Acta Acustica 2022, **6**, 50
© The Author(s), Published by EDP Sciences, 2022
https://doi.org/10.1051/aacus/2022044

Available online at:
https://acta-acustica.edpsciences.org

SCIENTIFIC ARTICLE

OPEN ACCESS

Acoustic analysis of professional singing masks

Bogac Tur[1,*], Matthias Echternach[2], Stefan Turowski[3], Meinard Müller[3], Marie Köberlein[2], Michael Döllinger[1], and Stefan Kniesburges[1]

[1] Division of Phoniatrics and Pediatric Audiology, Department of Otorhinolaryngology, Head & Neck Surgery, University Hospital Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91054, Germany
[2] Division of Phoniatrics and Pediatric Audiology, Department of Otorhinolaryngology, Munich University Hospital, Ludwig-Maximilian-Universität Munich, Munich 81377, Germany
[3] International Audio Laboratories Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen 91058, Germany

Received 4 May 2022, Accepted 6 October 2022

Abstract – Wearing face coverings became one essential tool in order to prohibit virus transmission during the COVID-19 pandemic. In comparison to speaking and breathing, singing emits a much higher amount of aerosol particles. Therefore, there are situations in which singers can perform or rehearse only if they are using protective masks. However, such masks have a more or less adverse effect not only on the singer's comfort and tightness of the mask but also on the radiated sound. For this reason, the spectral filtering and directivity of masks designed specifically for professional singing was measured. The tests were performed with a head phantom. Over most of the spectrum, attenuation is observed, although amplification happens at some low frequency bands for different mask types and directions. Especially singing masks with a plastic face shield showed partial amplification of up to +10 dB below a frequency of 2 kHz, while only slight significant attenuation and no amplification (minimal acoustic loss) were seen for woven fabric masks. Above 2.5 kHz, the transparent masks showed the greatest sound attenuation up to −30 dB, while woven fabric masks produced an overall lower sound attenuation of up to −5 dB. In addition at low frequencies, the sound was amplified or attenuated equally in all directions for masks with a stiff plastic face shield. At higher frequencies, the attenuation is higher to the frontal than to the backward direction.

Keywords: Professional singing masks, Acoustic analysis, COVID-19 pandemic, Sound modulation, Radiation directivity

1 Introduction

During the COVID-19 pandemic, many leisure and cultural activities were banned or allowed only under strict hygiene measures. Professional singing and singing in churches and choirs were restricted because, in contrast to speaking and breathing, singing produces a much higher emission of aerosol particles [1–5]. This resulted in internationally observed super-spreading events as described in [6–8]. Medical and non-medical face coverings have been shown to be an important protection tool to reduce or avoid person-to-person transmission of the SARS-CoV-2 virus, and can reduce both the spreading distance of airborne particle emission and the number of virus-laden particles in the air [9–11].

An important issue when wearing face coverings is the acoustic impact on speech intelligibility and the acoustic effects on speaking and singing. Llamas et al. [12] showed that speech intelligibility problems are mainly caused by the reduction of visual information and/or by the interference with speech articulation. Further studies also showed that transparent face coverings with a face shield exhibit higher attenuation than woven fabric masks above a frequency of 2–3 kHz and especially amplify sound at low and medium frequencies [13, 14]. But, wearing medical or community mask types during professional or layman singing not only changes the acoustic singing signal [15–19], it also leads to significant aerosol leakage due to increased articulation [10, 11, 20, 21] and causes a dry mouth [12]. To counteract all the mentioned problems, different masks specifically designed for singing have been developed. In a previous study on aerosol dispersion, five professional singing masks were investigate and showed significantly reduced frontal dispersion distances of emitted aerosol particles [22]. Thus, the aim of this study is to investigate the acoustic properties of these professional singing masks.

*Corresponding author: bogac.tur@uk-erlangen.de

Figure 1. Five singeing masks in front and side view, worn by a KEMAR head for acoustic evaluation.

2 Materials and methods

2.1 Singing masks

Five specially designed singing masks, as shown in Figure 1, were analyzed to determine their influence on the sound spectrum. The main difference of all singing masks studied here is that they exhibit a larger volume between the mask and the singer's face to enable the commonly large articulation motion of the mouth and face during professional singing while still providing a tight fit to singer's face. These masks were investigated with the focus on the aerosol dispersion in a previous study [22].

