9-12 AUGUST 2015
inter.noise 2015
SAN FRANCISCO, CALIFORNIA USA

Directivity characteristics of dental turbines and their relevance for sound-quality evaluation

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In order to instrumentally or perceptually evaluate and compare the sounds of dental turbines, a representative and reproducible procedure is desirable. DIN EN ISO 14457 (2013) specifies setup and conditions for measuring the maximum A-weighted sound-pressure level in the context of maximum noise limits, not of sound quality. However, this setup may also be used for measurements and recordings in the field of sound quality. With the aim of providing data to support the selection of an appropriate measurement setup, directivity characteristics of several dental turbines are presented and discussed in the present study. A special focus will be given to the relevance of the physical characteristics found for sound-quality evaluations. It will be shown that each component of the turbine sound can exhibit different directivity characteristics, which will affect the selection of a measurement setup suited for the desired application.

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1 INTRODUCTION

As it is the case for most noise-emitting products, two important scenarios exist that require recording or measuring the sounds of dental air-turbines: assessing noise exposure (for example Bono 2006, DIN EN ISO 14457 2013) or sound-quality design and evaluation (e. g. Yamada et al. 2007, 2009). Standardized measurement conditions and setup exist for measuring the maximum A-weighted sound-pressure level (DIN EN ISO 14457 2013), but not for measurements or recordings in the field of sound quality.

DIN EN ISO 14457 (2013) specifies that the A-weighted sound level produced by handpieces and motors used in dentistry must not exceed 80 dB(A), measured with a type 1 sound-level meter according to DIN EN 61672-1 (2014) in the middle of a room with a free radius of at least 1 m. For the measurement, the product must be operated at maximum rotational speed or maximum air pressure, respectively. The position of the sound-level-meter microphone is standardized at 0.45 cm distance from the device head, at a right angle between the device's direct axis and the main microphone direction (90° according to figure 1).

In the following, the sound radiated by three randomly selected dental air-turbine specimens of each of three randomly selected models is analyzed in detail. Different radiation directions are included in order to contribute data that will help substantiate the selection of a suitable measurement and recording position.

2 PROCEDURE

As basis for the analyses, the sounds of the turbines were recorded close to but not actually at the center of an acoustically-treated, shoe-box-shaped laboratory with an average reverberation time of about 55 ms and a volume of some 32 m^3. During the recordings, the turbines were run in idle condition at the maximum specified air pressure, with a pin according to DIN EN ISO 14457 (2013) instead of an actual drill bit. The turbines were mounted one at a time by a vertical extension rod at a turntable, with the pin pointing downwards towards the floor. The turntable was installed so that the turbines could be rotated horizontally around the pin in steps of 15°. A calibrated, free-field equalized pressure microphone was installed at the height of the turbine head at 45 cm distance, with its main direction pointing towards the head. Figure 1 shows the definition of the horizontal angle (azimuth φ) between microphone and handpiece that will be used in the following.

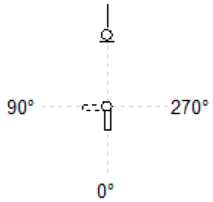

Fig. 1 – Definition of the horizontal angle (azimuth φ) between the measurement microphone's main direction and the dental air-turbine handpiece.

For each turbine specimen, 10 s samples of its sound were recorded at 44.1 kHz sampling rate and 24 Bit word length from 12 azimuths ranging in 15° steps from 0° to 165°. These samples were processed and analyzed at double-precision word length and 44.1 kHz sampling rate, resulting in the data presented in the following. Recording, signal processing, and analyses were carried out digitally using modules of the WindAcoustics Suite (2015).

The intensity of spectral components below some 500 Hz was in all recordings in the range of the background-noise in the measurement room. For that reason, the frequency range below 500 Hz is not shown and discussed here, which is considered reasonable due to the low intensity in that range and due to the listening impression. The broadband magnitudes shown below are practically independent of that frequency range.

3 RESULTS

Figure 2 shows the spectral intensity-density level l for a specimen of each of the three turbine models, measured at $\varphi = 90°$. The intensity-density level gives an overview of the basic stationary physical content of each signal.

