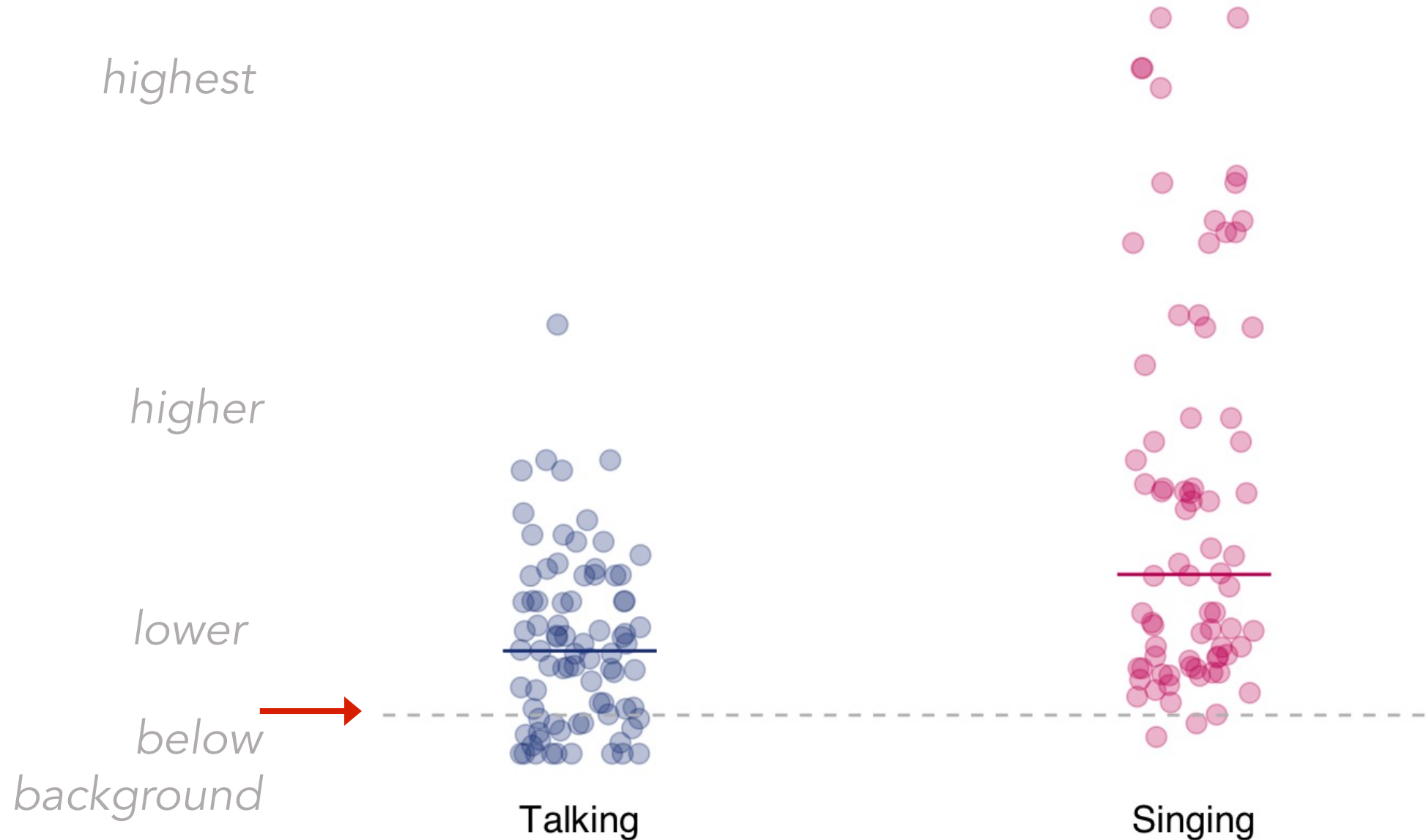
Singing (*happy birthday*) tends to produce more particles than **talking** (*The Caterpillar*)

[https://doi.org/10.1044/1058-0360\(2012/11-0134\)](https://doi.org/10.1044/1058-0360(2012/11-0134))

