Droplets and Aerosols generated by singing and the risk of COVID-19 for choirs.

Prateek Bahl[a], Charitha de Silva[a], Shovon Bhattacharjee[b], Haley Stone[c], Con Doolan[a], Abrar Ahmad Chughtai[c], C Raina MacIntyre[b]

[a] School of Mechanical and Manufacturing Engineering, UNSW Sydney, NSW 2052, Australia

[b] The Kirby Institute, UNSW Sydney, NSW 2052, Australia

[c] School of Public Health and Community Medicine, UNSW Sydney, NSW 2052, Australia

Corresponding Author

Prateek Bahl
School of Mechanical and Manufacturing Engineering,
UNSW Sydney, NSW 2052, Australia
Email: prateek.bahl@protonmail.com

Abstract

Choral singing has become a major risk during COVID-19 pandemic due to high infection rates. Our visualisation and velocimetry results reveal that majority of droplets expelled during singing follow the ambient airflow pattern. These results points toward the possibility of COVID-19 spread by small airborne droplets during singing.

Background

Singing in group settings has become an apparent risk for outbreaks of COVID-19 [1]. While social distancing is effective in normal social interactions, singing can produce a substantially larger number of respiratory droplets and aerosols than speaking, as it is louder and sustained for longer durations [2]. This may require further measures to be put into place to mitigate risks. In contained smaller spaces, the transmission risk may be higher, as respiratory aerosols may saturate the whole indoor environment [3]. Despite this, at present there is not a collective approach or response to the potential risks of group singing. Certain countries, including Germany and the Netherlands, have banned all group singing activities [4].

Choir-related outbreaks of COVID-19 in Berlin, Amsterdam, and Washington State had high attack rates of 75.6%, 78.5% and 86.9% respectively [1,4,5]. Since restrictions have eased globally, a rise in outbreaks related to singing has been reported [6]. A large proportion of these documented outbreaks associated with singing (approx. 69%), were reported from the United States resulting in over 544 cases [1].

COVID-19 is assumed to be transmitted through respiratory and contact routes; and transmission by respiratory droplets is believed to occur only in close contact (within 1-2 m) with someone who is infectious [7]. However, there is uncertainty about the dynamics of respiratory emissions during singing. Additionally, studies have shown that droplet and airborne transmission may not be mutually exclusive modes of transmission and exist as a continuum [8]. Hence, unravelling the spread of respiratory particles during singing, especially in closed environments, could inform infection control policy and practice.

Methods

To quantify and understand the spread of infection during singing we performed a detailed flow visualization of aerosols and droplets expelled during singing using an image-based flow diagnostic system. The visualisation technique employs a LED based light source (GS Vitec MultiLED PT) with a spherical lens to control the divergence of the light beam, along with a high-speed camera (nac MEMRECAM HX-7s) to capture the light scattered by the droplets expelled during singing. To capture the video, the head of the subject was adjusted in front of black backdrop/background and the light was positioned in a forward scatter arrangement to maximize the scattering from expelled droplets (Figure 1).

Once the position is adjusted, the subject was asked to sing a major scale using the solfège system and the high-speed video was captured with an exposure of 600 µs per frame at a resolution of 2 Megapixels. In addition to singing, the subject also counted from 1 to 10 and coughed voluntarily. The horizontal field of view captured in the high-speed video, from the mouth of the subject, was 26 cm approximately. Frames obtained from the video were first calibrated and a 2-axis stabilisation was applied to subject's head (Further details on this procedure can be found in [9]). Thereafter, all the frames were processed with a hybrid Particle Tracking Velocimetry technique [10]. This technique first performs a Particle Image Velocimetry (PIV) procedure to estimate flow velocity and these estimates are subsequently refined using a particle tracking algorithm applied to each droplet. Specifically, for the PIV step we used a variable interrogation window with an initial size of 96×96 pixels and a final size of 48×48 pixels with an overlap of 75%. For particle tracking we used a correlation window of 64 pixels and particle size range of 2 to 100 pixels in order to cover the entire size range of visible droplets. The flow visualisation together with detailed particle tracking results are included in supplementary video.

Results and Discussion

The results of detailed particle tracking (in supplementary video) reveals that the maximum velocity of droplets expelled, specifically for certain syllables such as 'do', 'fa' and 'ti', is approx. 6 m/s, which is similar to the velocities reported for speaking [11]. Upon further examining the motion of droplets at a distance of 15 cm from the mouth, we observed that almost 90% of the droplets are moving at velocities less than 1 m/s (Figure 2a). The droplets moving with velocities greater than 1 m/s are moving in the direction between 120° – 240° (θ = 0° towards subject (Figure 1)) and move away from the mouth. Moreover, approx. 75% of droplets observed are moving at velocities less than 0.5 m/s and the motion is equally distributed in all the directions, which implies that they do not settle rapidly and may follow the ambient airflow pattern. These results points toward high aerosol generation, as the behaviour of these droplets is like airborne particles [12]. Nevertheless, to accurately quantify the size, future work using particle counters, is essential to better understand the dynamics of these droplets.

