Risk assessment of the spread of breathing air from wind instruments and singers during the COVID-19 pandemic

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Note from the authors:

The following assessment refers to playing wind instruments (both woodwind and brass) and singing. Using the schlieren method presented in the following, the spreading of the breathing air, which could contain infectious aerosols, is made visible. The actual dispersion of aerosols is not recorded. Therefore, the evaluations can only be used to determine how far and to which extent the exhaled air is transported directly into the room. Additionally, it should be noted that each musician has developed his or her own blowing technique in addition to his or her individual physical characteristics. Furthermore, the angle at which the instrument is played must be taken into account in order to estimate the direction in which the air escapes from the bell and the tone holes and when exhaling between phrases (e.g. oboe, bassoon). The illustrations and explanations shown below are only a rough guideline for how far and in which direction the air escapes from the instrument. In addition to the images shown in this report, we would like to refer to the accompanying video of the recordings in front of the schlieren mirror at https://vimeo.com/431505952.

The removal of condensation water is not considered in the following. Here, reference is made to further studies or assessments by Willich et al. (2020), Spahn and Richter (2020), and Kaehler and Hain (2020).

Furthermore, the general hygienic regulations (disinfection, ventilation, etc.) should be observed in any case to minimize possible infection risks both inside and outside the sample room.

Schlieren imaging

Figure 1 Experimental setup of the schlieren imaging system at the chair of Building Physics at the Bauhaus University Weimar, Germany

As an optical, non-invasive technique, the schlieren[1] method allows visualizing density differences in transparent media (e.g. air). These density gradients are based on differences in temperature or pressure; they cause differences in the refractive index of the fluid. Due to the refractive index gradients, the light that passes the measuring field is deflected to the extent of the gradient. The experimental setup is shown in Figure 1. It consists of a concave mirror of astronomical quality with a diameter of 1 m, a camera that captures the measuring field, a knife edge, and a light source (LED).

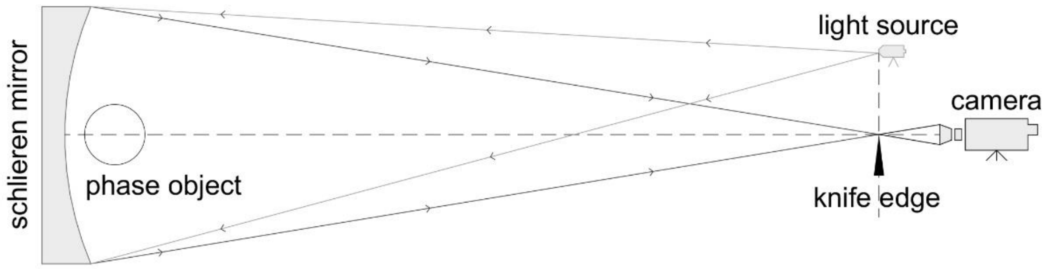

Figure 2 Schematic setup of the schlieren imaging system

The light rays from a point light source are reflected at the schlieren mirror and directed to the knife edge (in this case a conventional razor blade), which is mounted in front of the camera (Figure 2). Differences in the density of the fluid lead to refractive index gradients, which cause the light rays to deflect. The knife edge is brought into the focus of the camera to obstruct about 50 % of the light rays. Accordingly, the camera cannot capture these rays and creates dark areas. The light rays that are bend above the knife edge are detected from the camera, creating bright areas. Due to these differences in brightness, the difference in density and thus the air flow is visible (Gena et al. 2020).

The breathing air that escapes from the instruments has a higher temperature or humidity (or both) than the surrounding air. This applies even more for playing over a long period of time since the instruments warm up while playing. This allows visualizing the air escaping from the instruments using the schlieren

[1] *Schlieren* (German) describe disturbances in inhomogeneous transparent media. They appear as relatively small diffraction differences and deflect light rays in any direction other than the direction *z* of the medium (Settles 2001).

imaging system. Nevertheless, it was found that especially longer instruments with wide bores can cool the breathing air to the extent that it could not be visualized using the schlieren method (e.g. F tuba).