The Jazzchor-Dresden-Singmaske [23] ("Dresden Mask") consists of a 30 × 60 cm, 255 g/m^2 cotton fabric. On the sides, two rubber bands are sewn in, which create a bag-like mask that allows few restrictions on the movements of the mouth. In addition, there is also a metal wire on the top that can be adjusted to fit the nose contour. The mask is tied with two straps in the back of head and neck.

The Broadway Mask [24] is made of three layers with a total weight of 135 g/m^2. The inner and outer layers are made of a medium-weight cotton muslin with 120 threads. Between these two layers, there is a non-woven 100% polyester layer. At the nose part there is a metal bracket that can be adjusted to the shape of the nose. The mask is attached to the ears with two elastic straps and tightened. Special features of the mask are small windows cut out of the polyester layer near the upper cheek to allow a better air flow. At this position there are two layers instead of three.

The Insono Mask ("Heidelberg Mask") consists of two layers of 6% elastane and has a weight of 75 g/m^2. Between the two elastane layers, there is space for an optional filler layer which was not inserted during the tests. The mask is fixed behind the ears with two metal brackets.

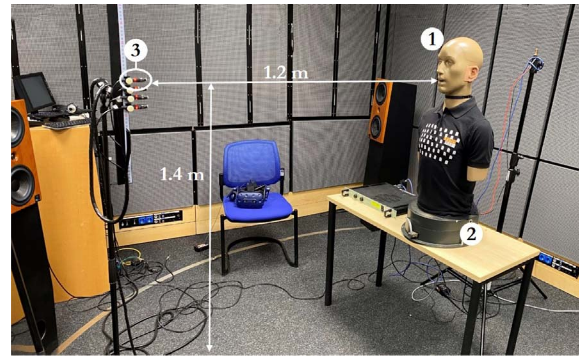

Figure 2. Measurement setup with the KEMAR head (1), the turntable system (2) and a microphone array (3) using exclusively the top microphone in this study.

The Japan Mask [25] consists of two parts: a cotton molton bandana with a weight of 200 g/m^2 and a transparent sewn-in layer 100% made of polyurethane. This polyurethane layer covers the mouth–nose area, whereas the cotton fabric covers the neck and chest area and is tied at the nape of the neck.

The SannaShield Mask ("Qatar Mask") consists of a face shield covered by a 100% cotton fabric. The classical face shield is made of polyethylene terephthalate (PET) and has the dimensions of 33 × 22 cm. On the top of the face shield, there is a foam for a tight and comfortable fit at the forehead. The face shield is clamped between the two-layer cotton fabric. The mask is fixed with an elastic band at the back of the head and with two adjustable cords at the neck and below the chin.

For all masks, we carefully checked the tight fit to the face of the phantom head to avoid sound effects due to leakages [30].

2.2 Experimental setup with head phantom

The experimental setup is shown in Figure 2. The acoustic measurements were carried out in an ITU P.800 standardized sound laboratory of the International Audio Laboratories Erlangen exhibiting a small reverberation time of about 0.23 s. Thus, the influence by sound reflection is estimated to be of negligible magnitude. A KEMAR 45BM (GRAS Sound & Vibration, Holte, Denmark) with an integrated 44AB mouth simulator (GRAS Sound & Vibration, Holte, Denmark) was used for sound generation. The sound signals were recorded with an AKG CK 31 condenser microphone capsule (Harman Deutschland GmbH, Munich, Germany) with cardioid polar pattern. The microphone was placed at a distance of 1.2 m from the KEMAR head at elevation $\psi = 0°$ for all measurements. With one fixed microphone position, 37 measurements were performed for azimuth angles φ between $-180°$ and $180°$ with a step size of 10° by turning the phantom head with a B&K 9640 turntable system (Brüel & Kjær, Nærum, Denmark). Thereby, the sound emission of both configurations with and without a mask were detected for each angular position of the phantom head. The total height mouth of the KEMAR head and the microphone above the ground was

