The Effect of Water Resistance Therapy on the Impulse Dispersion of Aerosols During Sustained Phonation

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SUMMARY: Introduction. Group singing has been associated with higher transmission risks via exhaled and spread aerosols in the CoVID19 pandemic. For this reason, many musical activities, such as rehearsals and lessons, but also voice therapy sessions, have been restricted in many countries. Consequently, transmission risks and pathways have been studied, such as aerosol amounts generated by exhalation tasks, convectional flows in rooms, or the impulse dispersion of different kinds of phonation. The use of water resistance exercises such as those utilizing LAX VOX®, are common in voice lessons and as vocal warm-ups. With this context, this study investigates the impulse dispersion characteristics of aerosols during a voiced water resistance exercise in comparison to normal singing.

Methods. Twelve professional singers (six male, six female) were asked to phonate a stable pitch through a silicone tube into a bottle filled with water, holding the end of the tube 5 cm below the surface. Before performing the tasks, the singers inhaled the vapor consisting of 0.5 L base liquid from an e-cigarette. The exhaled gas cloud coming out of the bottle was recorded in all three spatial directions and the dispersion was measured as a function of time.

Results. At the end of the phonation task, the median distance to the front was 0.55 m and the median of the lateral expansion of the cloud was 0.89 m, the maximum to the front reached 0.88 m, and the maximum of lateral expansion 1.05 m. For the upwards direction of the clouds a median of 1.00 m and a maximum of 1.34 m from the mouth were measured. Three seconds after the end of the task, the medians were declining.

Conclusion. The exhaled aerosol cloud can expand despite the obstacle of the water when using LAX VOX® during phonation.

Key Words: Singing—CoVID19—Aerosol dispersion—LAX VOX.

INTRODUCTION

Group singing activities like choir rehearsals and concerts have been associated with super-spreading events during the CoVID19 pandemic[1−3] and have therefore been restricted in many countries worldwide. It has been acknowledged that the SARS-CoV-2 virus can be transmitted by droplets and aerosols of different sizes which are generated in the respiratory tract and expelled by exhalation activities and phonatory tasks.[4] While the droplets ($> 5\ \mu$m) fall to the ground within 1.5 m of the emitter, aerosols ($< 5\ \mu$m) could hover in the air for a longer time and travel further distances due to the impulse of the emitter or secondary convectional flows in the room.[5−7] Aerosol emission has been found to be higher in singing than in speaking or simply breathing.[8] With regard to the aerosol dispersion, it has been shown that − in contrast to professional singers[9] − amateur singers could reach higher maximum distances in their impulse dispersion.[10]

As a consequence, safety concepts, such as distancing, singers' masks, room aeration systems, plexiglass walls, etc have been invented and evaluated, in order to assess and reduce the transmission risks as much as possible and to make musical gatherings, ie, lessons, rehearsals, and performances, possible and safe.[10−18]

Water resistance therapies (WRT) and semi-occluded vocal tract exercises (SOVTE), such as LAX VOX®[19] are widely used for both voice therapy and singing warm-ups.[20−31] During such exercises, the patient or singer phonates into a silicone tube, one opening in the mouth and sealed by the lips, the other opening submerged several centimeters under the surface of a fluid inside a bottle, which is held by the subject. After fragmentation of the airflow by the vocal folds, the airflow has to pass a fluid medium, such as water. It has not yet been clarified if the passage of the airflow through water and the subsequent release through bubbles affects the aerosol dispersion characteristics.

The presented experiment investigates the aerosol dispersion characteristics during this water resistance exercise.

MATERIAL AND METHODS

After the approval of the local ethical committee (20-1065), 12 professional singers (six male and six female consisting of members of the Bavarian Radio Chorus and two

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freelancers. One male choir singer had to be omitted from the results due to the cough that arose from the use of the e-cigarette) were included. All subjects were also part of a previously-published study analyzing singers' masks, measured on the same day.[11] There were no voice complaints by any of the subjects and their Voice Handicap Index showed no vocal impairments. Further, respiratory problems were excluded by medical history and spirometry (ZAN, Inspire Healthcare, Oberthulba, Germany).

Tasks

The subjects were asked to phonate at a stable pitch (male: 185 Hz, female: 370 Hz; the pitches were chosen because they are located within the comfortable mid-range of male/female voices) and at a comfortable volume through a LAX VOX® silicone tube (Figure 1; tube diameter: 9 mm, length: 30 cm), ending 5 cm below the surface in a bottle filled with water, over the duration of at least 6 seconds.