The streaks, which can be seen in the figures above parts of the human body such as the hands, head, or torso, are due to the human heat emission and are negligible in considering the spread of potentially infectious respiratory air. The air that escapes from the instruments is defined by lower volume flows and density gradients and, therefore, sometimes is only visible when looking closer at the images.

Regarding some instruments such as the bassoon, the Bb clarinet, the traverse and piccolo flute, the horn with a stopping mute, and singing, it can be seen that the air stream is transported further into the room than the mirror can detect. To capture these air flows completely, the background-oriented schlieren (BOS) method could be used in further investigations (Becher et al. 2020). Compared to the schlieren imaging system, the BOS method allows for spatially unlimited recording of the object of interest.

Woodwind instruments

In the case of woodwind instruments, in addition to the breathing air coming out of the bell, the air escaping from the tone holes and the air blown above the mouthpiece in the case of traverse flutes as well as the air coming out of the window in the case of recorders must also be taken into account.

Oboe

The tone holes of the oboe are covered with keys that have small holes from which a small amount of air can escape. Because of the small range, the air escaping from the tone holes is negligible. When playing at higher pitches, it can be seen that the air escapes in a smaller range than playing at lower pitches where most of the tone holes are covered (Figure 3 left and center).

The oboe is played with a high breath pressure. The air that is blown into the instrument cannot escape completely from the bell and the tone holes. Thus, the oboe player has to exhale intermittently between phrases. The air spreads around 60 cm into the room (Figure 3 right).

Figure 3 Oboe in front of the schlieren mirror: maximal range of the air escaping from the bell while playing the note Bb3 ≈ 233 Hz (left), note D6 ≈ 1175 Hz (center) and while intermittently exhaling (right) [cm] (cf. Richter et al. (2020))

Bassoon

When playing the bassoon at lower pitches, nearly all the air escapes from the instrument's bell and escapes over the edge of the schlieren mirror (Figure 4 left). At high pitches, however, hardly any air escapes from the bell. A smaller jet of air flow can be observed from the tone holes (Figure 4 center). The largest air flow escaping from the tone holes can be seen when playing the note F3 ≈ 175 Hz (Figure 4 right).

Similar to the oboe, the bassoon is played with a high breath pressure. The air blown into the instrument cannot escape completely from the bell and the tone holes. Between phrases, the air is exhaled intermittently and spreads around 80 cm into the room.

Figure 4 Bassoon in front of the schlieren mirror: maximal range of the air escaping from the bell while playing the note Bb1 ≈ 58 Hz (left) and the air escaping from the tone holes while playing the note C5 ≈ 523 Hz (center) and note F3 ≈ 175 Hz (right) [cm]

Bb clarinet and bass clarinet

When playing low notes, the air that escapes from the bell reaches around 20 cm into the room. When playing high notes, the air escapes over the edge of the schlieren mirror (Figure 5 left and center). At the tone holes, which are covered with keys, a small jet of air flow can be seen. Due to the small range, this is negligible. However, the air leak above the mouthpiece when the lips of the clarinet player tire has to be taken into consideration (Figure 5 right). This is typically not seen during physiologically "correct" playing, but it can be observed with untrained players (e.g. beginners and older clarinet players), especially during long rehearsals and concerts. The air spreads more than 90 cm into the room and escapes over the edge of the mirror.

Figure 5 Bb clarinet in front of the schlieren mirror: maximal range of the air escaping from the bell while playing the note C#3 ≈ 139 Hz (left), note E6 ≈ 1319 Hz (center) and the air leaking at the mouthpiece (right) [cm]

Figure 6 *Bass clarinet in front of the schlieren mirror while playing the note D2 ≈ 73 Hz (left), note Bb4 ≈ 466 Hz (center) and the maximal range of the air escaping from the bell (right) [cm]*

Traverse flute and piccolo flute

The air escaping from the traverse flute and the piccolo flute is similar. When playing the instruments, a similarly large blast of air escapes from the end of the flute with a range of less than 20 cm (Figure 7 and 8 left and center). Near the tone holes, which are covered with keys, hardly any escaping air can be observed. However, a large amount of breathing air is blown above the mouthpiece (Figure 7 and 8 right). The air is slightly directed downwards since it is blown downwards into or above the instrument and because of the Coandâ effect. Here, the air spreads over 100 cm and escapes over the edge of the mirror.