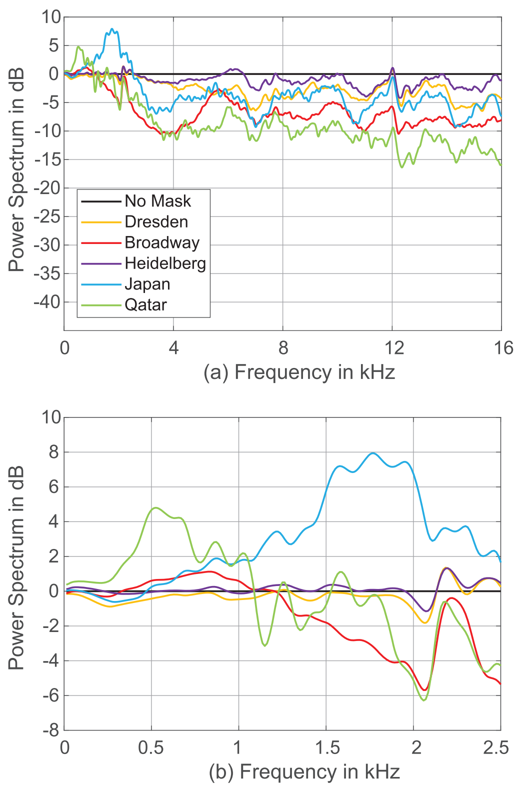

Figure 3. (a) Power spectrum of the singing masks averaged over azimuth angle φ in dB as function of the frequency from 50 Hz to 16 kHz in reference to task without a mask using white Gaussian noise as sound signal. (b) Enlarged representation in the range between 500 Hz and 2.5 kHz.

approximately 1.4 m. White Gaussian noise and a linear sinus sweep were used as input signals with a frequency bandwidth between 50 Hz and 24 kHz during the measurements. The sampling duration was 6 s with a sampling frequency of 48 kHz and a 24 Bit resolution.

2.3 Data analysis

All audio signals were analyzed in the frequency domain by calculating the power spectral density (PSD) [26, 27] with a frequency resolution bandwidth of 100 Hz by using a Kaiser window type [28] and a window length of 480 samples resp. 0.01 s. These specifications were found to be the best trade-off regarding readability of the spectra. Similar specifications were also applied in [13, 14, 17]. The sound attenuation of the respective mask was finally calculated by relating the PSD of the audio signal for the KEMAR head with mask to the PSD of the reference audio signal for the KEMAR head without mask obtained from the loudspeaker in the KEMAR phantom head. This means that the audio signal influenced by a mask was normalized to the measured audio signal without a mask as commonly done in other studies [13–15]. Both the generation of audio signal emitted by the KEMAR head and the subsequent data analysis were performed in MATLAB (The Math Works Inc., Natick, MA).

3. Results and dicussion

3.1 Mask modulation with head phantom

For each mask, a white Gaussian noise and a linear sinus sweep were emitted by the KEMAR head. The difference between the two signals was determined over all angles ($-180°$ to $+180°$), frequencies (50 Hz to 24 kHz) and masks. Based on the root mean square error the difference between the two signals was $+0.5$ dB. In addition, there were no non-linear effects in the spectra of sweep audio signals that were produced by the interaction with masks, i.e. higher harmonic or other discrete tones. Therefore, the following results represent the results for the white Gaussian noise emission. Figure 3a shows the acoustic effects of the singing masks in reference to the synthetic sound signal averaged over the total azimuth angle φ.

The results show that all masks attenuated the synthetic sound signal in a frequency range between 2.5 kHz and 16 kHz. The attenuation is thereby highly frequency dependent ranging between 0 dB and -5 dB for the Heidelberg mask and up to -17.5 dB for the Qatar mask. A similar sound attenuation of woven fabric masks (i.e. community masks) was observed in other studies [13–19, 29, 30].

Attenuation in the sound spectrum above 2.5 kHz might affect the singer's formant cluster, the perceived individual voice timbre and sound brilliance and the second formant of the vowel [i:]. The singer's formant is an energy peak in the sound spectrum of mainly male singers and low female voices which helps to make the voice seem louder, for example when singing solo against a whole orchestra [31].