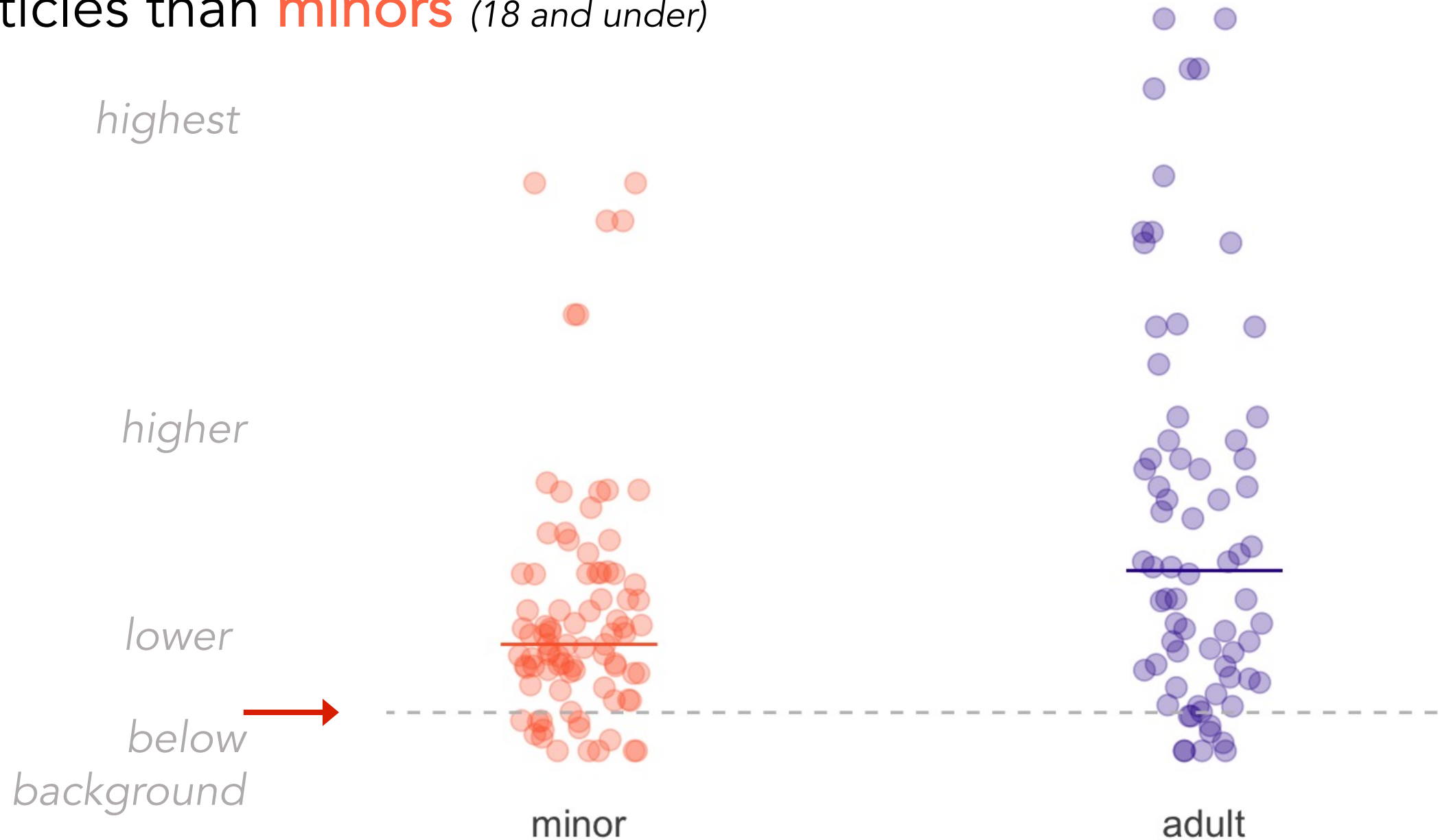


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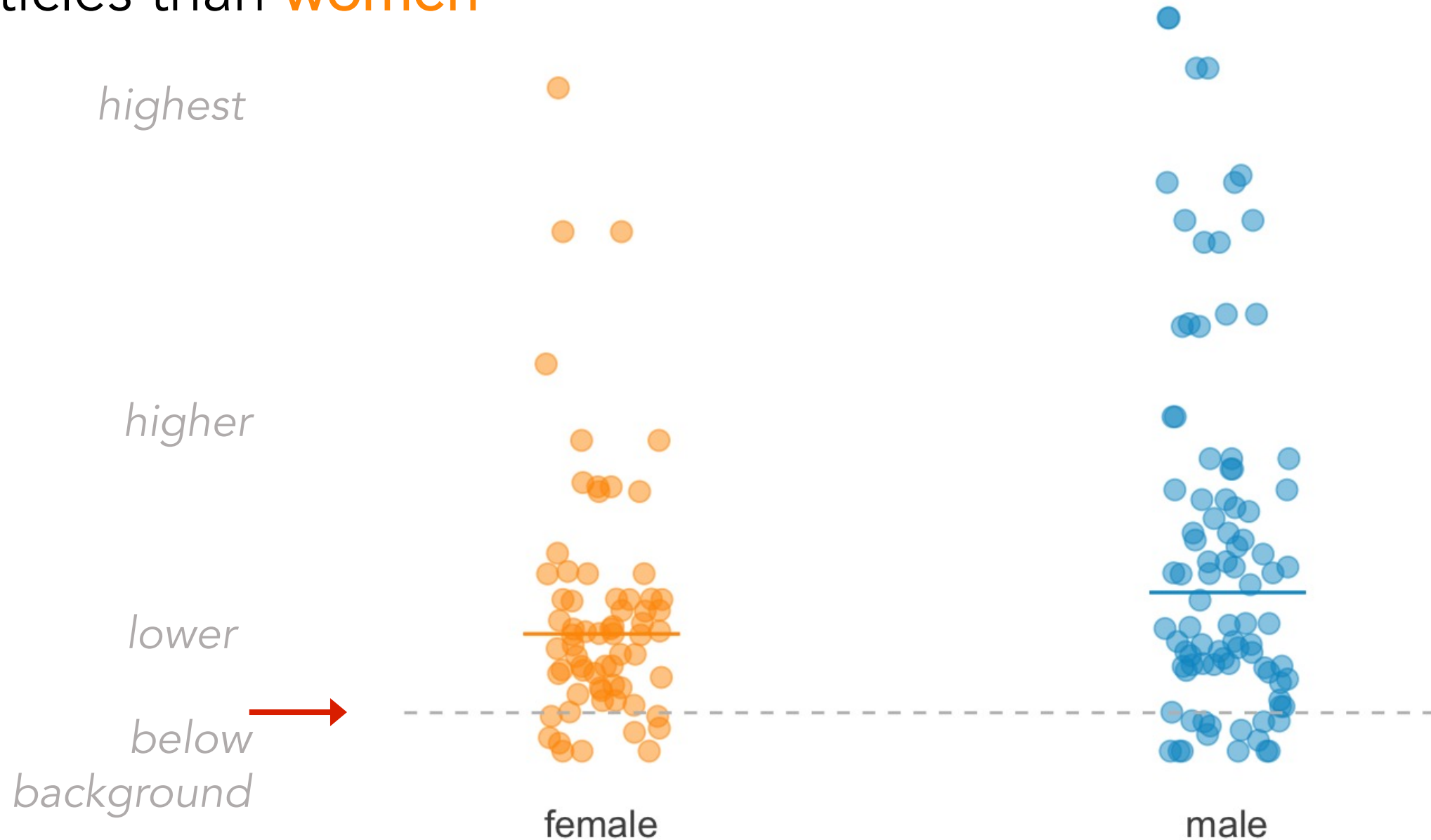
[https://doi.org/10.1044/1058-0360\(2012/11-0134\)](https://doi.org/10.1044/1058-0360(2012/11-0134))



Adults tend to produce more particles than **minors** (18 and under)