Figure 2b shows the distribution of droplet velocities obtained at 15 cm from the mouth for syllable 'fa' and the direction in which these droplets are moving. Approximately 50% of the droplets are moving at velocities less than 0.5 m/s and more than 75% are moving away from mouth (θ = 120° to 240°), which is also evident in the supplementary video. Figure 2c shows the velocity distribution of droplets that are visible while the subject was singing syllable 'sol' & 'la' and the direction in which these droplets are moving. It can be observed that all droplets are moving at velocities less than 0.5 m/s and are equally distributed in all directions. The direction in which these droplets are moving is important because it implies that for a normal choir configuration with multiple rows and heights, these droplets can pose a risk to those in the adjacent rows as well as to those in the distant rows.

Figure 2d and 2e shows the distribution for counting and coughing, respectively. In the case of coughing approximately 50% of the detected droplets were moving at velocities greater than 6 m/s whereas in case of speaking only 15% were moving at velocities greater than 6 m/s.

We note, the loudness measured during singing was within the range of 66 – 72 decibels. Further, it is also worth noting that some degree of variability is expected in the number of droplets expelled between different individuals, and due to other parameters, such as loudness, notes, consonants, and duration of each note sung. Nevertheless, the droplets observed do not appear to be settling down rapidly and without adequate ventilation, these droplets can potentially saturate the indoor environment which can likely explain the very high attack rates of COVID-19 seen in choirs in the US and Europe (almost 87% in Skagit County, Washington) [1].

We note the present study only provides visual evidence of the droplets and aerosols expelled during singing and compare the associated velocities and directions with speaking and coughing. However, these droplets have the capacity to potentially transmit viruses such as SARS-CoV-2. We only used a basic major scale for our experiments and during singing various other factors comes into play, such as pitch, rhythm, diction, etc. and it would be valuable to investigate all these aspects for future studies to have a better understanding of droplet and aerosol generation while singing. Nonetheless, the data presented combined with high infection rate among the choir members (60 – 90%) [1] points towards the possibility of airborne spread of COVID-19 during singing events, hence, should be considered when designing safety guidelines for public singing events.

These findings could inform safety guidelines for restarting choirs during and after the COVID-19 pandemic and other similar respiratory infection outbreaks. For example, rehearsals could be done with fewer people, greater physical distancing between singers, or face coverings and masks to reduce droplet and aerosol expulsion [13]. In addition to that either well ventilated large spaces or outdoor performances should be utilised to minimize the risk of infection.

Acknowledgements

Funding

This research was supported by NHMRC Centre for Research Excellence (Grant Number 1107393), Integrated Systems for Epidemic Response. C. R. MacIntyre is supported by a NHMRC Principal Research Fellowship, grant number 1137582.

None of the authors has any potential conflicts to disclose.

References

1. Hamner L, Dubbel P, Capron I, et al. High SARS-CoV-2 Attack Rate Following Exposure at a Choir Practice — Skagit County, Washington, March 2020. MMWR **2020**; 69:606–610.

2. Asadi S, Wexler AS, Cappa CD, Barreda S, Bouvier NM, Ristenpart WD. Aerosol emission and superemission during human speech increase with voice loudness. Sci Rep **2019**; 9.

3. Morawska L, Afshari A, Bae GN, et al. Indoor aerosols: from personal exposure to risk assessment. Indoor Air **2013**; 23:462–487. Available at: http://doi.wiley.com/10.1111/ina.12044.

4. Colborne F. German choirs silenced as singing branded virus risk. 2020. Available at: https://au.news.yahoo.com/german-choirs-silenced-singing-branded-virus-risk-025930646--spt.html%0D. Accessed 25 June 2020.

5. Lebrecht N. Concertgebouw chorus is devastated after pre-Covid Bach Passion. 2020. Available at: https://slippedisc.com/2020/05/concertgebouw-chorus-is-devastated-after-pre-covid-bach-passion/. Accessed 25 June 2020.

6. Porterfield C. Church-Related Coronavirus Outbreaks Reported As Trump Pushes For Reopening. 2020. Available at: https://www.forbes.com/sites/carlieporterfield/2020/05/23/church-related-coronavirus-outbreaks-reported-as-trump-pushes-for-reopening/. Accessed 20 June 2020.

7. WHO. Modes of transmission of virus causing COVID-19 : implications for IPC precaution recommendations. Sci Br **2020**; :1–3.

8. Bahl P, Doolan C, de Silva C, Chughtai AA, Bourouiba L, MacIntyre CR. Airborne or Droplet Precautions for Health Workers Treating Coronavirus Disease 2019? J Infect Dis **2020**; Available at: https://academic.oup.com/jid/advance-article/doi/10.1093/infdis/jiaa189/5820886.

9. Bahl P, de Silva CM, Chughtai AA, MacIntyre CR, Doolan C. An experimental framework to capture the flow dynamics of droplets expelled by a sneeze. Exp Fluids **2020**; 61:176. Available at: http://link.springer.com/10.1007/s00348-020-03008-3.

10. Cowen EA, Monismith SG, Cowen EA, Monismith SG. A hybrid digital particle tracking velocimetry technique. Exp Fluids **1997**; 22:199–211. Available at: http://link.springer.com/10.1007/s003480050038.