Before phonation they inhaled .5 l base liquid (50% glycerin and 50% polypropylene glycol) through a Lynden Vox e-cigarette (Lynden GmbH). The particles in the smoke of e-cigarettes have been shown to match the size of aerosols generated by human exhalation, which is 250-450 nm.[8,32,33]

FIGURE 1. Depiction of a LAX VOX® silicone tube in use: the mouth closes tightly around the entrance opening. The end of the tube is held several cm below the water surface in a bottle. Phonation causes bubbles in the water (Photorights by S.A. Kruse, T. Lascheit; Photographer: Jakob Voges).[19]

To not trigger convectional flows, the subjects were standing still on the same marked point on the stage during inhalation and exhalation. Similar to previous studies,[9−12,18,34] the study was conducted in a Bavarian Television Broadcasting Studio with the dimensions of 27 m x 22 m x 9 m. Three synchronized high-definition Sony television cameras (Sony, Tokyo, Japan, resolution 1920 × 1080 pixels, 25fps) recorded the tasks from a side view (C1), a front view (C2), and a top view (C3). Before and after all tasks and each subject the hall was aerated via opposing doors opened for a minimum of 2 minutes. Air humidity of 29.8% and an air temperature of 21°C was maintained in the room throughout all experiments. Three spotlights increased the contrast between the white aerosol clouds and the studio walls, which were covered in black cloth. To enable the conversion of pixels into metric values, the performance stage was surrounded by benchmark bars in all three spatial directions.

Data analysis

The analysis was performed similarly to previous investigations,[9−12,18,35] where the video footage was edited and set into a coordinate system to measure the aerosol cloud's expansion over time. The video editing included converting the footage into negative black and white, and objects that could have led to segmentation errors were masked. The cloud expansions of each video frame were segmented using the software Glottis Analysis Tools (University Erlangen-Nürnberg, Germany).[36] Due to light reflections and following segmentation artifacts, the footage of camera 2 was not used for analysis. The cloud expansions to the front of the subjects (x-direction) and in vertical direction upwards and downwards (z-direction) were taken from camera 1, while the expansion to the sides (y-direction) was taken from camera 3, see Figure 2.

The position of the mouth was taken as the zero-point concerning the expansion of the cloud. In the time domain, the time point zero (t = 0s) was set at the end of the task, ie, when phonation stopped.

After the segmentation of the vapor cloud, the resulting temporal devolutions of the maximum expansion of the vapor cloud in x, y, and z were determined, filtered by a moving median filter (window length of 30-time points), and finally smoothed by a cubic spline interpolation to remove segmentation outliers, using Matlab (The Mathworks Inc., Natick, MA) for computation.

RESULTS

All subjects were able to perform the task without interruption. The maximum and median values for all subjects at the end of the task, 3 seconds and 10 seconds after the end of the task are listed in Table 1.

At the end of the phonation task, the maximum distance to the front reached 0.88 m and the maximum diameter of the cloud in y-direction reached 1.05 m.

As illustrated in Figure 3, the medians at the end of the task were 0.55 m to the front, and 0.89 m for the expansion

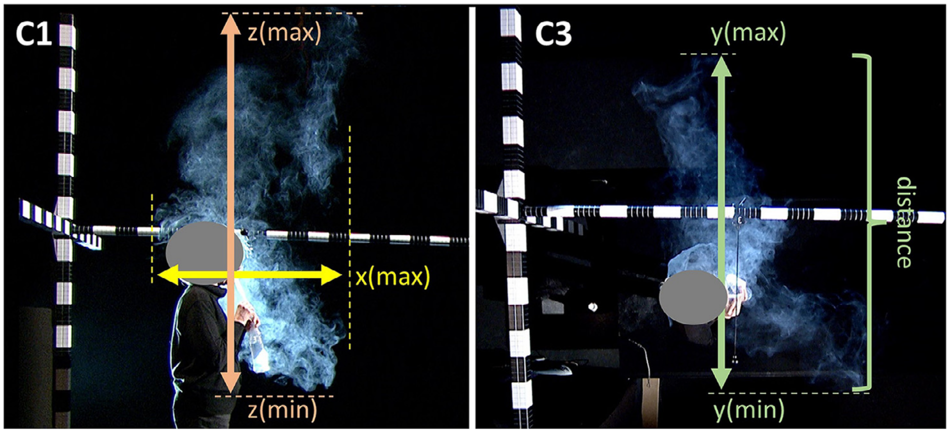

FIGURE 2. Pictures of camera 1 (left side) recording the x-dimension to the front and the vertical z-dimension from a side view, and camera 3 recording the y-dimension to the sides from a top view.

from the left to the right side. In z-dimension at the end of the task, the clouds reached a maximum of 1.34 m to the top with a median of 1 m, measured from the position of the mouth.

