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Wheel of Concert Hall Acoustics

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Summary
More than a hundred years of research on concert hall acoustics has provided an extensive list of attributes to describe and evaluate the perceptual aspects of sound in concert halls. This brief overview discusses the current knowledge, and presents a "wheel of concert hall acoustics" in which the main aspects are gathered together with the descriptive attributes that are commonly encountered in the research literature.

1. Introduction

Characteristics of concert hall acoustics can be described using a variety of terms: rich, dull, enveloping, overwhelming, live, clear, spacious, big, small etc. Most adjectives can be readily linked to attributes: richness, envelopment, liveness, spaciousness, clarity etc. that are often used as scales in perceptual evaluation. It is of course an individual choice which adjectives and attributes make the most sense; the association between an auditory perception and a particular term ultimately depends on the individual. However, in order to effectively communicate the perceptual effects of different acoustic and architectural solutions we need a common terminology and understanding of the associations between different attributes.

Fortunately, the terminology of concert hall acoustics has been well established in the course of studies starting with Sabine [30], and followed by many others [3, 4, 12, 2, 13, 32, 31, 10, 21, 19, 20]. For the uninitiated, however, the interpretations and conclusions of different authors may appear as disparate, because authors tend to prefer to use their own particular terms and the vocabularies obtained in different experimental studies are never exactly the same. Although the studies indicate that the listening experience in concert halls can be understood to consist of a number of common perceptual aspects that underlie the acoustic experience, it is difficult to extrapolate a single unambiguous attribute list to describe or evaluate acoustic quality in concert halls. In addition, there might be attributes that refer to slightly different auditory perceptions, but at the same time are related to the same underlying perceptual aspect. Often, the relations between different terms are not obvious and may result in confusion between people. This article makes an effort to present the perceptual aspects and the common attributes in a manner, that not only highlights the complexity of the perceptual space, but also indicates how commonly encountered attributes may be related. The aim is to clarify the common understanding of the perceptual space, and also to facilitate the communication between acousticians, architects, performers, music critics and common concert goers.

Representation in a wheel format is an established form for representing the perceptual characteristics of a product or sensory domain. The best known example is the Wine Aroma Wheel [26]. Concerning auditory domain, MURAL (MUltilevel auditoRy Assessment Language) [17] and more recently, a sound wheel developed by Pedersen and Zacharov [29] are examples of wheels representing the sensory characteristics and the terminology of reproduced sound. Some overlap in the terminologies describing the sound in concert halls and the reproduced sound can of course be expected as both are developed for auditory perceptions, but concert halls are designed and dedicated to music with unamplified instruments and the particularly long line of research motivates the development of a separate wheel for concert hall acoustics.

The list of terms making up the proposed wheel is not intended to be exhaustive; it represents those attributes which, in our opinion are the most important ones based on the research literature and our own descriptive profiling studies [21, 19, 20]. The wheel represents aspects that are mainly related to audience's perceptions. The important topic of stage acoustics and the many aspects describing performers' perceptions, such as hall response or the ease of playing in ensemble, would deserve a separate discussion and possibly another wheel. In addition, the presented attributes are mainly relevant for traditional concert halls, and for instance, they do not cover all aspects which might be apparent when active reverberation enhancement systems are used in modern multi-purpose halls. It is also true that many perceptual characteristics are essentially multi-modal with visual factors mediating the perceptual