Figure 7 *Traverse flute in front of the schlieren mirror: maximal range of the air escaping from the foot joint while playing the note E4 ≈ 330 Hz (left), note F6 ≈ 1397 Hz (center) and the air blown above the mouthpiece (right) [cm]*

Figure 8 *Piccolo flute in front of the schlieren mirror: maximal range of the air escaping from the foot joint while playing the note E5 ≈ 659 Hz (left), note G#7 ≈ 3322 Hz (center) and the air blown above the mouthpiece (right) [cm]*

Soprano recorder

Usually, the beak of the recorder is completely covered with the lips of the musician. Therefore, no air can escape directly at the mouthpiece. If the instrument is played at lower pitches, most of the tone holes are covered and most of the breathing air escapes from the foot joint (Figure 9 left). At higher pitches, in which many tone holes are open and allowing the air to easily escape, less air spread can be seen at the bell (Figure 9 center). A larger amount of breathing air is cut at the labium of the head joint and escapes from the window (Figure 9 right). Near the tone holes, hardly any air flow can be observed.

Figure 9 Soprano recorder in front of the schlieren mirror: maximal range of the air escaping from the bell while playing the note C5 ≈ 523 Hz (left), note G6 ≈ 1568 Hz (center) and the air escaping from the window (right) [cm]

Brass instruments

The breathing air blown into the mouthpiece flows through the instrument and escapes from the bell. With professional brass players, no air escapes between the mouth and the mouthpiece. Therefore, the complete breathing air escapes from the bell. The various natural tones of a brass instrument can be played by varying the pressure of the lips and the breathing air. This affects the range and angle at which the air exits the bell. If dampers are used, the air flow escaping from the bell is significantly restricted. Here, the air can only escape through the narrow gap between the brass of the instrument and the damper. The range of the emitted air is reduced.

Bb trumpet

The pitch of the played note affects how far and at which angle the air escapes from the bell. It can be seen that at higher pitches the air is transported further into the room than at lower pitches (Figure 10). If dampers are used, the air flow escaping from the bell is remarkably restricted (Figure 11).

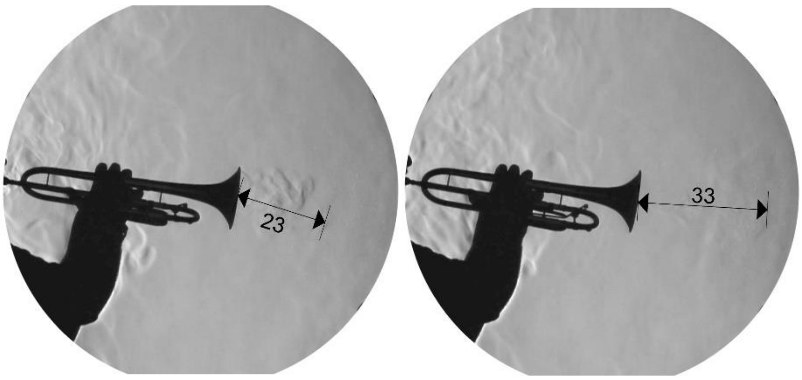

Figure 10 Bb trumpet in front of the schlieren mirror: maximal range of the air escaping from the bell while playing the note Bb3 ≈ 233 Hz (left) and note Bb5 ≈ 932 Hz (right) [cm]