Furthermore, attenuation might lead to poor self-perception of the singers which they might try to compensate by increasing their vocal intensity potentially resulting in vocal fatigue [32]. However, singers can learn to resist this effect.

In contrast to purely woven fabric masks, masks with included transparent parts in front of the face made of plastic sheets additionally amplify the synthetic sound signal at lower frequencies as shown in Figure 3b. The Qatar mask reaches a maximum gain of $+4.7$ dB at a frequency of 500 Hz and the Japan mask a maximum of $+7.9$ dB at 1.8 kHz. Those amplification effects of masks with integrated transparent plastic materials were similarly reported by Atcherson et al. [13], Fabry et al. [14], Oren et al. [15] and Corey et al. [17]. Amplification in the range of ca. 500–1000 Hz would match especially the fundamental frequencies of soprano voices and could support their strategy of formant tuning, i.e., an amplification of the fundamental frequency by vocal tract resonances [33].

3.2 Masks modulation based on the radiation directivity

Both effects, attenuation and amplification are additionally directional dependent as shown in Figure 4 for the three woven fabric masks (Broadway, Dresden, Heidelberg) and for the transparent sheet masks in Figures 5 and 6 (Japan, Qatar). Further polar plots at other frequencies are shown in the Supplementary material. Both close-meshed, multi-layered woven fabric masks of type Dresden and Broadway

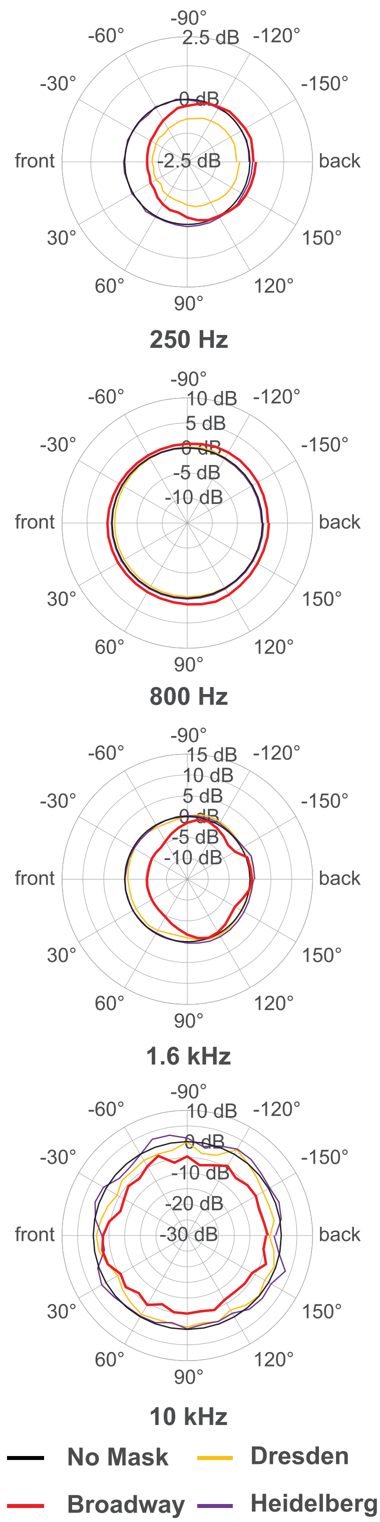

Figure 4. Polar plots of the sound radiation for the community masks Dresden, Broadway and Heidelberg normalized by the sound without (no) masks for specific frequencies (250 Hz, 800 Hz, 1.6 kHz and 10 kHz). Front indicates the position of the KEMAR head with the mouth pointing at the microphone, back indicates the back of the head pointing towards the microphone.

