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Sensitivity of stage acoustic parameters to source and receiver directivity: Measurements on three stages and in two orchestra pits

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ABSTRACT

Stage acoustic parameters are commonly determined in concert halls using omnidirectional transducers, but might be more valid when using directional transducers. In this paper, the sensitivity of stage acoustic parameters to source and receiver directivity has been investigated by measurements on three stages and in two orchestra pits. A single loudspeaker was used with a directivity similar to a trumpet, aimed in 12 evenly spread directions. As a directional receiver, a head and torso simulator (HATS) was used with its viewing direction towards the conductor position. Measurements were also taken with (nearly) omnidirectional transducers. i.e. a dodecahedron loudspeaker and a single microphone. The investigated stage acoustic parameters measuring reverberation time and reflected sound levels were sensitive to the directivity of the measurement transducers. The parameters dealing with early sound, *EDT* and $ST_{early,d}$, are more sensitive than the parameters dealing with late sound, T_{20} and $ST_{late,d}$. When comparing results measured with a head and torso simulator to results measured with an omnidirectional microphone, the *EDT* tends to be lower and the $ST_{early,d}$ higher for the ear directed towards the sound source. The results of measurement using the directional source show that *EDT* and T_{20} have lowest values and $ST_{early,d}$ and $ST_{late,d}$ highest values, when the sound source is directed towards the closest surfaces that cause a first order reflection towards the receiver. Further research is necessary to determine whether the differences in parameter values would lead to noticeable differences.

1. Introduction

Omnidirectional directivity of the sound source and receiver is used in the definition of many physical parameters in room acoustics describing energy decays, energy ratios, energy levels [1] or modulation reductions [2]. Exceptions are those that describe apparent source width and listener envelopment [1] which use directional transducers such as a figure-of-8 microphone or head and torso simulator (HATS) to simulate the directional hearing of humans. Omnidirectional parameters are also used to describe acoustic conditions for the orchestra on stages of performance spaces [3,4]. Directional properties of the musical instrument and the listener are not taken into account by these measures while possibly being relevant for the musicians on stage, as indicated by research recently presented by Dammerud [5] and Guthrie [6]. In the current paper, it is investigated whether measurements with directional transducers, that simulate the characteristics of an instrument and a listener, lead to significantly different stage acoustic parameters than when using omnidirectional transducers.

1.1. Background

For measuring room acoustic parameters, the dodecahedron loudspeaker is the most commonly used sound source, containing 12 drivers equally spread over a full sphere to approach omnidirectional directivity. Polyhedron loudspeakers are only omnidirectional below their 'cut-off frequency', which is determined by the radius of the sound source [7]. Leishman et al. found that the dodecahedral shape is the optimal choice for being the best possible combination of reasonable omnidirectional radiation and sufficient sound power. Due to the spherical radiation pattern room acoustic measures vary for different source rotations [8]. The error due to the directive behaviour at frequencies above 1000 Hz can partially be compensated by averaging over multiple source rotations [9]. Another type of practical omnidirectional source uses two drivers, face-to-face, with loudspeaker cabinets shaped as a cone [10]. This type of source is more omnidirectional but less

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powerful, which makes it less suitable for measurements in large rooms like performance spaces.

Orchestral instruments are well known for their directive projection of sound: brass instruments have a strong directivity in the direction of the bell while string instruments project sound perpendicular to their radiating body. For woodwind instruments, a complex directivity is found caused by the combined radiation of the open holes and the end of the tube. The directional properties of musical instruments have been investigated by Meyer [11] and by Pätynen and Lokki [12]. It is clear that their directivity is complex, depending on the tone played and varying among playing styles and different instruments of the same type [13]. Besides, the position of the acoustic centre of the source may vary per note played and per frequency, as shown by Shabtai and Vorländer [14]. As a result, it is difficult to simulate directivities of the various musical instruments by (single) loudspeakers. A possible solution to this problem is to perform measurements with individual loudspeakers in a spherical array and synthesizing any directivity from these responses using spherical harmonic decomposition, as investigated by Pasqual [15] and Pollow et al. [16]. However, a high spherical discretisation of loudspeaker positions is necessary to be able to simulate complex directivities at high frequencies, which is especially important for auralisation purposes. The large number of measurements per position makes the measurement procedure time consuming: a single measurement position can costs hours even when using fully automated measurement equipment. In the scarce amount of time available in concert halls when performing measurements, this procedure is not yet feasible for extensive room acoustic investigations in performance spaces.

Microphones can be omnidirectional up to high frequencies because of their limited size. By contrast, humans makes use of directional hearing and the human auditory system contains a set of complex mechanisms utilizing this directivity, for instance to localise sounds [17]. The directivity of the (outer) ears in the head are captured in the Head Related Transfer Function (HRTF). Individualised HRTFs are a necessary input for binaural reproduction of virtual acoustic environments for optimal immersion and localisation [18]. A HATS with a typical head and ear shape can be used to take into account the directivity of the ears in measurements [1]. In room acoustics, the HATS is used when measuring the Inter-Aural Cross Correlation. Besides, the HATS has been used to study the impact of a playback room acoustics on recorded room acoustics [19]. The HATS is not commonly used for measuring the typical ‘omnidirectional’ room acoustic parameters, but measurements did show a clear directivity of the hall for various room acoustic parameters measured with a HATS [20].