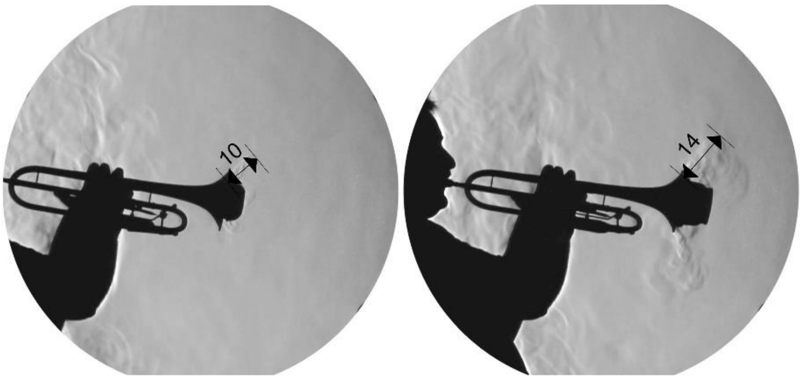

Figure 11 *Maximal range of the air escaping from the bell with straight mute (left) and cup mute (right) [cm]*

Tenor trombone

The pitch of the played note affects how far and at which angle the air escapes from the bell (Figure 12 left and center). It should also be noted that the escaping air is swirled when the position of the trombone slide is changed. More air escapes from the bell when playing at low pitches than playing at high pitches. However, if not only single notes but a phrase is played, the differences are hard to see because of the turbulence caused by moving the slide. If dampers are used, the air flow escaping from the bell is significantly restricted (Figure 13).

Figure 12 *Tenor trombone in front of the schlieren mirror while playing the note Bb1 ≈ 58 Hz (left), note Bb3 ≈ 233 Hz (center) and the maximal range of the air escaping from the bell (right) [cm]*

Figure 13 *Maximal range of the air escaping from the bell with damper [cm]*

Double horn

The horn is usually played with the right hand holding the bell from the inside. When playing at higher pitches, the air escapes further into the room compared to playing at lower pitches (Figure 14 left and center).

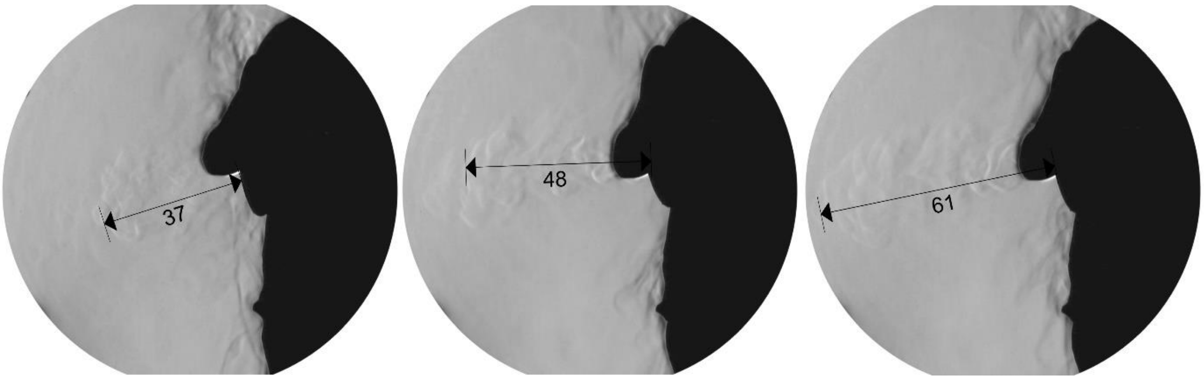

Figure 14 Double horn in front of the schlieren mirror while playing the note C2 ≈ 65 Hz (left), note D#5 ≈ 622 Hz (center) and the maximal range of the air escaping from the bell (right) [cm]

If the speed of the air flow is reduced or when using dampers, the air escaping from the bell is bent along the right hand or forearm. As with the other brass instruments, the air flow is highly restricted when using dampers (Figure 15 left and center). An exception is the stopping mute, where the air escapes from a narrow tube at higher pressure. Thus, it spreads over 70 cm into the room and escapes over the edge of the schlieren mirror. However, the flow is more difficult to detect due to the lower density gradient (Figure 15 right).