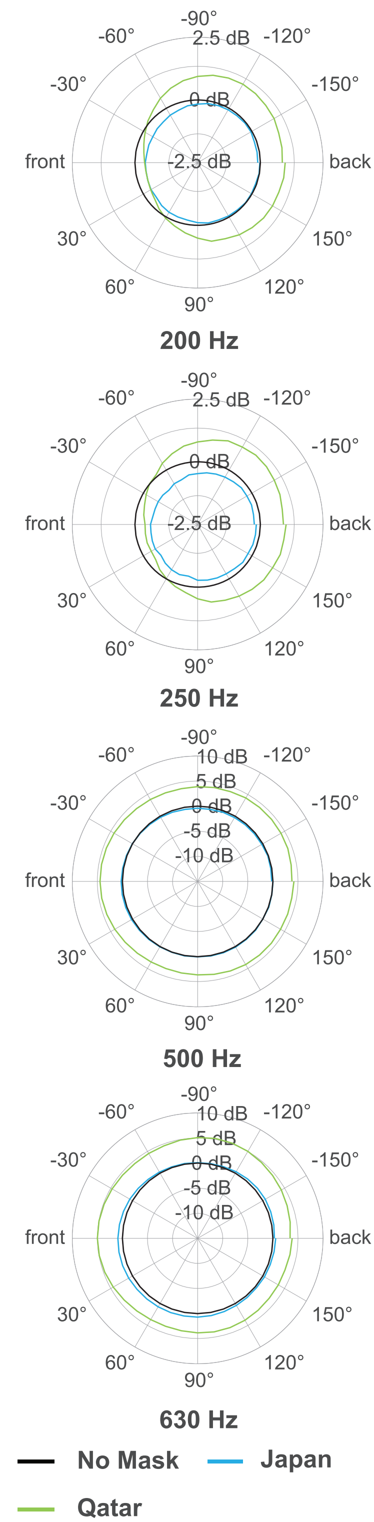

Figure 5. Polar plots of the sound radiation for the transparent masks Japan and Qatar normalized by the sound without (no) masks for specific frequencies (200 Hz, 250 Hz, 500 Hz and 630 Hz). Front indicates the position of the KEMAR head with the mouth pointing at the microphone, back indicates the back of the head pointing towards the microphone.

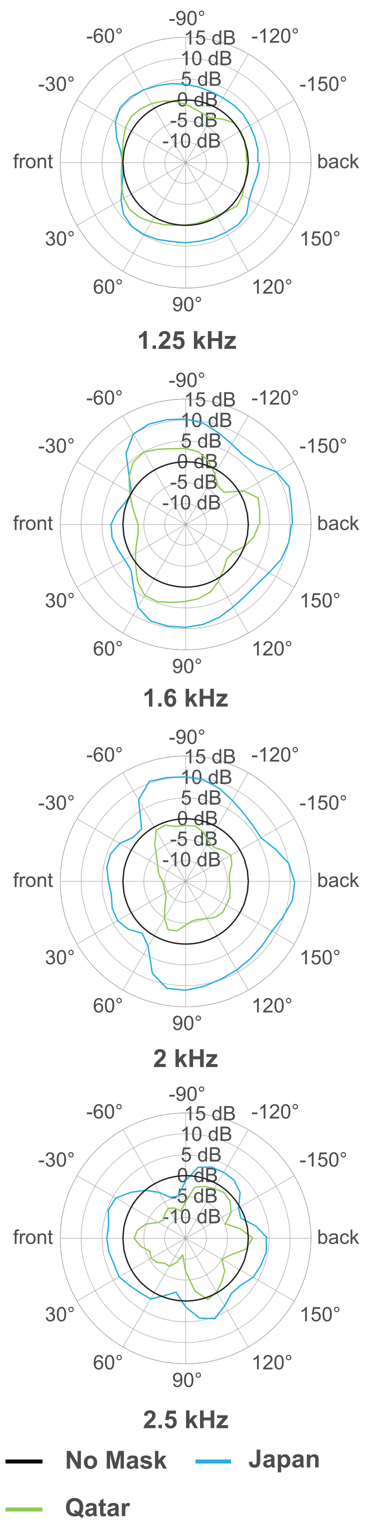

Figure 6. Polar plots of the sound radiation for the transparent masks Japan and Qatar normalized by the sound without (no) masks for specific frequencies (1.25 kHz, 1.6 kHz, 2 kHz and 2.5 kHz). Front indicates the position of the KEMAR head with the mouth pointing at the microphone, back indicates the back of the head pointing towards the microphone.

generated the largest attenuation in frontal direction, mostly pronounced in the lower frequency range as shown at 250 Hz and 1.6 kHz. In contrast, the Heidelberg mask showed only weak sound attenuation potentially owing to the wide-meshed woven fabric material the mask is made of.

