Respiratory Particle Emission During Voice Assessment and Therapy Tasks in a Single Subject

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Summary: Introduction. SARS-CoV-2 is transmitted via respiratory particles. Respiratory particle emission is impacted by manner of breathing and voicing, as well as intersubject variability. Assessment and treatment of voice disorders may include tasks that increase respiratory particle emission beyond typical breathing and speaking. This could increase the risk of disease transmission via respiratory particles.

Methods. Respiratory particle emission was measured during a single-subject, repeated measures clinical simulation of acoustic and aerodynamic assessment and voice therapy tasks. An optical particle sizer was used to measure particle count (1−10 μm in diameter). Assessment and therapy tasks were completed in three conditions: (1) 15 cm from the device, (2) 1 m from the device, and (3) 1 m from the device with the subject wearing a surgical mask.

Results. Condition 1 generated the highest particle count, with a median of 5.1 (13) additional particles above baseline, which was statistically significant (U = 381.5, P= 0.002). In condition 1, therapy and acoustic tasks combined produced more particles compared to the baseline and speech tasks, with a median difference of 6.5 additional particles per time point (U = 309.0, P= 0.002). This difference was not significant for conditions 2 and 3. Peak particle generation occurred in specific phonatory tasks, which was most pronounced in condition 1. Voice therapy tasks during condition 1 generated the highest peaks of normalized total particles with classical singing and expiratory muscle strength training. There was a significant difference in the amount of particle generation between condition 1 and 2, with a median difference of 5.2 particles (U = 461.0, P= 0.002). The particle count difference between conditions 2 and 3 was 2.1 (U = 282.0, P= 0.292), and this difference was not significant. The normalized total particles were assessed over time for each condition. For all conditions, there was no significant accumulation of particles.

Conclusions. For a single subject, production of voice assessment and therapy tasks combined resulted in an increased number of respiratory particles compared to speech and baseline (1−10 μm). EMST and classical singing generated the greatest concentration of particles. Respiratory particle counts were higher at 15 cm from the particle sizer compared to 1 m from the particle sizer, suggesting that physical distancing may reduce immediate clinician exposure to respiratory particles. Particle concentration did not accumulate over time.

Key Words: Voice therapy—Aerosols—Particle emission—COVID-19.

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1. INTRODUCTION

Since the emergence of the SARS-CoV-2 virus and onset of the COVID-19 pandemic, healthcare providers have rapidly adapted clinical practice patterns and expanded use of personal protective equipment (PPE) in an effort to mitigate disease transmission while continuing to provide medically necessary services. Medical procedures that increase exposure to respiratory droplets or aerosols have been identified as high-risk for disease transmission. Otolaryngologists and speech-language pathologists by nature of their professions are believed to provide a number of high-risk procedures including aerosol-generating surgeries,[1−3] outpatient nasal and laryngeal endoscopy,[1,4,5] dysphagia assessment and treatment,[6] and tracheostomy and voice prosthesis management.[7] Concerns and guidelines have been published and regularly updated for such services.[8−10] Recently, clinical practice guidelines were developed for providing voice therapy during the COVID-19 pandemic.[11] However, there is still a paucity of information about respiratory particle emission during voice therapy and the associated risk of providing in-person voice therapy services during the COVID-19 pandemic.

The SARS-CoV-2 virus is transmitted through respiratory particles,[12,13] and it is well known that respiratory particles are emitted during human speech and breathing. Emission rate is impacted by the manner of breathing and voicing, as well as intersubject variability. For example, mouth breathing tends to produce more particles than nose breathing, and coughing tends to produce more particles than mouth breathing.[14] Additionally, particle emission during phonation is greater in high intensity phonation versus quiet phonation, with a nearly linear increase in particle count as vocal loudness increases.[15] Even voicing and manner of articulation impact particle generation. The greatest emission of particles occurs during voiced sounds, and

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particle generation is higher for plosive consonants than fricatives.[16] For reasons as yet unknown, some individuals are speech “superemitters” and generate an order of magnitude more respiratory particles than peers across different respiratory and phonatory contexts.[15]

Respiratory particle emission may be increased during voice assessment and treatment. Instrumental voice assessments, including acoustic and aerodynamic measures, are used by speech-language pathologists to determine parameters of voicing such as mean fundamental frequency, pitch range, loudness range, glottal airflow, and subglottal pressure. Available voice therapy techniques vary widely based on patient need, but can include elements such as loud voicing, prolongation of vowels or consonants, respiratory training, singing, and phonatory tasks that can generate visible droplets, such as lip trills or straw phonation. With the purposeful manipulation of respiration and phonation, some of these assessment and treatment tasks may generate more respiratory particles than typical speaking or breathing. In particular, tasks produced with increased loudness, sustained voicing, or increased respiratory drive would be expected to generate more particles than breathing at rest or normal speaking. Evidence regarding impact of fundamental frequency on particle emission was not identified in the literature, but this may be another source of variability in particle emission.