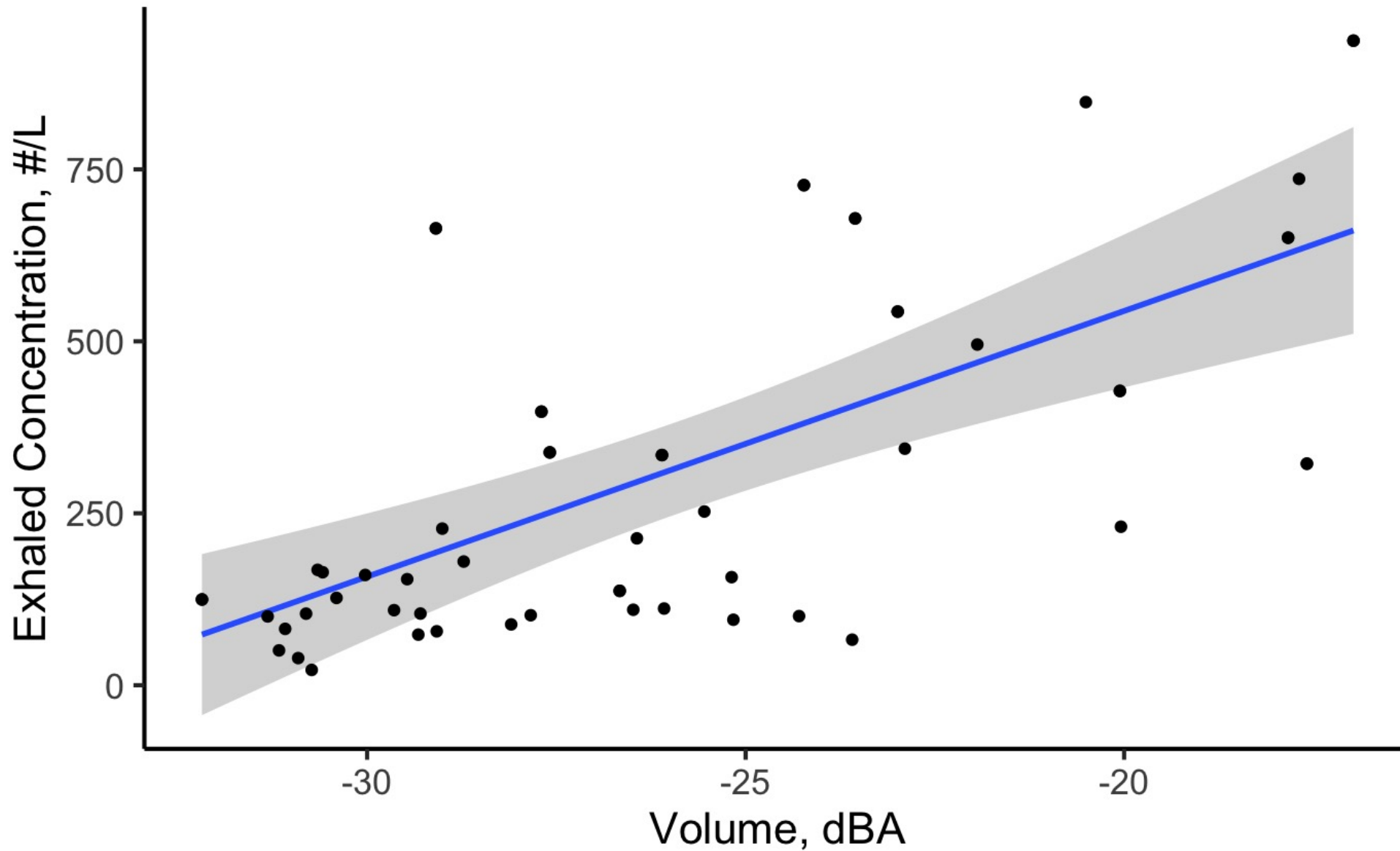


Men tend to produce more particles than **women**

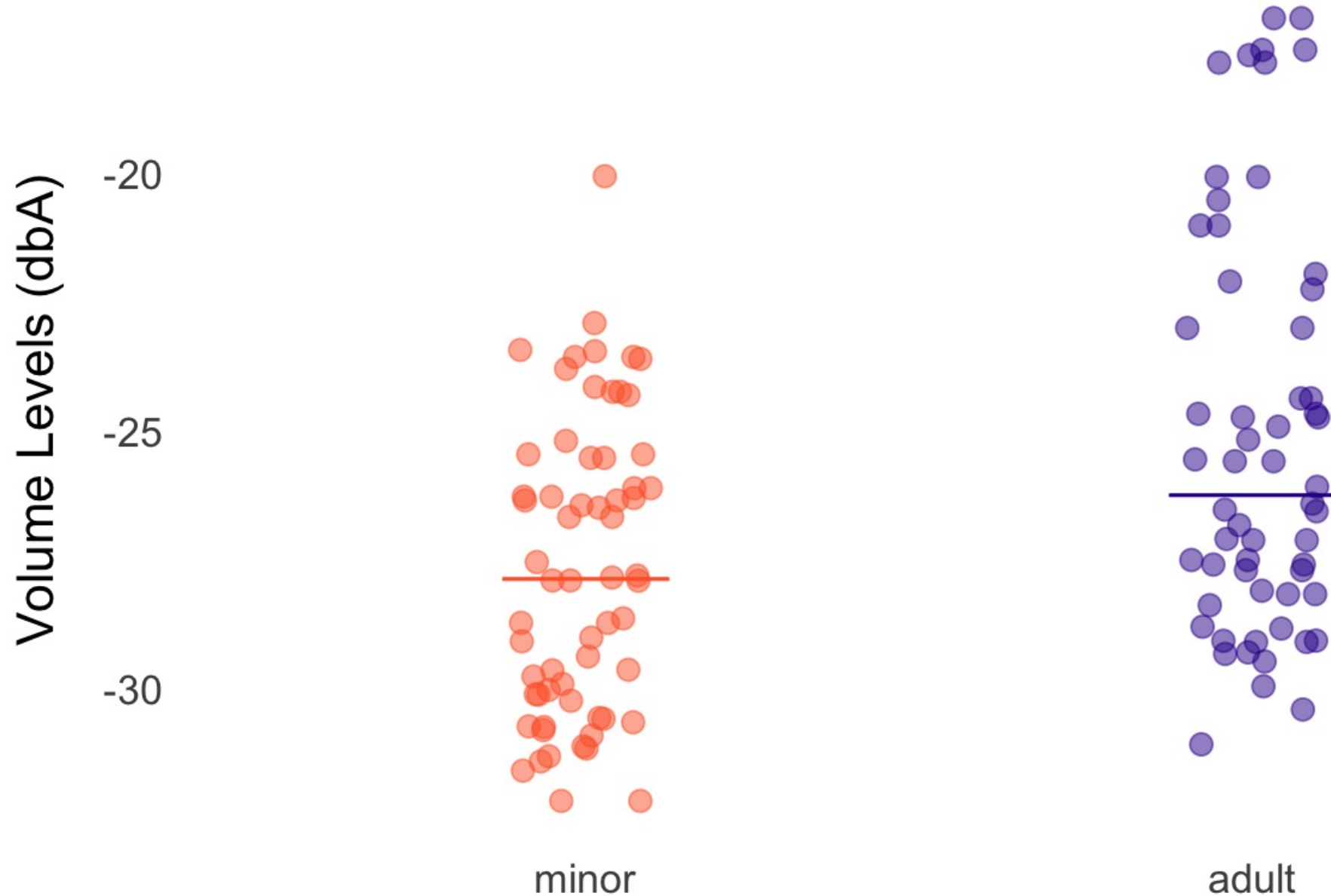


The differences in bioaerosol emissions between **men** & **women** and **minors** & **adults** are explained by two factors: voice volume and lung capacity.