The sound radiation characteristics shown in Figures 5 and 6 of the Japan and Qatar mask are highly directional with distinct attenuation and amplification effects. For the Japan mask, the sound is attenuated mainly in frontal direction for lower frequencies (200 Hz and 250 Hz) and hardly influenced for middle range frequencies (500 Hz and 630 Hz). In contrast, the Qatar mask with its included face shield produces an attenuation to the front in combination with backward amplification at lower frequencies (200 Hz and 250 Hz) and an omni-directional amplification at higher frequencies (500 Hz and 630 Hz).

At higher frequencies, the Qatar mask shows less amplification, whereas the attenuation increases with specific directional patterns. Accordingly, the Japan mask also produces a high directionality of the sound radiation with distinctive regions of attenuation and amplification in this frequency range.

It is assumed that these amplification effects are generated by the transparent plastic sheets included in these mask types caused by small excitation effects for the amplification in the frontal direction and by reflection the inside the mask for the amplification in the backward direction. Similar effects have been observed by Atcherson et al. [13] and Corey et al. [17] who found a significant amplification in backward direction by face shields in comparison to woven fabric masks. However, no amplification effects in the frontal direction had been observed so far. We assume that the amplification in frontal direction for these mask types are caused by a combination of reflection and resonance in the internal volume between the mask and the face.

Regarding the applicability of the singing masks in real singing situations, the professional singers reported that some of the singing masks still restricted the articulation motion of jaw and mouth during singing and impaired reflexive inhalation as reported by Echternach et al. [22]. Furthermore, the majority of the singers in the study also denied that these masks were suitable for official performances. In performances, the singers usually face the audience. Therefore an attenuation to the front and an amplification to the back is not suitable or preferable. In addition, amplification and attenuation are frequency dependent, probably resulting in sound distortions or imbalances for the audience. Such imbalances seem hardly to be compensated by the singers because in musical settings, i.e., melody and vowels, the frequency spectrum modulates continuously.

However, since not only performances with an audience were widely prohibited during the COVID-19 pandemic, but also rehearsals for any type of choir, these masks could be beneficial to enable rehearsing with reduced aerosol dispersion. Especially the Qatar and Japan masks were developed to provide a visible view of a singer's mouth during singing and speaking in a teaching situation. Additionally, Echternach et al. [22] reported that the masks increased the acoustical self-perception of the singers owing to the amplified backward radiation that certainly influences the singer's control of loudness and intonation. Both aspects of these two masks may be beneficial for singing classes as the teacher could inspect and improve the student's mouth dynamics and the student would get an increased acoustic feedback of his/her own voice during singing. On the other hand, it must be considered in each particular setting that a louder self-perception could unsettle inexperienced singers [34].

With the use of singing masks and consideration of acoustic effects and aerosol emission and dispersion, rehearsals may still become safer under certain additional conditions as, e.g., special ventilation strategies.

4 Summary and conclusion

In this work, the acoustic properties of professional singing masks were analyzed. For this purpose, five masks for professional singing were subjected to white Gaussian noise sound emission with the aid of a KEMAR phantom head in order to determine the sound modulation (attenuation and amplification) characteristics in relation to the audio signal without a mask. All masks showed frequency-dependent sound attenuation up to -17.5 dB. Additionally, masks with embedded transparent plastic sheets showed additional amplification effects for low and medium frequency ranges depending on the plastic sheet characteristic used. In addition, the mask types with a face shield show higher amplification in the back direction than in the front direction. Thus, the investigated professional singing masks highly influenced the sound signal, which may render the masks useless for official concert situations. However, an application in singing lessons might be conceivable to enable singing education during pandemics.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to this article.

Acknowledgments

The study was supported by the State of Bavaria, Ministry for Science and Arts. The International Audio Labratories Erlangen are a joint institution of the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and Fraunhofer Institute for Integrated Circuits IIS. We acknowledge financial support by Deutsche Forschungsgemeinschaft and Friedrich-Alexander-Universität Erlangen-Nürnberg within the funding programme "Open Access Publication Funding".

Supplementary material

The supplementary material of this article is available at https://acta-acustica.edpsciences.org/10.1051/aacus/2022044/olm.