11. Chao CYH, Wan MP, Morawska L, et al. Characterization of expiration air jets and droplet size distributions immediately at the mouth opening. J Aerosol Sci **2009**; 40:122–133.

12. Hinds WC. Aerosol technology: properties, behavior, and measurement of airborne particles. John Wiley & Sons, 2012.

13. Bahl P, Bhattacharjee S, de Silva C, Chughtai AA, Doolan C, MacIntyre CR. Face coverings and mask to minimise droplet dispersion and aerosolisation: a video case study. Thorax **2020**; :thoraxjnl-2020-215748. Available at: http://thorax.bmj.com/lookup/doi/10.1136/thoraxjnl-2020-215748.

Figure Legends:

Figure 1: *Schematic of the setup to capture the droplets expelled during singing.*

Figure 2: a*. – Probability density function (PDF) of droplet velocities and direction of droplets measured at 15 cm from the mouth of the subject while singing a full major scale.* ***b****. – PDF of droplet velocities and direction of droplets measured at 15 cm from the mouth of the subject while singing syllable 'fa'.* ***c****. – PDF of droplet velocities and direction of droplets measured at 15 cm from the mouth of the subject while singing syllables 'sol' and 'la'.* ***d****. – PDF of droplet velocities and direction of droplets measured at 15 cm from the mouth of the subject while counting from 1 to 10.* ***e****. –PDF of droplet velocities and direction of droplets measured at 15 cm from the mouth of the subject while coughing.*

Figure_1

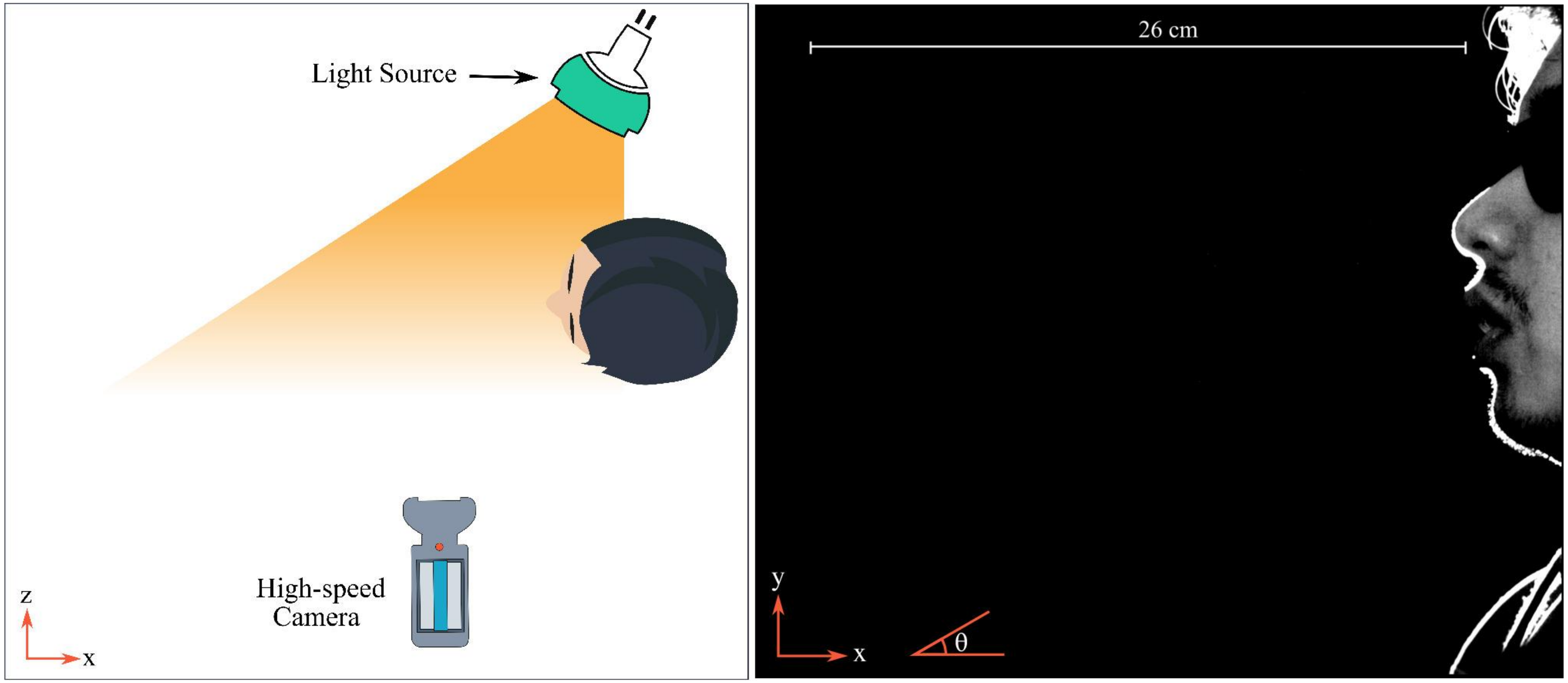

Figure_2