In room acoustic research, the directive properties of the instrument and the listener are considered in auralisation of measured sound fields [21] or simulated sound fields [22]. Also in stage acoustics, such auralisations have been used for listening tests to investigate the musician’s response to variations in stage acoustic conditions under laboratory conditions [23,6,24]. Some research has involved analyses of the direction of the arrival of sound using spherical microphone arrays in rooms [25] and concert halls [26]. Such methods can be used to analyse the spatial composition of the impulse response, showing direction and arrival times of reflections and the degree of isotropy of the late reverberant field. Pätynen et al. [26] claim that such 2D/3D visualizations “reveal considerably more information in an intuitive manner” than the ISO 3382-1 parameters. However, the results from their 2D/3D visualisations are difficult to quantify unambiguously and, as a result, findings cannot be easily related to perceptual aspects or compared to measurement results from others. Pätynen et al. [26] conclude that their methods “can be potentially used as a basis for novel objective indicators of the quality of concert hall acoustics”. The 3D visualisation tools seem promising, but their value in room evaluation and design is still to be established.

In stage acoustics, some researchers investigated the influence of directivity on ISO 3382-1 parameters. Schrärer and Weinzierl [24] calculated binaural room impulse responses using a geometrical acoustic model with the directivity of musical instruments included. The performance of musicians was investigated while playing their instrument in a real time auralisation of modelled concert halls. Measured performance attributes, e.g. *Tempo* and *Dynamic Strength,* were compared to calculated results of room acoustic parameters, e.g. reverberation time T and late support ST_{late}. The acoustic parameters were derived from the impulse responses including the source directivity. Even though results

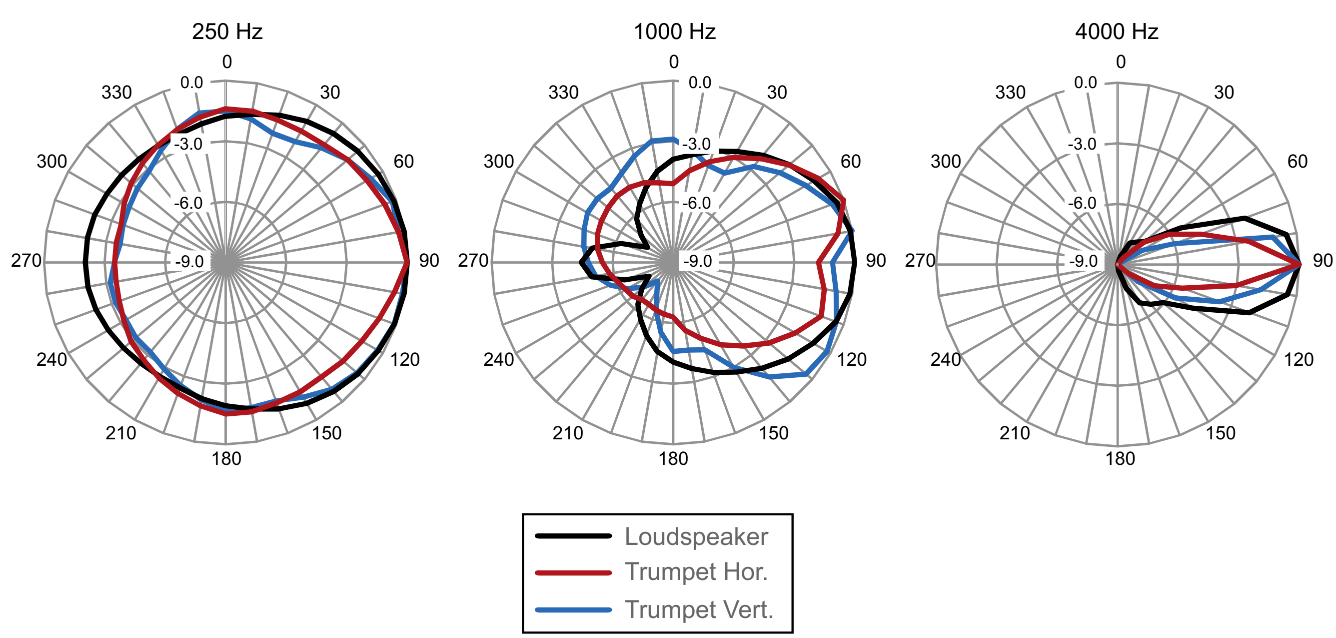

Fig. 1. The directivity of a single loudspeaker of the directive source compared to a trumpet for the octave bands 250, 1000 and 4000 Hz. The trumpet directivity is shown for the horizontal and vertical plane which are slightly different. For the loudspeaker, these are identical.