In addition to the use of tasks that may increase aerosol emission, voice assessment and therapy typically occur in a closed room with prolonged contact time in the range of 30−60 minutes. The infectious dose of SARS-CoV-2 for disease transmission is not known,[17] but risk of infection increases as exposure time increases.[18] In a closed room, particles may remain more concentrated and take longer to dissipate than in an open space. Thus, it stands to reason that prolonged indoor encounters centered around phonatory tasks are high risk. At the time of this study, there are no published findings on aerosol emission during voice therapy or the effectiveness of strategies such as clinician use of PPE, patient masking, or physical distancing to reduce exposure to aerosols during in-person visits.

The purpose of this study was to examine particle emission during simulated voice assessment and therapy in a clinical environment. We set out to determine if there is an accumulation of particle concentration over time, how particle emission during voice assessment and therapy compares to baseline and speaking, and how measures of physical distancing and patient masking may affect exposure to particles.

2. METHODS

2.1. Study Design and Participants

A single-subject, repeated measures clinical simulation was completed with one female volunteer (first author). The subject was a voice-specialized speech-language pathologist well versed in the included assessment and therapy tasks.

2.2. Study Environment

The clinical simulation was conducted in a voice therapy room at the USC Voice Center. The room is 142 square feet. Information regarding air changes/hour was not available for this room. A nearby room with similar dimensions (128 square feet) in the same center and ventilation system had an air changes/hour of 12.52 with 35 minutes required for removal (99.9% efficiency).

2.3. Device

Aerosol sampling was performed using an optical particle sizer (Model 7301 Remote Particle Counter, Particles Plus Inc, Stoughton, MA). The machine measures particle number and size using an optical technology between the size of 0.3 and 25 μm with a flow rate of 0.1 CFM. Particle size channels were set from 0.3 to 10 μm across 6 channels. The sampling duration was 30 seconds. Total particle counts by size over a 30-second period were collected (total particle count per 0.1 CFM).

2.4. Clinical Simulation

The clinical simulation was completed under three conditions with the participant 1. 15 cm from the device (Figure 1), 2. 1 m from the device (Figure 2), and 3. 1 m from the device masked with a standard surgical mask. In each condition, the device was placed on a mayo stand and the distance from the floor to the device port was 112 cm to approximate the position of a clinician’s face.

Assessment tasks were selected to simulate our typical protocol for acoustic and aerodynamic assessment of voice. Aerodynamic tasks were completed using the *Phonatory Aerodynamic System* Model 6600 by Pentax Medical. Aerodynamic and acoustic tasks were completed as described in the Recommended Protocols for Assessment of Voice,