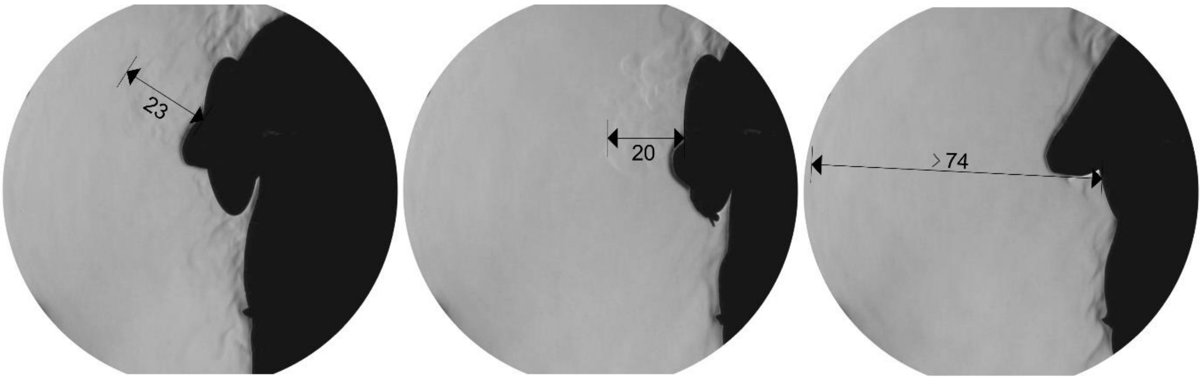

Figure 15 Maximal range of the air escaping from the bell with damper (left), hand stopping (center) and stopping mute (right) [cm]

F Tuba

Due to the wide bore and the length of the instrument, the breathing air cools down. Therefore, it can no longer be visualized with the schlieren mirror. The streaks that can be seen in Figure 16 is the ascending convection caused by the heat emission from the tuba player.

In order to visualize the air flow escaping from the bell, the tuba should be played over a longer period of time to increase the temperature of the instrument and thus the air escaping from the bell. Schurig (2020) reports the extent to which brass instrument, in particular, warm up when played over longer periods of time. Further experiments in this regard can be conducted in future investigations.

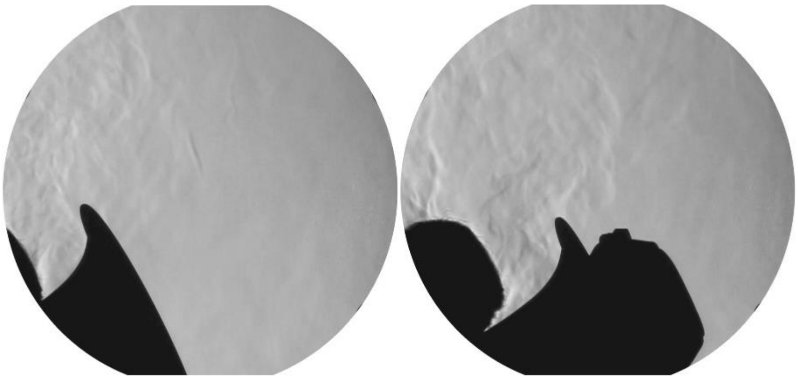

Figure 16 F tuba in front of the schlieren mirror (left) and with damper (right)

Singer – Baritone

When singing a note, the greatest air spread can be observed at the beginning of the note. If a tone is held or a longer phrase is sung, only a small amount of air escapes from the mouth of the singer. The greatest air spread can be seen when singing with a lot of articulation.

The evaluations show that the range of the exhaled air hardly differs in the variation of the pitch (e.g. when singing scales) (Figure 17 left and center). An increasing air spread can be observed when singing demanding musical pieces that require a lot of articulation as well as a strong command of the voice (Figure 17 right). Here, the air escapes over the edge of the mirror.

Investigations of the Hermann Rietschel Institute at the Technical University of Berlin under the direction of Prof. Dr. Kriegel also showed that singing spreads significantly more aerosols than normal speaking.