Three seconds after the end of the task, the medians of clouds had started to decrease, and ten seconds after the clouds had almost dissolved. The maximum clouds, however, had drifted 0.28 m further to the front and expanded 0.14 m in the y plane ten seconds after the end of the task.

DISCUSSION

This study investigated the aerosol dispersion in singing using the LAX VOX® exercise, ie, a silicone tube inserted below the surface of water in a bottle, in order to check its ability to slow down, block, or modify aerosol dispersion. The results show that the aerosol clouds could expand despite the obstacle of the water.

To interpret the values of aerosol dispersion when singing with LAX VOX®, the results of previous studies have to be taken in comparison. For the same subjects recorded the same day, singing a melody of comparable length with text, the distances were as follows: At the end of the task, the maximum in x-direction reached 1.14 m with a median of 0.76 m; in y-direction the maximum diameter of the cloud was 0.98 m, with a median of 0.57 m. The highest value in z-direction was 1.17 m (upwards from the mouth).[11]

Consequently, for the zero-point at the end of the task, there is a difference for the maximum in x-direction of 0.26 m and a difference in the median of 0.21 m, with the LAX VOX® exercise showing the lower values. However, for the lateral expansion, the LAX VOX® exercise had higher values with a difference of 0.07 m for the maximum and a difference in the median of 0.32 m. Concerning the maximum in z-direction (upwards), singing with LAX VOX® went 0.17 m higher than normal singing.

In a previous study conducted eight months before the presented experiment, the subjects also performed the melody phrase as a vocalize without consonants.[12] The comparison to this task is useful, because LAX VOX® also prohibits consonants. In the vocalize task, the distances at the end of the task were found to be as follows: maximum to the front: 0.99 m, median to the front: 0.62 m; maximum diameter of lateral expansion 1.46 m with a median of 0.7 m; maximum expansion to the top 1.13 m, with a median of 0.52 m. This means, in comparison, in frontal direction LAX VOX® had a .11 m lower maximum and a 0.07 m lower median. The lateral expansion maximum was 0.41 m lower with LAX VOX®, but in contrast, the median of the lateral expansion was 0.19 m higher. In the upwards direction the maximum went 0.21 m higher and the median 0.48 m higher when using LAX VOX®.

These comparisons with normal phonation show that LAX VOX® has lower values for the front direction, however the lateral expansion of the clouds is mostly larger than in normal singing, and the distances reached with LAX VOX® would still necessitate safety distancing.

In phonation without LAX VOX®, it appears that the aerosols have a frontal directivity, while with LAX VOX® this horizontal directivity is equalized by the vertical exit

TABLE 1.
The Maximum and Median Values for the end of the Task (0 s), as Well as 3 and 10 Seconds Later

	x-Dimension			Diameter in y-Plane			z-Dimension		
	0 s	3 s	10 s	0 s	3 s	10 s	0 s	3 s	10 s
Maximum	0.88 m	1.02 m	1.16 m	1.05 m	1.16 m	1.19 m	1.34 m	1.33 m	1.19 m
Median	0.55 m	0.51 m	0.005 m	0.89 m	0.83 m	0.06 m	1 m	1.06 m	0.02