References

1. M. Alsved, A. Matamis, R. Bohlin, M. Richter, P.-E. Bengtsson, C.-J. Fraenkel, P. Medstrand, J. Löndahl: Exhaled respiratory particles during singing and talking. Aerosol Science and Technology 54 (2020) 1245–1248.
2. S. Asadi, A.S. Wexler, C.D. Cappa, S. Barreda, N.M. Bouvier, W.D. Ristenpart: Effect of voicing and articulation manner on aerosol particle emission during human speech. PLoS One 15 (2020) e0227699.
3. F.K.A. Gregson, N.A. Watson, C.M. Orton, A.E. Haddrell, L.P. McCarthy, T.J.R. Finnie, N. Gent, G.C. Donaldson, P. L. Shah, J.D. Calder, B.R. Bzdek, D. Costello, J.P. Reid: Comparing aerosol concentrations and particle size distributions generated by singing, speaking and breathing. Aerosol Science and Technology 55 (2021) 681–691.
4. D. Mürbe, M. Kriegel, J. Lange, H. Rotheudt, M. Fleischer: Aerosol emission in professional singing of classical music. Scientific Reports 11 (2021) 14861.
5. D. Mürbe, M. Kriegel, J. Lange, L. Schumann, A. Hartmann, M. Fleischer: Aerosol emission of adolescents voices during speaking, singing and shouting, PLoS One 16 (2021) e0246819.
6. L. Hamner, P. Dubbel, I. Capron, A. Ross, A. Jordan, J. Lee, J. Lynn, A. Ball, S. Narwal, S. Russell, D. Patrick, H. Leibrand: High SARS-CoV-2 attack rate following exposure at a choir practice – Skagit County, Washington, March 2020. Morbidity and Mortality Weekly Report 69 (2020) 606–610.
7. M.S. Islam, K.M. Rahman, Y. Sun, M.O. Qureshi, I. Abdi, A. A. Chughtai, H. Seale: Current knowledge of COVID-19 and infection prevention and control strategies in healthcare settings: A global analysis. Infection Control & Hospital Epidemiology 41 (2020) 1196–1206.
8. K.A. Prather, C.C. Wang, R.T. Schooley: Reducing transmission of SARS-CoV-2. Science 368 (2020) 1422–1424.
9. M. Echternach, S. Gantner, G. Peters, C. Westphalen, T. Benthaus, B. Jakubaß, L. Kuranova, M. Döllinger, S. Kniesburges: Impulse dispersion of aerosols during singing and speaking: A potential COVID-19 transmission pathway. American Journal of Respiratory and Critical Care Medicine 202 (2020) 1584–1587.
10. S. Kniesburges, P. Schlegel, G. Peters, C. Westphalen, B. Jakubaß, R. Veltrup, A.M. Kist, M. Döllinger, S. Gantner, L. Kuranova, T. Benthaus, M. Semmler, M. Echternach: Effects of surgical masks on aerosol dispersion in professional singing. Journal of Exposure Science and Environmental Epidemiology 32 (2022) 727–734.
11. C. Westphalen, S. Kniesburges, R. Veltrup, S. Gantner, G. Peters, T. Benthaus, B. Jakubaß, M. Köberlein, M. Döllinger, M. Echternach: Sources of aerosol dispersion during singing and potential safety procedures for singers. Journal of Voice Foundation (2021). https://doi.org/10.1016/j.jvoice.2021.03.013.
12. C. Llamas, P. Harrison, D. Donnelly, D. Watt: Effects of different types of face coverings on speech acoustics and intelligibility. York Papers in Linguistics 2 (2009) 80–104.
13. S.R. Atcherson, B.R. McDowell, M.P. Howard: Acoustic effects of non-transparent and transparent face coverings.