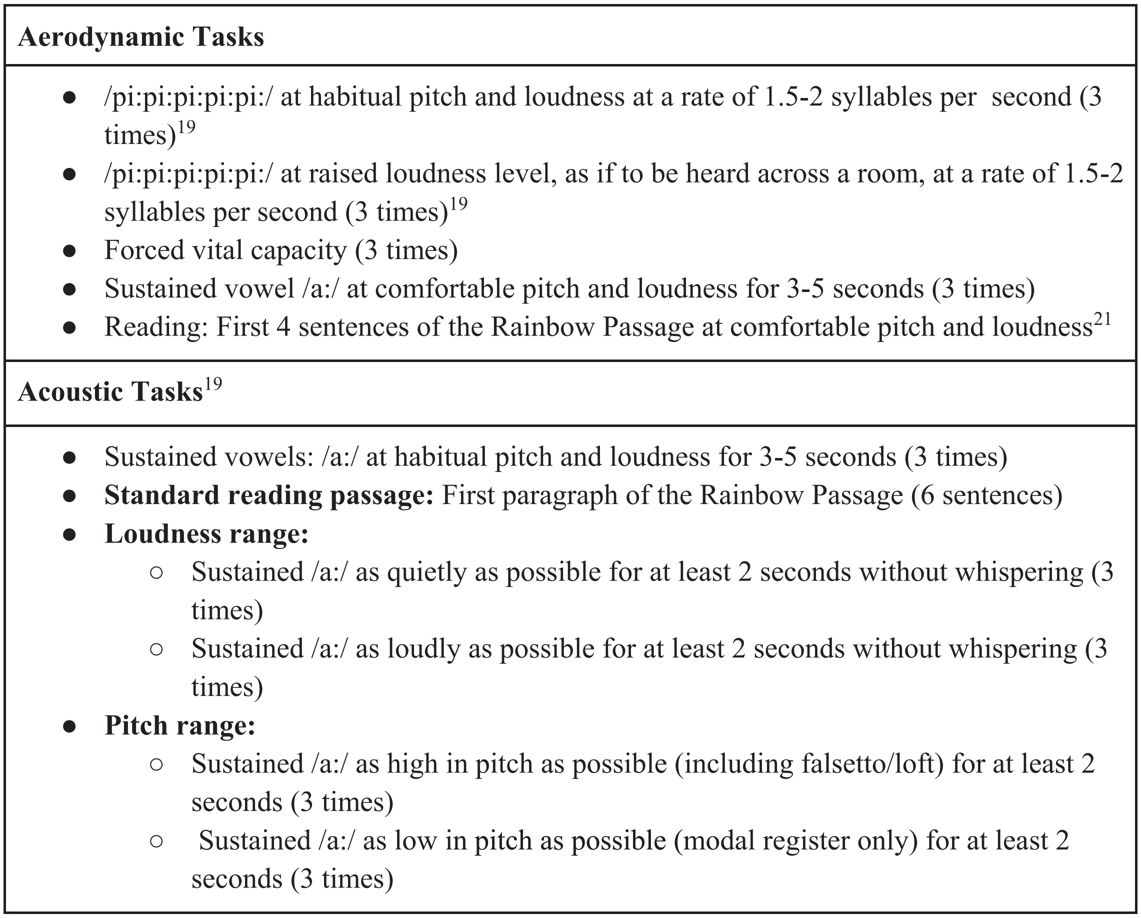
FIGURE 1. 15 cm from airflow head to device port (port is capped in this image but was uncapped for data collection).

FIGURE 2. 1 m from airflow head to device port.

developed by an expert panel from the American Speech-Language Hearing Association[19] with the addition of standard of care tasks at our center (Figure 3). Tasks were completed with at least 1 minute between them to simulate the time used by clinicians to explain the next task, analyze collected data, open the next protocol, and zero their equipment.

A variety of techniques used by speech-language pathologists were included in the voice therapy simulation (Figure 4). The list of techniques is not exhaustive, but it is representative of an array of common physiologic and symptomatic approaches to voice therapy. Each task was repeated for 2 minutes to simulate repetition of tasks during a voice therapy session. Between each task, the Rainbow Passage was repeated for a duration of two minutes using tenets of Conversation Training Therapy (eg, crisp clear consonants, pitch inflection).[20] The same number of repetitions of each task was constant across the 3 conditions (Figure 4). Conditions 1 and 2 were identical in task completion, while condition 3 did not include instrumental assessment tasks since aerodynamic assessment cannot be completed with a mask, and it did not include EMST-150 for the same reason (Figure 4). The final Rainbow Passage repetition was also omitted from Condition 3.

A 15-minute baseline/washout period was recorded at the start of each condition, following acoustic and aerodynamic assessment, and following voice therapy tasks. The subject turned on the device, left the room, and returned at the end of each baseline/washout period to start the phonatory tasks. At the conclusion of the final baseline/washout period for each condition, the subject entered the room once more and turned off the device. Each time the subject left or entered the room, a single door was opened. This was done to simulate a true clinical environment and to measure baseline particle count without the subject in the room.



Aerodynamic Tasks

- /pi:pi:pi:pi:pi:/ at habitual pitch and loudness at a rate of 1.5-2 syllables per second (3 times)[19]
- /pi:pi:pi:pi:pi:/ at raised loudness level, as if to be heard across a room, at a rate of 1.5-2 syllables per second (3 times)[19]
- Forced vital capacity (3 times)
- Sustained vowel /a:/ at comfortable pitch and loudness for 3-5 seconds (3 times)
- Reading: First 4 sentences of the Rainbow Passage at comfortable pitch and loudness[21]

Acoustic Tasks[19]