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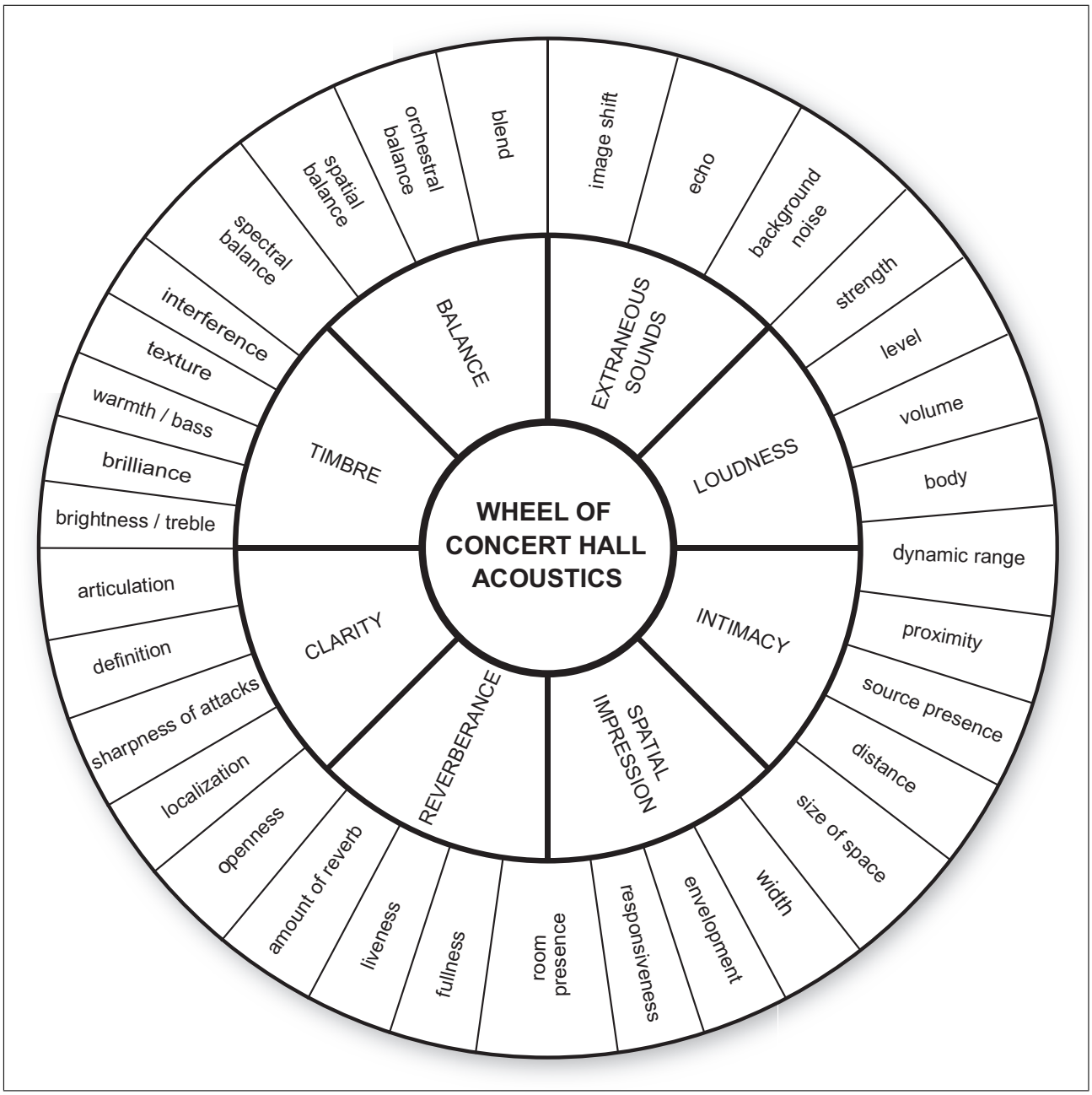

Figure 1. Wheel of concert hall acoustics.

responses, but these are not discussed here to keep this treatment concise.

The proposed wheel, depicted in Figure 1, is structured hierachically into two tiers: The inner tier includes the main categories that underlie the perception, are well established in the literature and can be thought to already have existing formal names. One category also represents **extraneous sounds** that are often associated with well-known acoustic defects and problems. As illustrated above the terms of the main categories as they appear in the wheel are typed boldfaced in the overview.

The outer tier consists of the attributes that represent different subcategories, facets, nuances, or "flavors" of the main characteristics. These are terms that are commonly used by the listeners for describing their subjective responses. The terms included in the wheel are typed in *italics* in the following section.

It is clear that one attribute may be related to more than one main characteristic (e.g. dynamic range contributes to loudness and intimacy), while other terms are clearly associated with different sides of a single perceptual feature (e.g. width and responsiveness, which both contributes to spatial impression).

The overall structure and the locations of individual terms are based on the authors' own understanding and interpretation. The aim has been to organize the wheel as logical and easy to inspect as possible. A comprehesive discussion about the relationships between perceptual aspects and the objective acoustic measures is outside the scope of this presentation.

2. Overview

Sabine's ([30]) studies in the early 1900's are generally regarded as the beginning of the science of architectural acoustics as we know it today and they serve as a good starting point for considering also the terminology in this field. Sabine identified three aspects that affect the perception of sound in auditoriums: 1. Loudness; 2. Distortion of complex sounds: interference and resonance; and 3. Confusion: reverberation, echo and extraneous sounds [30]. Most of Sabine' terms also appear in the proposed wheel.

Loudness is the perception of sound intensity and such a fundamental property of hearing that Sabine rightfully identified it as one main aspect affecting the sound in auditoriums. The term **loudness** is often used in this regard, but other common terms are collected to the outer tier. They are *volume* [4], *level*, *strength* and *body* [32]. In addition, acknowledging the fact that the sensation of sound strength varies continuously in musical sound, and that there is interaction between the dynamic changes and the hall acoustics, the term *dynamic range* [27] is also included in the outer tier.