Journal of the Acoustical Society of America 149 (2021) 2249.
14. D. Fabry, T. Burns, M. McKinney, A. Bhowmik: Unmasking' benefits for hearing aid users in challeging listening environments. Hearing Review 27 (2020) 18–20.
15. L. Oren, M. Rollins, E. Gutmark, R. Howell: How face masks affect acoustic and auditory perceptual characteristics of the singing voice. Journal of Voice (2021). https://doi.org/10.1016/j.jvoice.2021.02.028.
16. B.T. Balamurali, T. Enyi, C.J. Clarke, S.Y. Harn, J.-M. Chen: Acoustic effect of face mask design and material choice. Acoustics Australia 49 (2021) 1–8.
17. R.M. Corey, U. Jones, A.C. Singer: Acoustic effects of medical, cloth, and transparent face masks on speech signals. Journal of the Acoustical Society of America 148 (2020) 2371.
18. M. Magee, C. Lewis, G. Noffs, H. Reece, J.C.S. Chan, C.J. Zaga, C. Paynter, O. Birchall, S. Rojas Azocar, A. Ediriweera, K. Kenyon, M.W. Caverlé, B.G. Schultz, A.P. Vogel: Effects of face masks on acoustic analysis and speech perception: Implications for peri-pandemic protocols. Journal of the Acoustical Society of America 148 (2020) 3562.
19. C. Pörschmann, T. Lübeck, J.M. Arend: Impact of face masks on voice radiation. Journal of the Acoustical Society of America 148 (2020) 3663.
20. M. Echternach, F. Burk, M. Burdumy, L. Traser, B. Richter: Morphometric differences of vocal tract articulators in different loudness conditions in singing. PLoS One 11 (2016) e0153792.
21. L. Hermann, B. Tur, M. Köberlein, S. Gantner, C. Westphalen, T. Benthaus, M. Döllinger, M. Echternach, S. Kniesburges: Aerosol dispersion during different phonatory tasks in amateur singers. Journal of Voice (2022). https://doi.org/10.1016/j.jvoice.2021.11.005.
22. M. Echternach, L. Hermann, S. Gantner, B. Tur, G. Peters, C. Westphalen, T. Benthaus, M. Köberlein, L. Kuranova, M. Döllinger, S. Kniesburges: The effect of singers' masks on the impulse dispersion of aerosols during singing. Jorunal of Voice (2021).
23. J. Morgenstern, J. Morgenstern: Die Masked-Singers: Singen mit Sicherheit und Stil – Die Jazzchor Dresden Chormaske. Accessed November 15, 2021. https://jazzchor-dresden.de/the-masked-singers.
24. Broadway Relief Project. Accessed November 15, 2021. https://www.broadwayreliefproject.com/singersmask.
25. The Asahi Shimbun: New face shield for concert singers nothing to sneeze at. Accessed April 26, 2022. https://www.asahi.com/ajw/articles/13569468.
26. F.J. Harris: On the use of windows for harmonic analysis with the discrete Fourier transform. Proceedings of the IEEE 66 (1978) 51–83.
27. P. Welch: The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms. IEEE Transactions on Audio and Electroacoustics 15 (1967) 70–73.
28. Digital Signal Processing Committee of the IEEE Acoustics, Speech, and Signal Processing Society, Eds.: Selected papers in digital signal processing, vol. II. New York: IEEE Press, 1976.
29. A. Goldin, B. Weinstein, N. Shiman: How do medical masks degrade speech reception? Hearing Review 27 (2020) 8–9.
30. T.J. Cox, G. Dodgson, L. Harris, E. Perugia, M.A. Stone, M. Walsh: Improving the measurement and acoustic performance of transparent face masks and shields. Journal of the Acoustical Society of America 151 (2022) 2931–2944. https://doi.org/10.1121/10.0010384.
31. I.R. Titze: Principles of voice production. Prentice Hall, University of Michigan, 1994.
32. S. Tonkinson: The Lombard effect in choral singing. Jorunal of Voice 8, 1 (1994) 24–29.
33. R.R. Vos, D.T. Murphy, D.M. Howard, H. Daffern: The perception of formant tuning in soprano voices. Jorunal of Voice 32, 1 (2018) 126.e1–126.e10.
34. H. Jers, The impact of location on the singing voice, in: G.F. Welch, D.M. Howard, J. Nix, Eds. The Oxford handbook of singing, New York: Oxford University Press, 2014, pp. 241–253.

Cite this article as: Tur B Echternach M Turowski S Müller M Köberlein M, et al. 2022. Acoustic analysis of professional singing masks. Acta Acustica, **6**, 50.