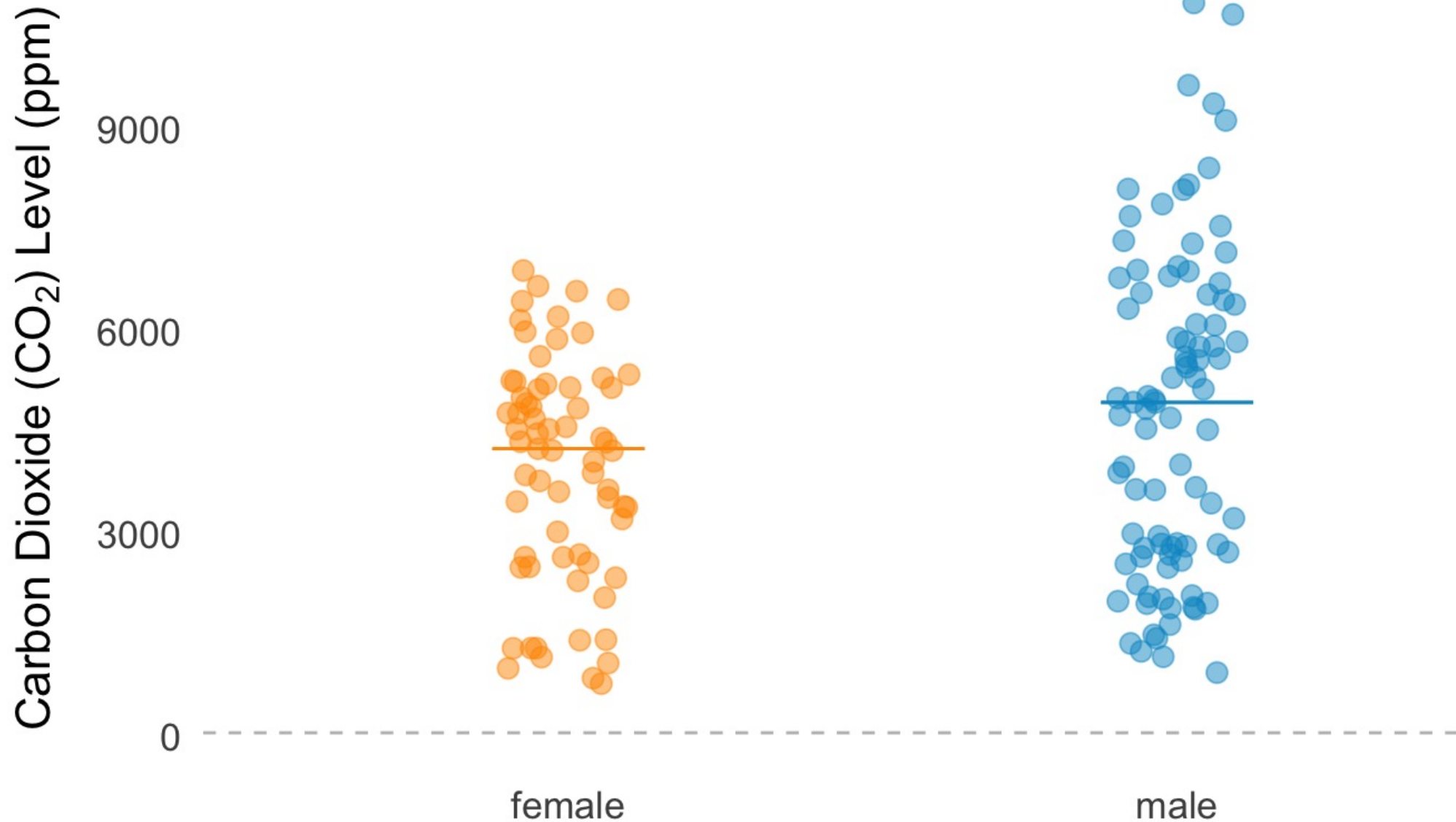
Particle emissions are correlated with voice volume



Adults (& men) tend to speak, sing louder than minors (& women)



Men tend to have larger lungs (and thus exhale more air) than **women**



If we account for *voice volume* and exhaled CO_2 in our models of vocal emissions, then the differences between men & women and adults & minors become negligible.

This means that monitoring volume and CO_2 levels indoors will provide a decent indicator of exposure risk for infectious aerosol.

- Ventilation, masking, distancing will remain part of the “layered” approach for risk reduction
- Vaccination >> all these interventions

Closing thoughts

1. Our data collection is complete; we continue to study our results and plan to publish these data (open access) this Summer.
2. We still do not know (as a scientific community) how many COVID19 virions it takes to produce an infection in humans.
 - This is not really a single number. It likely varies with the mode of transmission, your genetics, health status, etc.
 - Until we have a better idea of this number (and the proportion of particles that carry active virus), we cannot define your absolute risk.
3. Although we cannot define *absolute risk*, we can define *relative risk*. Look for *continued guidance from our group and others in the coming months*.
 - *Absolute risk: In this setting, you have a 25% chance of becoming infected*
 - *Relative risk: If you do this, you can lower your chance of infection by 50%*
4. Get vaccinated!

Thank you to those who made this work possible!

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