Intimacy was brought into discussion of concert hall acoustics by Beranek [3] and it is many times described as "hearing the music as though being near the performers in a relatively small space". Accordingly, attributes such as *proximity*, *distance* and also *the size of space* are common terms related to auditory experience of being close to the performers. Attributes *source presence* and *room presence* have been used by Kahle [14] and also advocated by Haapaniemi and Lokki [11]. Source presence is associated with intimacy, whereas room presence is more related to spatial impression and reverberance.

Early studies of **spatial impression** [23, 15, 1] established the importance of laterally arriving sound to the listening experience. Spatial impression is generally regarded as being composed of apparent source *width* and listener *envelopment*. Spatial *responsiveness* [23, 22] can be thought to refer to the perceived changes in the spatial composition of the sound field resulting from the *dynamic changes* in the music. For example, studies have indicated that the perception of both *width* [15] and *envelopment* [7] is level dependent. Moreover, since the dynamic variation in musical expression changes the spectrum of the sound, resulting in higher levels of upper harmonics, and because these harmonics are perceptually emphasized due to the properties of binaural hearing when they arrive to the listener from certain lateral directions, the above mentioned spatial effects may be especially apparent in halls which provide strong lateral reflections [28].

Reverberance, i.e. the perception of reverberation is perhaps the most researched perceptual aspect of auditorium acoustics starting with the studies of the reverberation time [30]. Maybe because it is so well studied and well known, it is often referred with just reverb, or *amount of reverb*, but many times also with terms like *liveness* and *fullness*.

Reverberance is often associated with the perceived **clarity** of sound, because excessive amounts of reverberant sound tends to make the music sound muddy, with lack of distinction. In the literature **clarity** is an established aspect commonly referred to with terms such as *definition* and *articulation* that point to how clearly notes and instruments can be perceived in the music. Other facets of **clarity** are the *sharpness of attacks* and the *localization* of sounds, which both can be smeared or enhanced by the surrounding acoustics [6]. Finally, *openness* is a positive feature of the **reverberance** that enables simultaneous **clarity**.

Timbre or tone color in the context of concert hall acoustics is a less studied aspect. However, it seems to be one of the factors that distinguish concert halls [20]. Due to its multidimensional nature [25], **timbre** is often divided into different subcategories, like *warmth* or the amount of *bass* and *brightness*, but can be assessed also holistically with such attributes as *texture* [5] and *spectral balance* [13]. Sabine used the term *interference* to refer to the influences of room modes on the relative intensities of the harmonics in a complex tone [30] and we have decided to include this term in the wheel as well. (Note that Sabine's resonance refers to how the sound source reacts to the acoustics and thus would be part of the aspects of stage acoustics that are excluded from this wheel.) *Brilliance*, in turn, has been used to describe a sound rich in higher harmonics [3].

The overall impression of **balance** [13]can be subdivided into the previously mentioned *spectral balance* as well as *orchestral* and *spatial balance* [8]. The attribute *blend* is also commonly used to describe how the sounds of various instruments mix together so that the listener finds them harmonious [12, 6].

Finally, there are a few miscellaneous attributes which are often associated with acoustic defects such as *image shift*, audible *echo(es)*, and excessive levels of *background noise* as well as other **extraneous sounds** (e.g., traffic, ventilators, fans etc.). It is worthwhile to note that also these attributes may be connected to other perceptual aspects - for instance, the level of background noise affects the audible dynamic range of music [6].

3. Concluding remarks

This wheel represents only one possible organization of the perceptual aspects and attributes that are often used to describe the acoustics of concert halls. As mentioned before, the positioning of the terms may not represent factual truth about the associations between the terms per se, but it is based on our recent research [21, 19, 20, 27]. Our objective has been to present the terms as logically as possible based on the literature and the authors' current understanding.

Concerning spatial audio as well as sound quality in general, there are some very comprehensive lists of attributes, for instance the spatial audio quality inventory [18], and the sound wheel for reproduced sound [29],

that have been developed by formal discussions by experts and/or structured elicitation techniques. The proposed wheel complements these terminologies by specifying the subset of attributes which are commonly used in the context of concert halls with unamplified instrument sounds. Although this wheel is only restricted to the most common attributes, it clearly highlights that the auditory experience in concert halls is rich with a multitude of flavors and factors. Such complexity of the listening experience makes concert hall acoustics both a fascinating and a difficult subject to study.

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