Is the perception of listener envelopment in concert halls affected by clarity?

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Introduction

It is widely agreed that *spatial impression* (SI) plays a key role in the evaluation of concert hall acoustics. Nevertheless the model to describe this perception has been adjusted many times in the past. In the last 15 – 20 years a concept of subdividing SI into the aspects of *apparent source width* (ASW) and *listener envelopment* (LEV) has gained the momentum to be included into the ISO 3382 [1] standard on measuring the acoustics of performance spaces, especially in order to gain further experience with the more recently introduced acoustical quantities such as Late Lateral Sound Level (LG) [2]; which showed correlation to the subjective listener aspect of LEV.

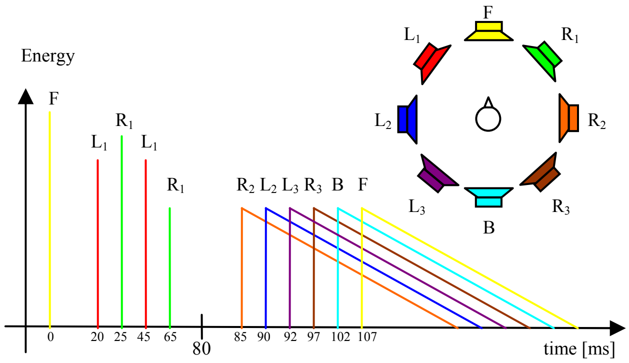

Image 1: Systematic drawing of the impulse response and the setup of the synthetic sound field.

Preceding work

In 1988 Barron [3] introduced a concept showing the dimensions of auditive perception and their dependencies with each other. He showed that SI is correlated to the sensation of *reverberance* and *intimacy*. The role of the perception of *clarity* was not identified with the desired precision. It is discussed whether this is due to a limited bandwidth of *clarity* in the studied symphony halls or due to a limited diversity of the participants of this study.

In his efforts to establish a difference limen DL for LEV the author [4] has conducted psychometric tests using binaural stimuli collected in some concert halls. Unfortunately the efforts were not overly successful in determining the just noticeable difference for LEV, however, some of the results were of such a statistic significance that they were subject to further analysis. For one specific trial, for instance, it turned out that subjects seemed to judge *clarity* although they were asked to evaluate LEV. Such a biasing effect of *clarity* concerning LEV has also been voiced before, however, previous studies failed to develop an unambiguous result.

Experimental technique

In contrast to the previously mentioned studies it was sought after to have a better control of the acoustic quantities describing the subjective attributes of the sound field. For this reason it was decided to trade the high degree of realism of a real concert experience or a dummy head recording with the high flexibility of synthetic sound fields.

Eight loudspeakers were placed in an anechoic chamber and positioned in a circle with a 2 m radius and a circumferential distance of 45°. Each participant of the listening tests was placed in the centre of the circle, hence having the same distance to all loudspeakers. Image 1 shows a systematic drawing of the setup and the impulse response that was used to generate the stimuli.

The amplitudes of the reflections and the reverberation tails were chosen to achieve a defined value of C_{80} and LG, while keeping the sound strength G constant for all stimuli. The range of values that was covered is shown in image 2. The tests were conducted with two musical motivs. Motiv 1 is characterised by short orchestral chords and quickly played string scales taken from the bars 1 – 20 from Glinka's "Russlan and Ludmilla"-Ouverture. Motiv 2 consists of the bars 79 – 97 from the same piece of music and consists of a slow string melody.

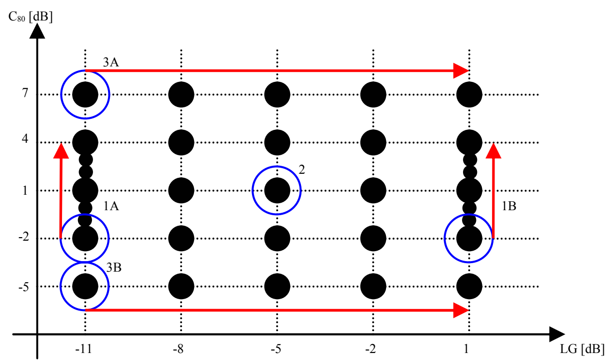

Image 2: Range of values covered in the listening tests. The blue circles mark the reference stimulus for the different experiments. The red arrows indicate the range of stimuli that were compared to the respective reference. Ref. 1A/1B: Exp. 1, Ref. 2: Exp. 2,Ref. 3A/3B: Exp. 3

Experiment 1

Before focussing on the questions of *envelopment* and its sensitivity to *clarity* it is essential to determine whether the covered range of values allows a stable discrimination in respect of *clarity*.