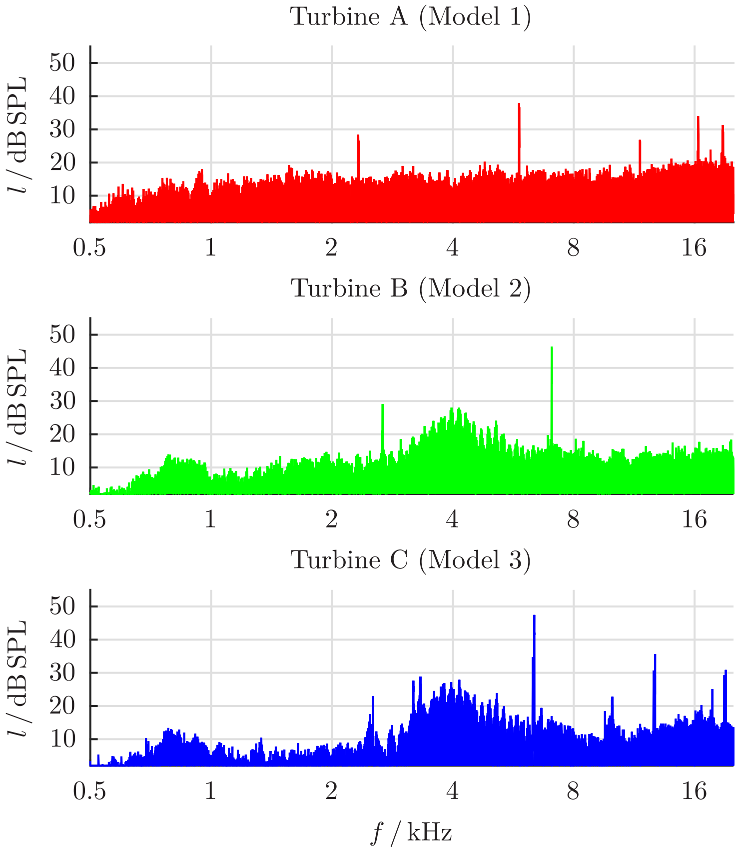

Fig. 2 – Intensitiy-density level l of the idle sounds of dental air-turbines as a function of frequency f (10 s each, recorded at 90° azimuth, 0° elevation, 45 cm distance in a slightly reverberant laboratory environment with 55 ms average reverberation time).

All sounds are globally combined of noise-like and tonal components, but differ in detail. In the rather broadband background noise as well as in the tonal components arise differences between the turbine specimens and maybe also in the corresponding models. While the background noise globally increases linearly with frequency for turbine A, both other turbines show more irregular frequency dependencies. Also, the turbines show a different number of tonalities, at different frequencies and levels.

All the listed properties may depend differently on the radiation direction for different turbine specimens or models. As an attempt to address the direction dependency of this specific spectral configuration and its components, the overall intensity, the contribution of tonal components, and their frequencies were analyzed and will be discussed separately.

3.1 A-weighted Overall and Maximum Sound-Pressure Level

The average (RMS) A-weighted sound-pressure level L_A and the maximum A-weighted level $L_{\mathrm{A}_\mathrm{max}}$ were calculated for every recording. This resulted for three turbine specimens per model and direction in three values, of which the medians are shown in figure 3.

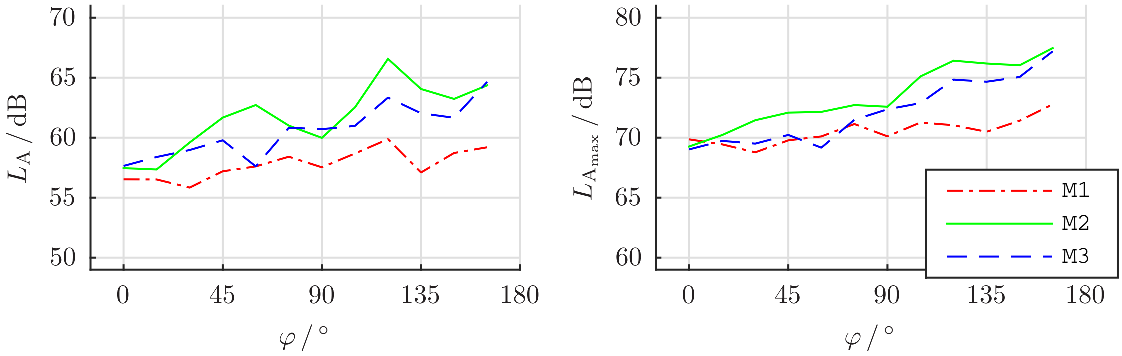

Fig. 3 – Medians of the A-weighted sound-pressure level (left) and A-weighted maximum level (right) over three specimens of each of three turbine models (M), recorded at 0° elevation and 45 cm distance in a slightly reverberant laboratory environment with 55 ms average reverberation time.