- Sustained vowels: /a:/ at habitual pitch and loudness for 3-5 seconds (3 times)
- **Standard reading passage:** First paragraph of the Rainbow Passage (6 sentences)
- **Loudness range:**
    - Sustained /a:/ as quietly as possible for at least 2 seconds without whispering (3 times)
    - Sustained /a:/ as loudly as possible for at least 2 seconds without whispering (3 times)
- **Pitch range:**
    - Sustained /a:/ as high in pitch as possible (including falsetto/loft) for at least 2 seconds (3 times)
    - Sustained /a:/ as low in pitch as possible (modal register only) for at least 2 seconds (3 times)

FIGURE 3. Acoustic and aerodynamic assessment tasks. Tasks included in study analysis are bolded.[19,21]

Conditions 1 and 2

1. Rainbow passage (2 minutes)
2. Lip trills
    a. 5x voiceless, 5x voiced, 5x hills, 5x glide up, 5x glide down
3. Rainbow passage (2 minutes)
4. **PhoRTE*[22]**
    a. 10 repetitions of sustained /a:/ for 10 seconds at approximately 85 dB
    b. 10 phrases in “calling voice” at approximately 85 dB
5. **Rainbow passage (2 minutes)**
6. **Vocal Function Exercises[23]**
    a. Full protocol with all maximum phonation tasks sustained for 10 seconds
7. **Rainbow passage (2 minutes)**
8. **Classical singing (2 minutes)**
9. **Rainbow passage (2 minutes)**
10. **Expiratory Muscle Strength Training[24]**
    a. EMST-150 device with 5 sets of 5 repetitions, approximately 10 seconds between sets (deviation from typical program)
11. **Rainbow passage (2 minutes)**

Condition 3

12. Rainbow passage (2 minutes)
13. Lip trills
    a. 5x voiceless, 5x voiced, 5x hills, 5x glide up, 5x glide down
14. Rainbow passage (2 minutes)
15. PhoRTE (cite)
    a. 10 repetitions of sustained /a:/ for 10 seconds at approximately 85 dB
    b. 10 phrases in “calling voice” at approximately 85 dB
16. **Rainbow passage (2 minutes)**
17. **Vocal Function Exercises[23]**
    a. Full protocol with all maximum phonation tasks sustained for 10 seconds
18. **Rainbow passage (2 minutes)**
19. **Classical singing (2 minutes)**

FIGURE 4. Voice therapy simulation. Tasks included in study analysis are bolded. *Included in analysis for condition 1 only.[22,23,24]

2.5. Statistical Considerations

Statistical work was performed using *SPSS* (IBM Corp., Armonk, NY). Mean and standard deviation were used to show normally distributed data, while median and interquartile range were used for non-normal distributions. Shapiro-Wilks test was used to test for normality. Baseline particle counts were averaged for each conditions 1, 2, and 3. The baseline particle average was subtracted from the total particle counts (1, 2.5, 5, and 10 μm) at each 30-second interval. Nonparametric Kruskal-Wallis test was used to explore the differences in particle distribution between the three study conditions. Post-hoc Mann-Whitney *U* test was used to determine the differences between individual groups for non-normally distributed data. To determine if any particle accumulation occurred, Spearman’s bivariate correlation was performed.

3. RESULTS

3.1. Data Reduction for Analysis

Unexpectedly, initial data review indicated that particle count notably increased each time the door to the room opened or closed. In each instance, it took between 7 and 10 minutes for particle count to return to baseline. To account for this unexpected confounder, tasks completed within the first 10 minutes of entering the room were removed from analysis.

At baseline, ambient particle counts for particles smaller than <1 μm were high and variable. This may have been due to environmental particles such as dust. Further, particle count did not appear to be affected by voicing or by presence of the subject in the room. Therefore, data for particles measuring 0.3 and 0.5 μm were excluded from analysis.

TABLE 1.
Study Conditions and Task Lengths

Condition Number	Study Condition	Task	Study Time (Minutes)
1	Mouth 15 cm from device	Speaking (Rainbow passage)	8
		Voice therapy	8
		Acoustics/Aerodynamics	4
2	Mouth 1 m from device	Speaking (Rainbow passage)	10
		Voice therapy	7
		Acoustics/Aerodynamics	4
3	Mouth 1 m from device with a mask	Speaking (Rainbow passage)	5
		Voice therapy	5

3. 2. Particle generation with variable study conditions

Three testing conditions were investigated (1) mouth 15 cm from the device, (2) mouth 1 m from the device, and (3) mouth 1 m from the device with a mask. A series of phonatory assessment and therapy tasks were performed for a variable amount of time, ranging between 4 and 12 minutes (Table 1). Total particle counts (1, 2.5, 5, and 10 μm) were measured at thirty second intervals (Appendix).

