The relevant frequency bands and the influence of loudness on the perception of Apparent Source Width

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Introduction

While it is widely accepted that Apparent Source Width (ASW) is an important factor in characterising the acoustics of a concert hall, there is still a lively discussion on how to refine the physical measures for ASW. A lot of experience has been gathered in interaural-cross-correlation and lateral-sound-incidence measures in recent years. As a result it was learned that different frequencies contribute differently to the perception of ASW and the level of a sound also influences the perception of the apparent width of a source. This paper presents the results of listening tests that were conducted to determine the influence of both frequency and loudness, on the perception of ASW.

Preceding work

The works of Morimoto may be considered the spearhead of the research that was conducted with the goal to develop an understanding how spatial impression is perceived. In regard to the question of which frequencies play a key role in perceiving ASW two of his publications play a prominent role. In 1988 he published [1] the results of experiments to clarify the effects of low frequency components on ASW. In these experiments he presented different broadband white noise signals to test listeners. These stimuli had a common upper cut-off frequency of 5300 Hz and a lower cut-off frequency ranging from 100 Hz to 3150 Hz. While his results mark a valuable first insight to how the lower frequencies contribute to the perception of ASW the test design impedes a clear view of how specific frequency bands contribute on the perception of ASW.

Only recently Morimoto and Iida [2] approached the question of which frequency bandwidth is appropriate for dealing with ASW. Even though the incitement for his studies was the question if IACC- and LF-measurements with narrow band signals (1/3-octave bands) properly reflect the perception of ASW, the results show that listeners are well capable of evaluating ASW from narrow band signals.

On the basis of these results one might confirm that only the lower frequencies are responsible for the perception of ASW, if it weren't for Blauert and Lindemann [3] who resolutely state that, "… it seems to be quite clear that *all* spectral components of early lateral reflections contribute to auditory spaciousness…". Indirectly this statement is supported by the fact that sound localisation is enabled by interaural level differences at higher frequencies.

The current state of knowledge may be reflected in the findings of Mason, Brookes and Rumsey [4]. In the light of the scope of this study the central point of their results reflects the effect of a simulus' frequency on the perception of ASW. While focussing on IACC as the measurand for ASW they determine the relationship between frequency and ASW.

Although voiced earlier many times it required the efforts of Marshall and Barron [5] to develop a first formulation of the effect of a sound's loudness on the perception of ASW. The reason why this relationship did not gain the momentum of further impact may be accounted to the missing third-party-confirmation of this formulation and the limited application of concepts such as "Degree of source broadening" or "Early level".

Common Practice

In ISO 3382 [6] the current state of the art in terms of room acoustical measurement procedures is specified. In this document the balancing act between the results of previous work and necessities of practical application is attempted. Despite the knowledge that two effects are mainly responsible for spatial hearing, i.e. interaural time difference (ITD) at lower frequencies and interaural level difference (ILD) at higher frequencies, the constraints of commonly used sound sources restrict meaningful measurements to frequencies up to 1 kHz. Furthermore, an averaging using constant weights for the octave bands ranging from 125 to 1000 Hz is used to facilitate the calculation process.

Experimental Design

Common ground of many psychometric studies is the widely accepted approach in which the parameter of interest is varied while other parameters that are known or assumed to have an influence on the perception are carefully controlled and remain constant. The challenge in this practice is the keen knowledge of the relationship between the technical parameter and its perceptual counterpart. This concept is most evident in the relationship between SPL and loudness for different frequencies. Consequently the stimulus that is presented to the subjects needs to meet a number of requirements.

Since spatial impression is a concept that finds its application in room acoustical considerations the frequency range of speech and music will be taken as a reference, hence frequency bands ranging from 100 Hz to 12.5 kHz are the focus of this study. Keeping in mind that the effect of loudness is also part of the scope of this investigation it appears reasonable to restrict the bandwidth of the stimuli to the width of the critical bands. For practical applications it

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has been shown that these critical bands can be approximated to 1/3-octave bands.

In order to treat the loudness of the stimuli in a perceptually correct manner the signals have been presented in 2 groups with constant levels of 50 and 60 phons, i.e. 2 and 4 sones.