Both levels shown in figure 3 change for models 2 and 3 (solid and dashed) more with the azimuth φ than for model 1 (dash-dotted). The highest maximum levels occur, with the recording setup used, in the rear area (along the handle) for models 2 and 3. The turbines of model 1 elicit lower levels in the rearward direction. The lowest levels occur for all turbines around 0°. It must be taken into account that the data only stem from three specimens per model and may therefore not represent the model.

3.2 Intensity of Tonal Components

In order to address the directivity of single tonal components, figure 4 illustrates the three highest-level components per azimuth. Each panel shows the median data of three specimens of the respective turbine model.

The columns represent the models, while each row contains one of the three highest-level tonal components, in downwards descending order. That is, the upper row shows the highest-level component, the middle row represents the second-highest, and the bottom row the third-highest level component, each per direction and per turbine model.

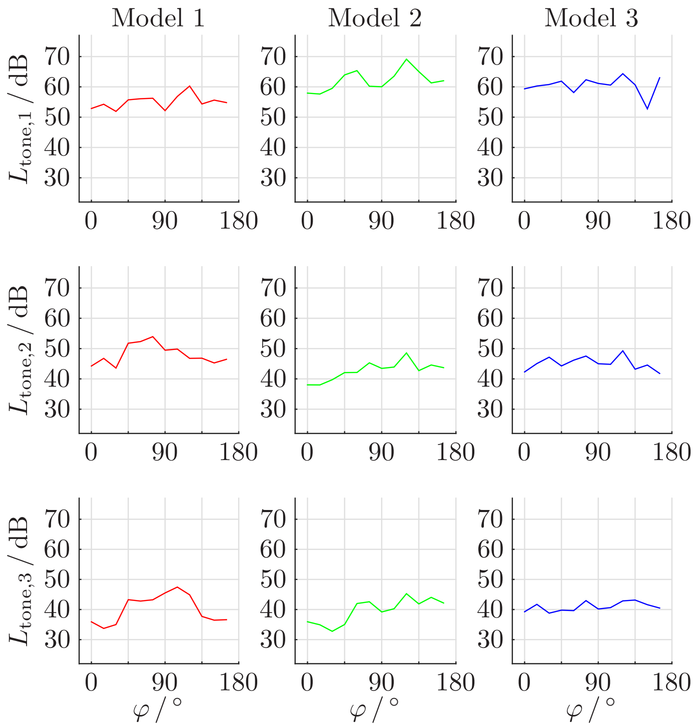

Fig. 4 – Median of the spectral intensity maxima per direction of the sounds of three specimens of each turbine model. Upper row: highest-level component $L_{tone,1}$, middle and bottom rows: second and third highest-level components $L_{tone,2/3}$, recorded at 0° elevation and 45 cm distance in a slightly reverberant laboratory environment with 55 ms average reverberation time.

In selecting the components, their frequencies did not play a role, the only criterion was their level. As a consequence, it is not given that for example the highest-level component for different azimuths is always the "same" one (located at the same frequency). Figure 5 illustrates this circumstance in showing the frequencies of the components depicted by means of their levels in figure 4.

The highest-level component lies on average between some 50 dB and 60 dB for model 1, between about 55 dB and 65 dB for model 3, and between some 60 dB and 70 dB for model 2. For the highest tonal component, the tendency of increasing levels towards the rear of the turbine (towards 180°) is visible only slightly, if at all, most clearly for model 2. For this model, the increase with azimuth φ also occurs in the second and third-highest components, whereas these components of the other models behave differently: for model 3, no clear azimuth dependency occurs, with a slight tendency of increasing levels with azimuth of the third-highest component. Model 1 on the contrary shows an increase of components 2 and 3 towards 90° azimuth, but then a decrease towards 180°. Globally, the second and third-highest-level components show comparable levels for all models (between some 40 dB and 50 dB for the second, and between some 35 dB and 45 dB for the third-highest component).

The frequencies corresponding to the highest-level components (figure 5, top row) lie for models 2 and 3 on average at 6.9 kHz and 6.3 kHz, respectively. For model 1, however, at most directions the highest-level component lies at 5.9 kHz, but between 20° and 50°, it occurs at 16.4 kHz. At most other directions, the second-highest-level component of model 1 resides in this frequency range. The median frequencies of the second and third-intense tonal components (middle and bottom rows in figure 5) do not show such a clear structure for any model. Globally, frequencies above and below that of the most-intense component occur.