For each study condition, a specific baseline particle count was derived without any phonation. Baseline particle counts are shown (Table 2).

The total number of particles were normalized based on each condition's specific baseline. Conditions and general phonatory tasks are shown (Table 3). Overall, condition 1 generated the highest particle count, with a median of 5.1 (13) additional particles above baseline, which was statistically significant (U = 381.5, *P*= 0.002). In condition 1, therapy and acoustic tasks combined produced more particles compared to the baseline and speech tasks, with a median difference of 6.5 additional particles per time point (U = 309.0, *P*= 0.002). This difference was not significant for conditions 2 and 3, which were 1.4 (95% confidence interval [CI]: −1.3−4.1) and 3.0 (95% CI: −1.9−8.0) particles, respectively.

The testing condition demonstrated a significant impact on the degree of particle generation, (F(2,96) = 10.15, *P*= 0.006). There was a significant difference in the amount of particle generation between conditions 1 and 2, with a median difference of 5.2 particles (U = 461.0, *P*= 0.002). The particle count difference between conditions 2 and 3 was 2.1 (U = 282.0, *P*= 0.292), and this difference was not significant.

TABLE 2.
Baseline Total Particle Counts for Each Condition

Condition Number	Time (Minutes)	Average Baseline Particle Count (Mean ± SD)
1	17	26.9 ± 11.1
2	17	26.1 ± 4.5
3	12	21.3 ± 5.9

Testing conditions with particle ranges are shown (Figure 5).

3.3. Accumulation of particles based on condition

The normalized total particles were assessed over time for each condition. For all conditions, there was no significant accumulation of particles. The correlation coefficients for conditions 1, 2, and 3 were 0.036 (95% CI: −0.30 to 0.35), −0.28 (95% CI: −0.58 to 0.05), and −0.39 (95% −0.74 to

TABLE 3.
Median and Interquartile Range of Total Particle Counts Compared to the Baseline

	Condition 1 Normalized Median Particle Count (Interquartile Range)	Condition 2 Normalized Median Particle Count (Interquartile Range)	Condition 3 Normalized Median Particle Count (Interquartile Range)	*P* Value
Speaking (Rainbow passage)	2.1 (10.5)	−1.1 (8)	0.7 (6.5)	
Therapy	8.1 (20)	−0.1 (7)	1.7 (9)	
Acoustics	6.1 (25)	3.8 (6.8)		
Overall	5.1 (13)	−0.6 (7)	1.2 (7)	0.006

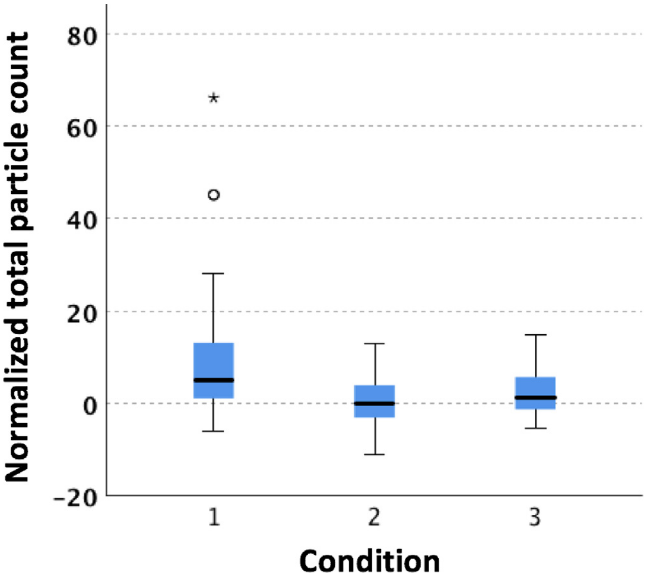


FIGURE 5. Normalized total particle counts for each condition. Thick black line = median, Box = interquartile range (data points between the 25th and 75th percentile), Brackets = range of data excluding outliers, o = outlier (between 1.5 and 3 interquartile boxes from 25th or 75th percentile), * = extreme outlier (greater than 3 interquartile boxes away from the 25th to 75th percentile.

0.11), respectively. Scatterplots for each condition are shown (Figure 2).

3.4. Particle generation based on phonatory specific tasks

Peak particle generation occurred in specific phonatory tasks, which was most pronounced in condition 1. Voice therapy tasks during condition 1 generated the highest peaks of normalized total particles with classical singing and expiratory muscle strength training as the highest and second highest peaks respectively (66.1 and 45.1 particles, respectively). Top particle-generating tasks in this study are listed (Table 4).