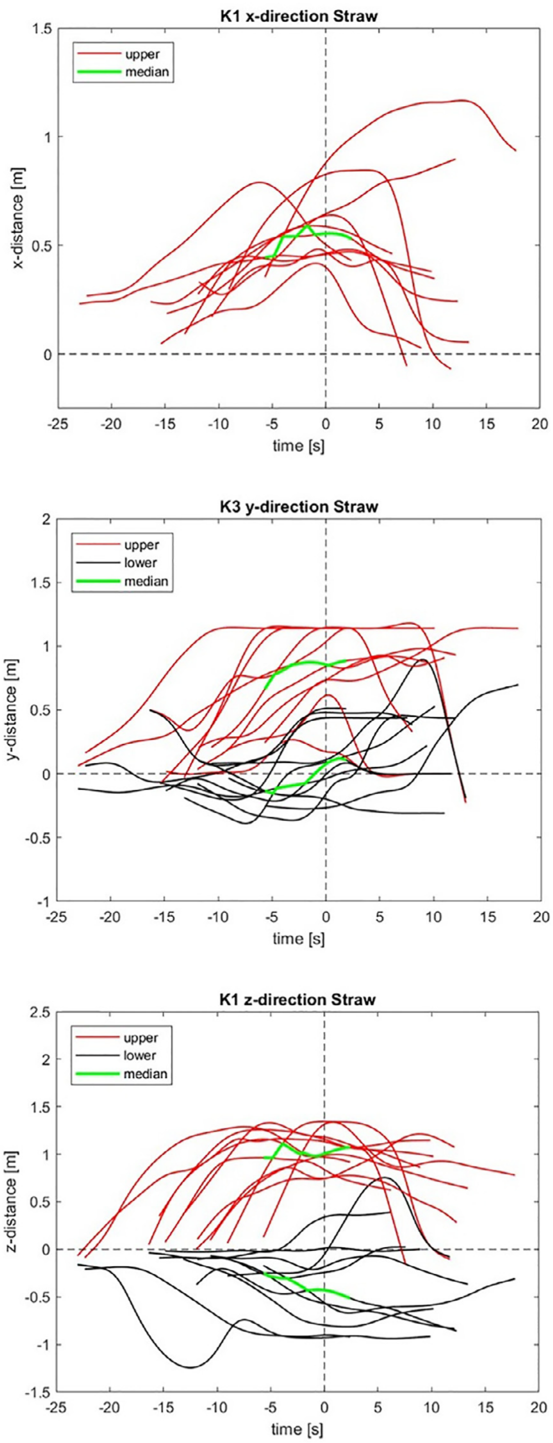

FIGURE 3. Shows the development of median and maximum expansions for all directions. The zero-point in the time domain is the moment at the end of the phonation task.

from the bottleneck, and is deflected upwards. The medians of 0.55 m to the front and 0.89 m lateral diameter suggest a circular spread with a radius of 45-55 cm. This model would explain the higher median values in lateral and upwards direction for LAX VOX®. Because gas escapes water in a vertical direction, these results seem to be transferable to other SOVT exercises including water. However, the horizontal spread might differ depending on the water area and vessel opening width. The extent of the horizontal spread regarding these factors should be the subject of a follow-up study.

In this study the subjects phonated at a single, sustained, comfortable, mid-voice pitch. It can be questioned if phonation at a higher pitch would increase the medial compression and therefore change the outcomes. Data on differences of aerosol impulse dispersion patterns regarding pitch have not yet been investigated. However, an increasing compression can also be found for singing at higher loudness levels. In a previous study[9] there was no statistically significant relation between loudness and dispersion distance. The subjects in this study sang at their individually comfortable loudness, why different levels of compression might be represented in the outcomes.

Another aspect concerning the use of LAX VOX® is that it is suitable for a variety of vocal warm-ups, for learning melodies, or for voice-improvement exercises. However, since it prevents the pronunciation of text and for the checking of the effects of the exercises, in practical application LAX VOX® usually appears combined with tasks of normal phonation. Consequently, for the planning of safety concepts, the results of other studies on the dispersion of aerosols during other phonation tasks[9-12] have to be combined.

Limitations

The discussed comparisons might be limited, since the task of the LAX VOX® experiment was a stable pitch, while the compared tasks contained a whole melody phrase with various pitches.

In this experiment, only professional singers were performing the task, because they were suspected to cope with the e-cigarette vapor more easily and, therefore, to produce more reliable results. Non-professional singers might show different outcomes. However, in normal singing phonation the values of aerosol impulse dispersion in amateur singers were mostly comparable to professionals.[10] With amateurs, a larger distance to the front for individual cases could then be explained by the smaller mouth opening and a resulting jet-stream effect. This effect is not expected in the presented experiment because the mouth openings are always the same, due to the uniform tube opening width. A difference in the outcome due to differences in breath control and applied pressure could be investigated in future experiments.

This study only focused on LAX VOX®. However, there are several more SOVTE, such as straw phonation, humming (using /m/, /n/ or /ŋ/), lip trills, tongue trills, and consonants (s/z, ʃ/ʒ, f/v, th/ð) or a hand over the mouth. For fricative consonants[12] and narrow-opening straw phonation[10] a jet-stream effect leading to larger distances compared to usual phonation in frontal direction could be presumed, while more research is needed for the other task forms.

The data show only the primary impulse dispersion of one phrase sung by one subject and cannot predict the development or accumulation of aerosol clouds when singing over a longer period of time, nor with several persons at the same time. Neither can the effects of convectional flows in non-laboratory settings be represented. Furthermore, the artificially introduced aerosols cannot represent the concentration of virus-laden particles within the exhaled cloud, which is also specific to each potentially-infected individual. Moreover, the method does not allow for statements about possible retention of aerosols in the water inside the bottle.

CONCLUSION

The data show that the water resistance exercises utilizing LAX VOX® lower the impulse dispersion distance to the front, however the lateral expansion might be larger than in usual singing and safety distances would still be required in all directions.

DECLARATION OF COMPETING INTEREST

None.

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