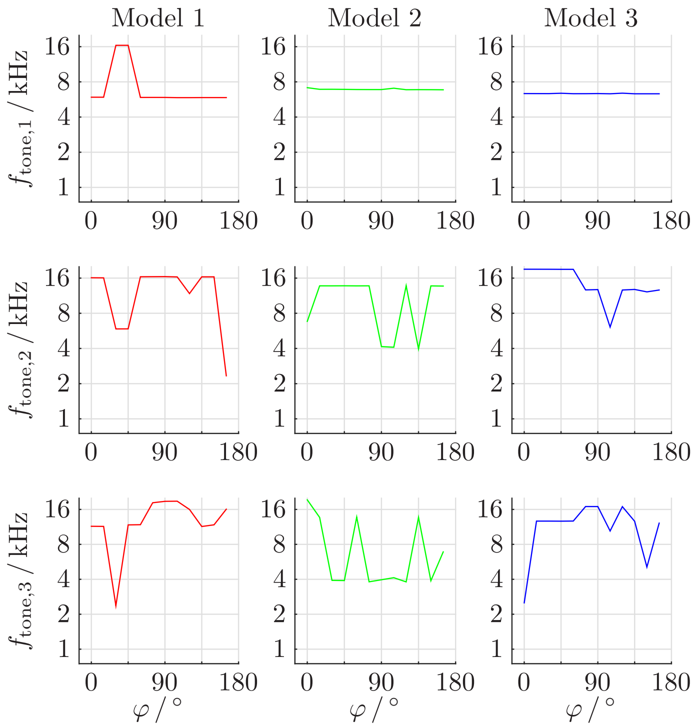

Fig. 5 – Median of the frequencies of the spectral intensity maxima per direction of the sounds of three specimens of each turbine model. Upper row: frequency $f_{tone,1}$ of the highest-level component (cf. figure 4), middle and bottom rows: frequencies $f_{tone,2/3}$ of the second and third-highest-level components. Recorded at 0° elevation and 45 cm distance in a slightly reverberant laboratory environment with 55 ms average reverberation time.

4 SUMMARY AND CONCLUSIONS

In this contribution, a physical analysis of the idle sounds of dental air turbines was conducted. The sounds of all turbines are combined of a somewhat turbine respectively model-specific broad-band background noise and of several tonal components with characteristic levels and frequencies. Additionally, different radiation characteristics per component occur. With the aim of quantifying these directivities, the following components were calculated for different horizontal radiation directions (azimuths) for three randomly selected specimens of each of three randomly selected turbine models:

- A-weighted overall levels and maximum levels
- Levels of the three most-intense tonal components
- Frequencies of the three most-intense tonal components

Both A-weighted levels increase with increasing azimuth, that is towards the turbine handle. For model 1, this increase is smaller, on average in the range of 4 dB going from across the handle to the direction along the handle. For models 2 and 3, a larger increase of about 8 dB occurs, in the maximum and the average level. Consequently, the highest levels are produced by all turbines in the rearward direction, along the handle, whereas the lowest levels occur in the frontal direction, across from the handle. While the levels elicited by all models are comparable in the frontal directions, differences exceeding 5 dB occur close to the handle.

The average levels of the most intense tonal components increase only slightly with the azimuth, but differ by more then 10 dB between the models. The second and third-most intense components show globally comparable average levels for all models, but in detail different azimuth dependencies: while those of model 3 proceed rather azimuth independently, an increase of about 10 dB going from across to along the handle occurs for model 2. The levels of the second and third-most intense components of model 1 are similar in front and back, and show an increase of more than 10 dB towards 90°.

The average frequencies of the most-intense tonal components are independent of the azimuth for models 2 and 3, at 6.3 kHz and 6.9 kHz, respectively. For model 1, a higher-frequency component at 16.4 kHz dominates on average at azimuths between 20° and 50°, in contrast to 5.9 kHz on average at the other directions. The average frequencies of the second and third-most intense components show no clear azimuth dependency for any model.

Taking into account the relatively small number of three specimens per model, the data presented here are not representative for the corresponding models. Much rather, the results are meant to provide a basis for the substantiated selection of a most universal recording and measurement position, with regard to physical analysis and listening experiments. Looking at the results, however, it becomes apparent that not only the overall level of the turbine sounds varies considerably with the horizontal radiation direction, but also their spectral configuration. Considering that the magnitudes of both variations range between 5 dB and 10 dB, loudness and timbre respectively sound-color variations are to be expected. The results of physical measurements and especially of sound-quality evaluations will consequently depend in a model or even turbine-specific manner on the recording position. In order to select the most universal recording position, more data and a criterion are necessary, as for example looking at the worst-case scenario or the most annoying sound. For a realistic and complete noise or sound-quality characterization of a turbine sound, more than one measurement position is required, for example close to the handle, at a right angle to the handle, and across from the handle.

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