TABLE 4.
Highest Normalized Total Particle Counts (1-10 μm) Based on Specific Tasks in Descending Order

Task	Condition	Total Particle Count
Classical singing	1	66.1
EMST	1	45.1
Acoustics/aerodynamics – reading	1	28.1
Acoustics/aerodynamics – pitch range	1	23.1
Speaking (Rainbow passage)	1	15.1
Classical singing	2	12.9

4. DISCUSSION

In the initial months of the COVID-19 pandemic, many speech-language pathologists completed all voice evaluations and treatment sessions via telehealth. As the pandemic has continued, however, clinicians are increasing their in-person caseloads. ASHA guidelines support use of telehealth services where appropriate and recommend use of masks and other precautions, such as plexiglass barriers and physical distancing, when in-person speech pathology services are deemed necessary.[25] Beyond these general guidelines, specific information about the relative risk of voice therapy and specific therapeutic techniques is still developing. The most recent clinical practice guidelines recommend the following PPE for in-person voice assessment: N95 or higher level respirator, face shield, gloves, and a long-sleeved gown.[11] Further, face-to-face interactions should be limited to 15 minutes maximum, and some elements of the evaluation can be completed via telehealth to reduce contact time.[11]

The purpose of this study was to better understand particle emission during voice assessment and therapy tasks in the clinical environment as an initial step toward understanding potential risk of providing in-person services. The SARS-CoV-2 virus is transmitted through respiratory particles, though the primary mechanism of transmission, droplet or short-range airborne, is still debated.[12,13] The exact viability of the SARS-CoV-2 virus in suspended droplet nuclei is unknown, but early research suggests the virus is viable for at least 16 hours.[26] If respiratory particles accumulate versus dissipate over time in the clinical environment, potential virus exposure could theoretically be compounded and exponentially increase the risk of infection. Thus, the first aim of the study was to determine if there is an accumulation of particles over time during continuous phonatory tasks. The normalized total particle counts (1–10 μm) were assessed over time for each condition. For all conditions, there was no significant accumulation of particles. In condition 1 (15 cm from the device), the trend line illustrates a minimal, nonsignificant accumulation of particles (Figure 6). In conditions 2 and 3, the trend lines illustrate a non-significant decrease in particle counts over time. Interestingly, baseline particle counts also seemed to decrease and become less variable over time (Table 2). This may be due to an increased number of ambient dust or respiratory particles during initial experiment set-up with multiple researchers in the room. As time from the initial set-up increased, baseline particles decreased. It is unclear how particles would be affected with both a clinician and a patient in the room, but these findings suggest that particle exposure does not compound over time in this particular clinic space. However, this is likely dependent on particular room dimensions and airflow. In a study of dispersion of and exposure to droplets from a simulated cough, researchers found that particle concentration from a single simulated cough was relatively unchanged 20 minutes after the cough compared to the initial minutes after the cough, and particles dispersed throughout the entire room.[27] Theoretically,

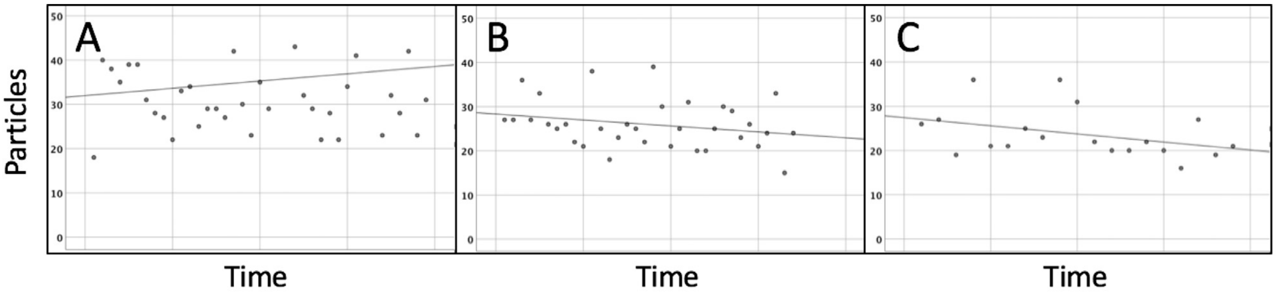


FIGURE 6. Scatterplots of total particle count vs time for each condition (1, 2, and 3) are shown with trend lines (Spearman's correlation, ρ). For each condition, particle counts were measured every 30 seconds. **A**. Condition 1: mouth 15 cm from the device, $\rho = 0.036$ (95% CI: −0.30−0.35), **B**. Condition 2: mouth 1 m from the device $\rho = -0.28$ (95% CI: −0.58−0.05), C. Condition 3: mouth 1 m from the device with a mask, $\rho = -0.39$ (95% −0.74−0.11).

additional coughs would have increased the particle concentration in this setting. Even in environments where particle concentration does not significantly increase over time, longer exposure times would yield higher exposure to respiratory particles than shorter exposure times.