For the listening tests a synthetic sound field has been set up in an anechoic chamber using eight loudspeakers with an angular distance of 45° to each other. The sound field has been designed to have a constant reverberation time of $EDT = T_{60} = 1.95$ s and a clarity index of $C_{80} = 2$ dB for all stimuli at all frequencies and loudness levels.

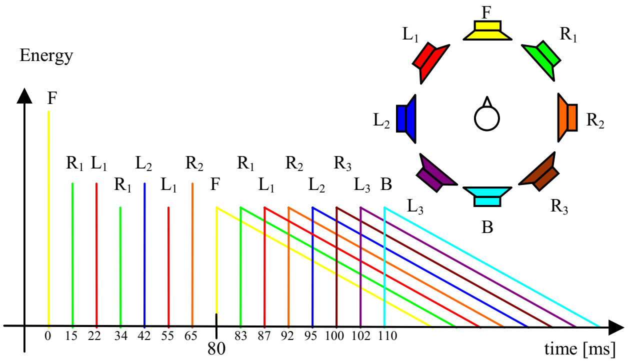

Figure 1: Systematic drawing of the impulse response and the setup of the synthetic sound field.

This impulse response was excited with a sequence of short noise pulses with each having a length of 230 ms including a 40 ms ramp at the beginning and at the end of the pulse. The pulses were amplified and band filtered to meet the demands to stimuli in regard of loudness and frequency band.

The impulse response as shown in Figure 1 has a lateral fraction parameter of about 40 %. Slight IACC fluctuations have to be expected due to slight head movements of the subjects that are unavoidable despite the headrest mounted at the listeners chair.

The listening test was conducted in a darkened anechoic chamber and followed an identical procedure for all subjects. After a short accommodation sequence that included the instructions for the participants the actual test started. During the listening test the stimulus was presented to the subjects while they where asked to adjust two light marks on a horizontal bar to match the angular extend of ASW they perceived. 48 subjects participated in the test. None of them reported to suffer from a known hearing defect.

Results

The central result of the listening tests is summarised in Figure 2. Here the perceived angular width (ASW) of the different stimuli is presented as a function of frequency and loudness. The curves show that frequencies below 1 kHz as well as frequencies above 5 kHz are perceived to have a larger degree of source broadening. The two curves for different loudness levels show a high correlation coefficient of about $p_{N_{50}N_{60}} \approx 0{,}974$. The increase in loudness of 10 phons yields an increase in ASW of $\Delta_{ASW} \approx 4{,}8°$ in average.

In order to determine and quantify the different factors influencing to the results a multifactor ANOVA was applied to the data of the listening test. As a result it was found that the separate factors of frequency and loudness are significant for the perception of ASW. Furthermore the interaction of frequency and loudness does not have a significant influence on the perception of ASW.

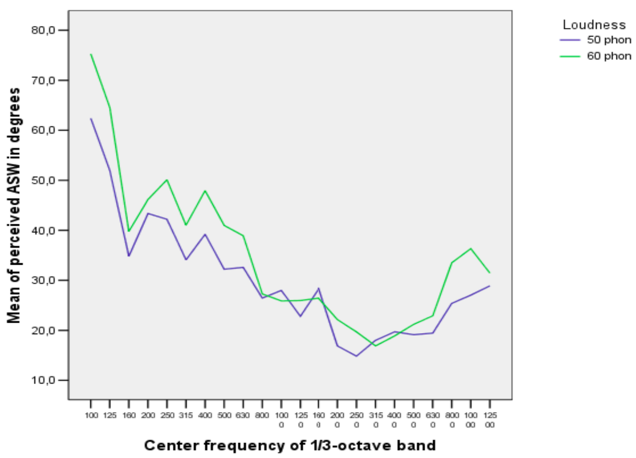

Figure 2: Apparent Source Width as a function of frequency and loudness

Conclusion and Future Work

The authors are of the opinion that the presented results reflect only the progress of an ongoing work. In order to gain further insights further listening tests should be conducted with different levels of loudness as well as with sound fields comprising more than one degree of lateral sound incidence. Furthermore it needs to be studied how more complex sounds comprising more than a 1/3 octave band are perceived in terms of ASW. Eventually this might lead to an understanding of how music generates a spatial impression.

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