AUDITORY DISTANCE PERCEPTION IN CONCERT HALLS AND THE ORIGINS OF ACOUSTIC INTIMACY

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1 INTRODUCTION

Intimacy is one of the most intriguing concepts in auditorium acoustics, because it is so elusive and difficult to prove, and yet intuitive and palpable for many. Introduced by Beranek[1], *intimacy* has been regarded as one of the most important aspects of the concert experience. "Acoustical 'intimacy' suggests to the listener the size of the space in which it is performed"[1] and implies "that listeners hear the music as thought they are near the performers"[2]. Beranek proposed initial-time-delay gap (ITDG), the interval between the direct sound and the first reflection (at a central position in the audience area), as an indicator of *intimacy*, but this simple measure still lacks definitive confirmation from others[3].

An extensive discussion about *intimacy* has been given by Hyde[4], who also relates *intimacy* to the perception of the size of the room. He states: "Sound field components in small spaces essentially define intimacy and the issue for achieving intimacy in large halls becomes one of reproducing as many of these components as possible." Futhermore, he continues: "A significant cue providing this illusion of a closer and more Intimate distance is visual". The evidence is compelling, and it is clear that not only the feeling of *intimacy*, but also most other perceptual features (e.g., spaciousness, width, envelopment, definition) are produced or at least heavily influenced by the multisensory integration of hearing and seeing the performers within the surrounding environment. Given that the concert experience is holistic in nature, it is true that the results of all laboratory experiments are to be met with caution. It is, however, also highly difficult to conduct any sensible perceptual comparisons between halls in-situ when a myriad of factors change from concert to concert.

Hyde's discussion is excellent, but *intimacy* is such an intriguing concept that it deserves revisiting. In order not to repeat the previous work, we try to extend the discussion from mainly auditory and psychological perspectives, focusing on possible relationship between perceptual distance and the feeling of auditory closeness to the performers and try to link these to the current knowledge about neuronal pathways in the auditory system. Thus, the *intimacy* treated in this text is most of all auditory with a psychological twist while we urge the reader to keep in mind the multisensory nature of the concert experience.

The present interest on *intimacy* as well as on auditory distance perception (ADP) stems from the observations made in our previous studies of concert hall acoustics. In our research we have used multichannel auralizations in decriptive profiling framework. Many people described perceptual differences between halls with attributes related to distance even though the auralizations had been produced from the same physical receiver distance in each hall[5,6]. Moreover, the perception of proximity (our coarse synonym for *intimacy*) was associated with shared preferences, and even the preferences of assessors who had not used distance related attributes, were shown to correlate with proximity[7]. Motivated by these results, we have investigated auditory distance perception in auralized concert halls, and the current discussion is accompanied by a short summary of the results from one of our experiments. The methods of spatial room impulse response measurements and auralization are outside the scope of this paper, and the interested reader is directed to references[8,9,10,11,12].

2 AUDITORY DISTANCE PERCEPTION IN CONCERT HALLS

Auditory distance perception in rooms has been reviewed by Zahorik[13], and here we only note that most previous studies have focused on small and middle sized spaces with short or moderate reverberation times. Moreover, the distance judgments have been made to a single sound source. Only some direct evidence[14] exist on the differences in ADP between large rooms with long reverberation times, and there is one interesting study of ADP in open field[15] with distances ranging from 25 to 800 meters. A common finding has been that distances are progressively underestimated the further the source(s) are. Overestimation of short distances has been generally found to occur up to around 2 meters from the listener, but this effect may be due to the restricted range in these studies because in the open field study, distances were correctly or even overestimated up to as far as 100 meters.

A psychophysical power function, $p = kr^a$, where p represents the perceived distance, r real physical distance, k is a linear scaling factor, and a indicates the amount of non-linear compression (<1) or expansion (>1) is commonly used to represent the relationship between actual and perceived distances. In previous studies, the average values of k and a have been 1.32 and 0.54[13], respectively, but in the open field study the estimate of k was as great as 12. It has been speculated that k may be associated with the amount of reverberation[16], but it is possible that it is also related to the experience of size and extent of the surrounding space and the distances which are likely or plausible in this space[15]. Overall, it seems clear that reverberation gives us a cue of the size of the space we are in, which may be used to infer the generally possible distances to sources inside that space.