The second aim of the study was to broadly examine particle generation in a variety of voice assessment and therapy tasks compared to speaking and baseline particle counts. In condition 1, tasks were completed with the mouth or airflow head 15 cm from the particle counter inlet port. Assessment and therapy tasks combined generated significantly more particles (1−10 μm) compared to baseline and to speaking. This finding was expected since voice assessment and therapy tasks include features that are known to increase particle emission, such as sustained phonation, increased respiratory drive, and increased vocal loudness.[15,16] Though the intent of this study was not to measure particle counts for isolated tasks, two tasks were outliers and indicated greater particle generation than any other tasks. EMST, which utilizes forceful exhalation, was an outlier and classical singing, produced with increased vocal loudness and sustained phonation, was an extreme outlier (Figure 5). While this is the first study to our knowledge to specifically measure particle emission during voice therapy tasks, emission during speech tasks in the clinical environment has been measured with optical particles in other recent studies. Workman et al found that speech generated significantly more particles than panting, while Rameau et al found that speech did not generate significantly more particles than breathing.[1,28] Similar to the current study, both studies looked at a limited particle range of 1−10 μm, and sample sizes were small (N = 2). The small sample size in our study and others do not allow for capturing the notable intersubject variability of particle emission that has previously been established.[15]

The third study aim was to determine if there is a change in particle count when using physical distancing with and without masking. In conditions 2 and 3, the device was placed 1 m from the subject's mouth to mimic typical clinician positioning. The subject was unmasked in condition 2 and masked in condition 3. Particle count during phonatory tasks was significantly lower in both conditions 2 and 3 (1 m) compared to condition 1 (15 cm), indicating that physical distance between clinician and patient can reduce immediate exposure to respiratory particles. Though the immediate particle count was reduced with physical distancing between the device and subject, it is possible that a clinician could still be exposed to respiratory particles in a closed room when using physical distancing. In a cough simulation in a closed room, researchers found that over the course of 20 minutes, exposure to cough particles occurred regardless of device position compared to the cough simulator.[27]

Masking of both clinicians and patients has been recommended in the clinical setting to help reduce the transmission of SARS-CoV-2.[25] A recent systematic review and meta-analysis found that face masks appear useful in reducing respiratory disease transmission with N95 respirators being more effective than surgical masks, but surgical masks more effective than no mask.[29] The addition of a surgical mask in condition 3 did not yield a significant difference in particle count compared to condition 2, indicating that the mask in this setting did not further reduce particle count exposure in the range of 1−10 μm more than physical distancing alone. It is important to emphasize that our study only examined the effect of mask use on particles within the range of 1-10 μm. However, respiratory particles can range in size from < 1 to 1000 μm, and the reported size distribution of respiratory particles varies based on study design and particle counting methodology.[14,30,31] Respiratory particles also change size over time as particles evaporate down to droplet nuclei. Using a microscope to view droplet stain marks and a dust monitor, Xie et al found that 15% of expired respiratory particles emitted during speech were <10 μm in diameter, 52% were <50 μm, and 80% were <100 μm.[32] Using interferometric Mie imaging and particle image velocimetry, Chao et al found the mean diameter of particles during speaking was 16.0 μm.[33] Such studies indicate that many of the respiratory particles generated during our study protocol may not have been measured by our optical particle counter. It is possible that the spectrum of particles not captured in our study (<1 and >10 μm) are more affected by masking. Certainly, large visible droplets, as generated by tasks such as lip trills in this study, would be captured with masking. However, smaller particles may not be captured. Thus, clinicians should wear appropriate PPE if in-person services are necessary, including an N95 respirator.[11]

5. LIMITATIONS

The present study was conducted with a single subject in a single clinic room. Therefore, generalizability is limited. Previous studies indicate significant intersubject variability regarding particle emission during speech and breathing.[15,16] A subset of people are considered speech “superemitters,” but the reasons for super emission are unknown. We can assume that some patients will be superemitters, but we cannot predict who these individuals will be. Speech super emitters may pose a greater risk for disease transmission since they emit more respiratory particles. Further, repetition of this study in another room would likely yield differences in results, as room size and air circulation can affect particle suspension and dispersion.