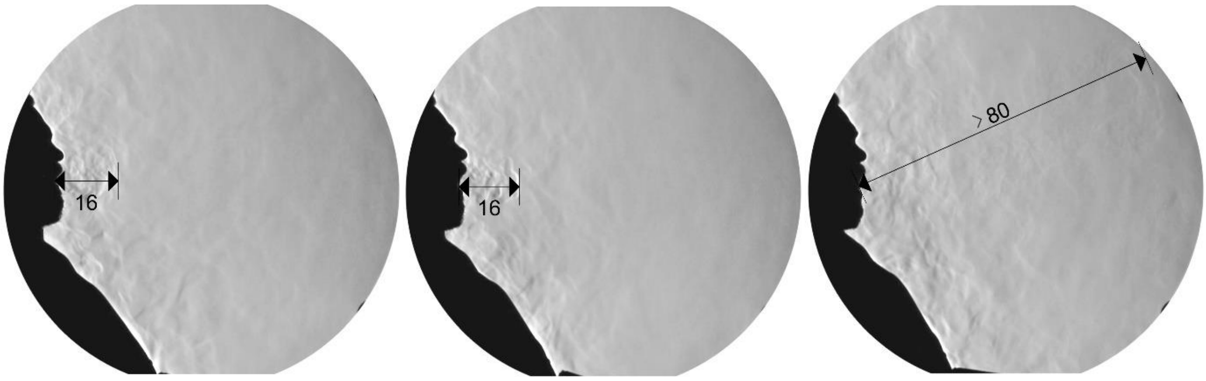

Figure 17 Baritone in front of the schlieren mirror while singing the note G2 ≈ 98 Hz (left), note D#5 ≈ 622 Hz (center) and the maximal range of the air escaping from the mouth (right) [cm]

Conclusion

Table 1 shows a comparison of the maximal spreading ranges of the different instruments as well as the singer. For woodwind instruments, it can be seen that the breathing air that escapes from the bell can be detected over much shorter distances in comparison to the air that escapes during various activities (air leak, exhalation, etc.), some of which are essential for sound production.

Furthermore, the air escapes further into the room with low-tuned brass instruments compared to instruments played at higher pitches.