Regarding sounds originating beyond few meters range, the main acoustic distance cues are sound intensity (loudness), direct-to-reverberant ratio (DRR) and spectrum. For nearby sources, also binaural cues, i.e., interaural level and time-differences as well as cross correlation can be used as distance cues[13]. Commonly, the main relative cue is loudness, because we have learned that the sources further away are more quiet than sources nearby. In the context of auditoriums, sound strenght G is commonly employed as an indicator of loudness of the sound field. DRR in turn has been found to be used as an 'absolute' cue of distances[17] that may be used when relative differences does not exist, and for instance, when a sound is heard the first time. It is also known, that spectral changes, for instance the attenuation of higher frequencies of sounds that have traveled in air more than 15 meters, can be used as a distance cue[18]. Spectral changes and coloration (e.g., comb filtering) due to reflected sound may provide an additional cue independent of the variation in the overall sound level. Thus, it is easy to imagine that hall design, surface materials and other features such as canopy reflection may produce such spectral changes that also affect distance perception.

Our recent efforts to investigate ADP in auralized concert halls will be presented in an upcoming publication[19] and here only the main results are highlighted. In short, the study investigated ADP in four auralized concert halls and included five distances from 10 to 26 meters to the middle of the orchestra, see Fig. 1 for abbreviations, hall designs, and common objective room-acoustic parameters. At these distances, the main distance cues can be assumed to be DRR and intensity or loudness, which in this context is represented by G. DRR and G values are plotted in Fig. 2. Two anechoic materials were used in the study: 1) An excerpt of Bruckner's symphony nro. 8, second movement and 2) a stream of sounds from a brass quartet. Besides the distance judgments, which are presented in Fig. 3, we also collected pairwise preferences between 14 and 22 meters within each hall, and also between the halls at a central seating position (18 m). The results of the preference tests are illustrated in Fig. 4.

In summary, the results indicate that in MT, the perceived auditory distances change more linearly than in other halls when moving from the seats at the front to the seats at the back in a straight line. SB seems to make the orchestra sound generally a little further than in other halls, while the orchestra was perceived at similar distances in BB and BK. The average values for parameter k and a were estimated as 3.8 and 0.47 respectively. For each hall these were: BB: k = 4.1 and a = 0.41, BK: 5.0 and 0.33, MT: 1.8 and 0.7 and SB: 4.2 and 0.45. Thus, the results indicate that there are notable differences between halls in terms of ADP.

The preference results show that SB was not liked in R3, and that the preference for R2 over R4 is the most obvious in MT. Also in BK and SB R2 has been liked more than R4, but in BB this difference is at chance level. These preference ratings indicate a general preference for a closer (or louder) sound, and imply that it is more important to choose a close seating position in MT than it is in the three other halls inluded in this study.

Considering the DRR and G values plotted in Fig. 2 we see that much of the results can indeed be explained by the differences in DRR and G between the halls. Especially, the results seem to verify that sound strength G, or loudness was used as the determining cue for the relative distance differences, as the preceived distances can be associated with the pattern observed in the figure. One can also find an association between the DRR and G values. For instance, in BK DRR drops more than 10 dB between 10 and 26 meters, while G values seize to decrease after 18 meters. This relationship indicates that high level of reverberant sound in the hall compensates for the decrease in the direct sound energy when moving away the sources. In MT, the drop in DRR is just a few decibels, while G continues to decrease still at the back of the hall. The direct sound clearly dominates across the hall, and it is not surprising that MT has been informally described to have a very precise and analytical sound character with high definition.

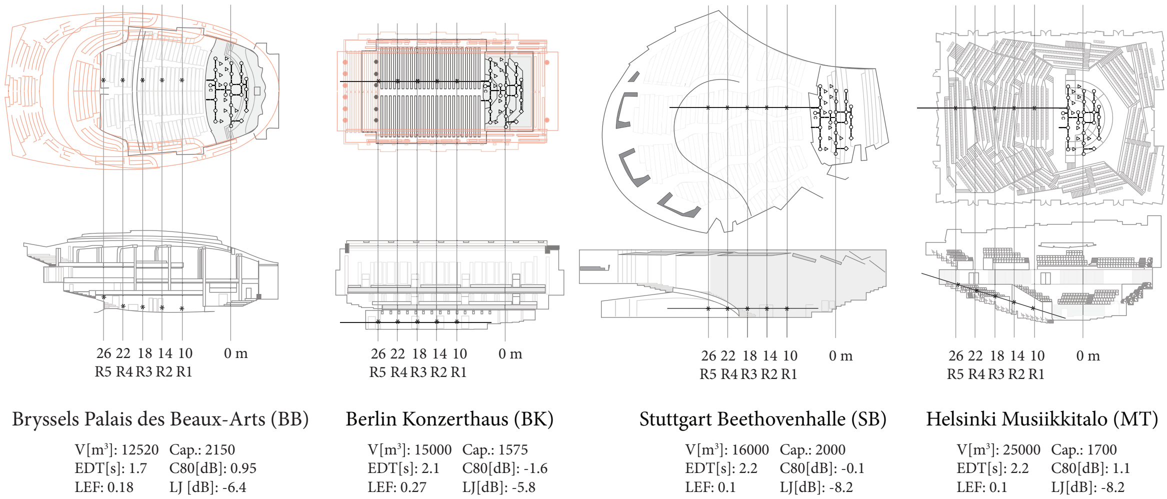

Figure 1 Layouts of the studied halls and some averaged parameter values.