This study also examines a limited range of particle sizes. The optical particle counter used in this study was set to capture particles between 0.3 and 10 μm. Human respiratory particles, however, can be as large as 1000 μm in diameter and as small as 0.3 μm or less when dried to droplet nuclei.[14,30,31] Thus, we were able to measure only a narrow segment of the particle size spectrum for respiration and phonation. Other studies within the otolaryngology literature have similarly examined this same range of particle size,[1,28] and future studies should examine a larger range of particle size in order to develop a comprehensive understanding of particle generation. Though our particle counter measured particles as small as 0.3 μm, only particles between 1 and 10 μm were analyzed. This is because ambient aerosol concentrations of sizes below 1 μm were high at baseline and remained high and noisy throughout the study. This may have been due to environmental particles such as dust, an expected confounder in the clinical versus lab setting. While this study sought to examine particle count and accumulation in an unaltered voice therapy room, future studies could include the use of a HEPA filtration system to reduce ambient particle count prior to and in-between study conditions.

Finally, analysis was limited to a subset of voice tasks due to unexpected changes in particle count when the clinic door was open or closed. The full study protocol included a complete acoustic and aerodynamic assessment task battery and 6 distinct therapeutic techniques, but particle counts during aerodynamic tasks, lip trills, and much of the PhoRTE protocol were not analyzed. However, when considering any accumulation of particle concentration, we can consider that these tasks were completed by the subject and did not contribute to particle accumulation.

6. CONCLUSIONS

This study is a preliminary examination of respiratory particle emission during voice therapy and assessment tasks. In the range of $1-10$ μm, assessment and therapy tasks combined resulted in an increased number of respiratory particles compared to speech and baseline. EMST and classical singing generated the greatest concentration of particles. Respiratory particle counts were higher at 15 cm from the particle counter compared to 1 m from the particle counter, suggesting that physical distancing may reduce immediate clinician exposure to respiratory particles. Particle concentration did not accumulate over time. Future studies should examine particle counts for specific assessment and treatment tasks with additional participants and across a broad spectrum of particle sizes.

APPENDIX - 1

Condition	Task	Time (min)	1 μm	2.5 μm	5 μm	10 μm	Total particles
1 – Mouth 15 cm from device	Baseline	17	23.1 ± 7.3	2.6 ± 3.7	0.6 ± 1.1	0.7 ± 1.0	26.9 ± 11.1
	Speaking (Rainbow passage)	8	24.8 ± 5.0	2.9 ± 1.3	0.9 ± 1.1	1.8 ± 1.8	30.4 ± 6.6
	Voice therapy	8	31.4 ± 15.9	6.4 ± 6.6	1.6 ± 1.8	2.9 ± 2.8	42.4 ± 20.5
	Acoustics/Aerodynamics	4	27.7 ± 10.8	4.1 ± 2.7	1.4 ± 1.6	2.6 ± 3.0	35.9 ± 12.4
2 – Mouth 1 m from device	Baseline	17	23.5 ± 4.7	1.9 ± 1.5	0.4 ± 0.6	0.3 ± 0.5	26.1 ± 4.5
	Speaking (Rainbow passage)	10	23.1 ± 5.4	1.4 ± 1.3	0.6 ± 0.7	1.2 ± 0.9	26.2 ± 6.4
	Therapy	7	23.2 ± 4.0	1.5 ± 1.1	0.5 ± 0.9	1.3 ± 1.3	26.5 ± 4.8
	Acoustics/Aerodynamics	4	23.2 ± 4.0	2.8 ± 1.9	2.0 ± 1.4	1.8 ± 0.8	29.8 ± 4.2
3 – Mouth 1 m from device with mask	Baseline	12	19.6 ± 5.7	1.3 ± 1.2	0.3 ± 0.5	0.1 ± 0.3	21.3 ± 5.9
	Speaking (Rainbow passage)	5	20.4 ± 4.9	2.1 ± 1.3	0.3 ± 0.4	1.3 ± 1.0	24.0 ± 5.3
	Voice therapy	5	21.0 ± 6.0	1.8 ± 1.0	0.2 ± 0.7	1.3 ± 1.0	24.3 ± 6.2

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