Experiment 1 consisted of two sequences of pair comparison tests in which the reference stimuli 1A and 1B (see Image 2) were each compared with 6 stimuli which differed only in respect of C_{80}. The results of these tests are found in Table 1. The statistical analysis was done with "psignifit"-toolbox 2.5.6 by J. Hill [5]. Monte Carlo simulations that were carried out to assess the goodness of fit indicate a probability of 85 % that the results of the listening tests are well described by the implied model. The results are based on 13 trials of the listening tests.

Table 1: Difference Limen (DL) for C_{80}

	DL [dB – C_{80}]	68% - uncertainty	95% - uncertainty
Motiv 1	2,05	−0,33 – +0,28	−0,65 – +0,62
Motiv 2	2,68	−0,45 – +0,48	−0,94 – +1,02

Orientation experiment

In this experiment the ability to discriminate a difference in *envelopment* of pairs that also differed in various degrees of *clarity* was examined. This was done in a pair comparison test in which the reference stimulus 2 was presented with 25 stimuli (including the reference itself) as indicated by the large circular areas in Image 2. Participants of the tests were asked to identify the member of the pair that was larger in respect of *envelopment*.

Unfortunately the results of this test showed such a deviation from the presumed model that a statistical evaluation proved to be in vain.

Experiment 2

In view of the results of the orientation experiment a more temperate approach was pursued. In this experiment two sequences of pair comparison tests in which the reference stimuli 3A and 3B were each compared with 5 stimuli (including the respective reference itself). In these sequences the members of the pairs differed only in respect of *envelopment*. It was expected that that an influence of *clarity* would become evident in a change of the difference limen. The results of these tests are found in Table 2. The results are based on 14 trails of the listening tests.

Table 2: Difference Limen (DL) for LG

	DL [dB – LG]	68% - uncertainty	95% - uncertainty
Motiv 1 C_{80} = 7 dB	9,04	−1,40 – +1,81	−3,28 – +5,40
Motiv 1 C_{80} = −5 dB	> 25	−0,0 – +0,0	−0,0 – +0,0
Motiv 2 C_{80} = 7 dB	8,98	−2,57 – +17,7	−7,53 – +inf
Motiv 2 C_{80} = −5 dB	11,61	−3,78 – +inf	−10,15 – +inf

The results of the Monte Carlo simulations showed a high probability (65 – 95%) that the results of the listening tests are well described by the implied model. The results of the sequence using Motiv 1 with a C_{80}-Level of −5 dB had to be rejected on the basis of 95% certainty that the model does not describe the results of the listening test.

Conclusions

In this study the difference limen for *clarity* and *envelopment* has been established on the grounds of a fast and a slow musical motiv.

Depending on the choice of music a difference of 2,0 – 2,7 dB in C_{80} is sufficient to be discriminated by 50 % of all test listeners. These results are very much congruent with the findings of R. Höhne [6] who determined the difference limen to about 2,5 dB in concert halls.

The results of experiments focusing on the perception of LEV are not of such unanimity. For samples with a high *clarity* a DL of 9,0 dB in LG is determined with a reasonable confidence even if it is accounted that the domain of uncertainty is much higher than it is for the C_{80}-difference limen. Although not quite significant in this respect the initial findings of Bradley and Soulodre [2] suggest a DL of at least 5 dB in LG. A reduction in *clarity* seems to raise the DL of *envelopment*. A result that appears peculiar as a low C_{80} indicates little energy in the direct sound and the early reflections and would, hence, suggest an unhindered focus on the reverberant tail of the impulse response.

The influence of the musical motive cannot be conclusively stated.

The author recognises the preliminary nature of the results as there are some factors such as a too small domain of values and a too small number of test listeners that might introduce a significant amount of uncertainty. Therefore this work will be continued.

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References

[1] ISO 3382:997, „Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters", International Organisation for Standardisation, Geneva, Switzerland

[2] J. S. Bradley, G. A. Soulodre, „The influence of late arriving energy on spatial impression," *Journal of the Acoustic Society in America.* **97** (4), 2263 – 2271 (1995)

[3] M. Barron, "Subjective study of British symphony concert halls", *ACUSTICA* **66**, 1 – 14 (1988)

[4] I. B. Witew, G. K. Behler, M. Vorländer, "About just noticeable differences for aspects of spatial impressions in concert halls", *Acoust. Sci. & Tech.* **26**, 185 – 191 (2005)

[5] F. A. Wichmann, N. J. Hill, "The psychometric function: I. Fitting, sampling, and goodness of fit", *Perception & Psychophysics* **63** (8), 1314 – 1329 (2001)

[6] R. Höhne, G. Schroth, "Zur Wahrnehmbarkeit von Deutlichkeits- und Durchsichtigkeitsunterschieden in Zuhörersälen," *Acustica* **81**, 309 – 319 (1995)