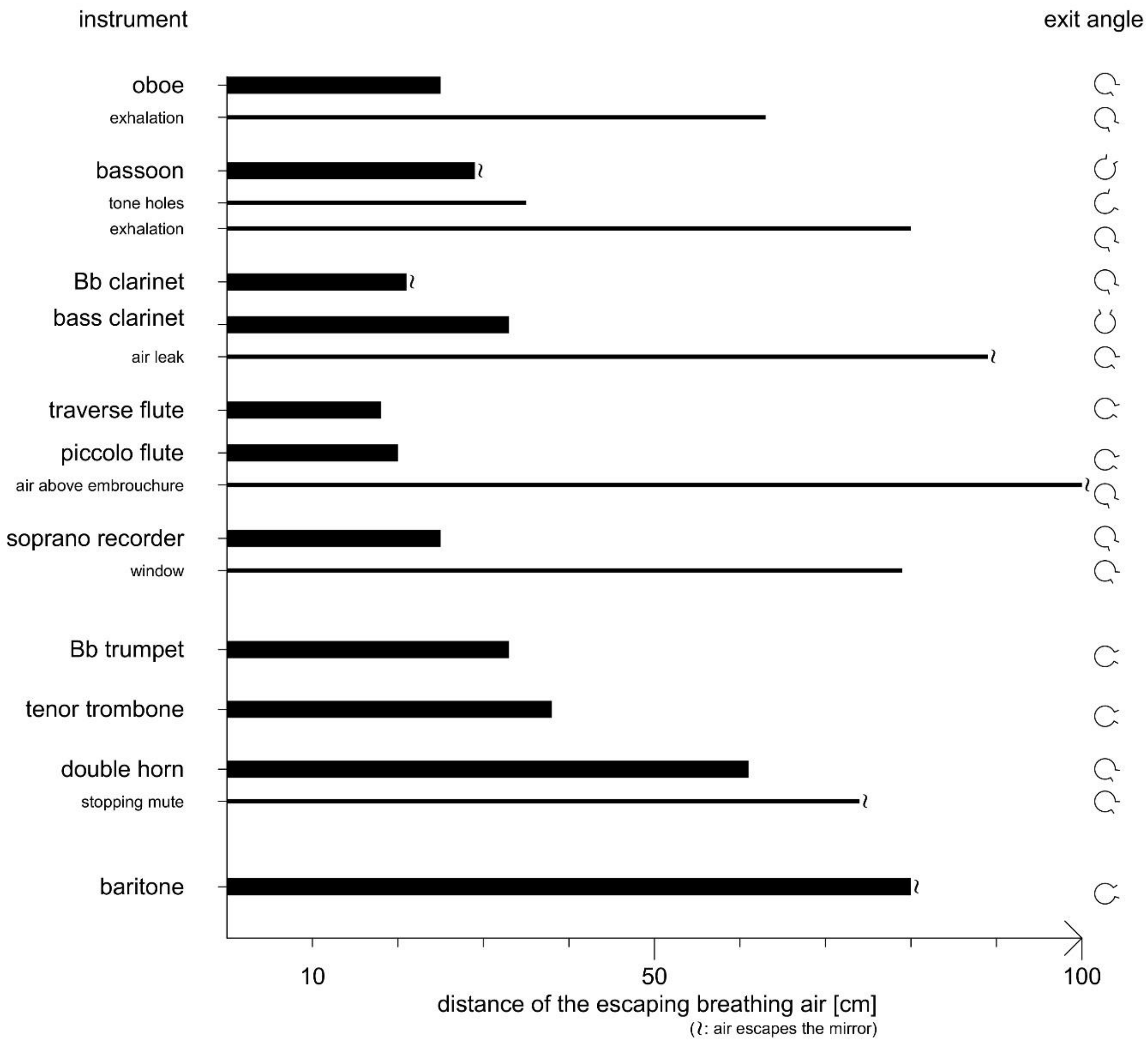

Table 1 *Maximal spreading distance of the breathing air from wind instruments and singers*

References

Becher, L.; Voelker, C.; Rodehorst, V.; Kuhne, M. (2020): Background-oriented schlieren technique for two-dimensional visualization of convective indoor air flows. In *Optics and Lasers in Engineering* 134, p. 106282. DOI: 10.1016/j.optlaseng.2020.106282.

Gena, A. W.; Voelker, C.; Settles, G. S. (2020): Qualitative and quantitative schlieren optical measurement of the human thermal plume. In *Indoor Air*. DOI: 10.1111/ina.12674.

Kaehler, C. J.; Hain, R. (2020): Singing in choirs and making music with wind instruments – Is that safe during the SARS-CoV-2 pandemic? University of the Bundeswehr Munich, Germany.

Richter, B.; Echternach, M.; Traser, L.; Burdumy, M.; Spahn, C. (2020): The Voice – Insights into the Physiology of Singing and Speaking. DVD-ROM and App. 2.th ed. Helbling, Esslingen, Innsbruck.

Schurig, J. (2020): "Heiße" Musik sichtbar gemacht. In *Forschung und Lehre* 27 (6), p. 534.

Settles, G. S. (2001): Schlieren and Shadowgraph Techniques. Visualizing Phenomena in Transparent Media. Berlin Heidelberg: Springer-Verlag Berlin Heidelberg.

Spahn, C.; Richter, B. (2020): Risk assessment of a coronavirus infection in the field of music. With assistance of A. Schuster, H. Hengel, H. Buerkle. Freiburg Institute for Musician's Medicine (FIM), University Hospital and Freiburg University of Music, Germany.

Willich, S. N.; Berghoefer, A.; Wiese-Posselt, M. K.; Gastmeier, P. (2020): Stellungnahme zum Spielbetrieb der Orchester während der COVID-19 Pandemie. Hospital Charité Berlin, Germany.