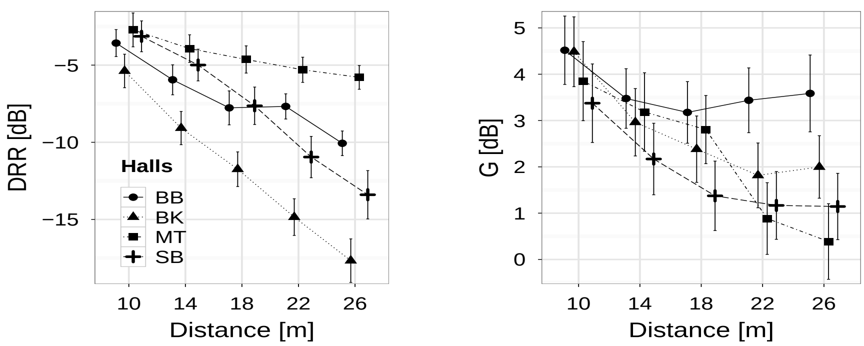

Figure 2 DRR and G averages over source positions and 500 Hz and 1 kHz centered octave frequency bands. Bars represent the 95 % confidence intervals, calculated from the variation over 24 source positions and the two frequency bands and give an indication of how much the position on the stage influences the value of the parameter.

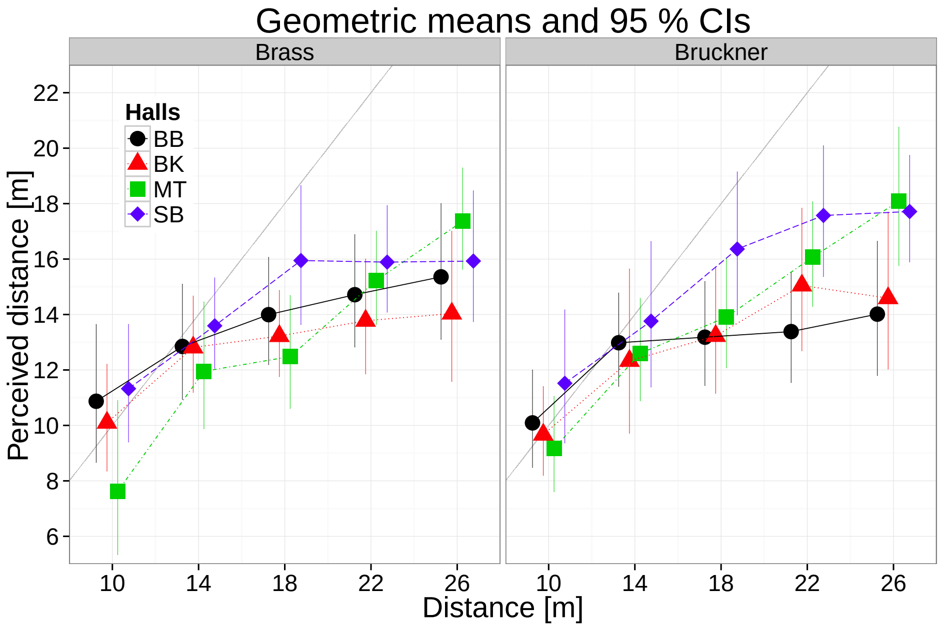

Figure 3 Geometric means and 95 % confidence intervals for Brass and Bruckner sound materials

3 THE ORIGINS OF ACOUSTIC INTIMACY

It is clear that the results summarized above do not give direct evidence on *intimacy*. Nevertheless, conducting these listening experiments illuminated the dichotomy between such clear cut and tangible perceptual aspects such as the apparent distance, and more complex features such as envelopment, warmth and *intimacy*. The complex nature of the common perceptual features becomes highlighted, when trying to figure out what to ask from the listeners. Dissemination of the actual task, and the focus of attention associated with the perceptual features of room acoustics leads to a reflection on the mechanisms of auditory nervous system and the distinction between 'what' and 'where' auditory pathways.

Consider the evidence that separate neuronal pathways, i.e., 'what' and 'where', in the human auditory system are engaged differently with different tasks[20]. Our attention modulates the processing of task relevant cues, and practice, learning and/or adaptation also facilitates the processing. For instance, it has been found that the exposure to the room acoustics improves speech intelligibility[21,22,23], while reverberation in general is known to have an adverse effect on intelligibility. For speech intelligibility, and perhaps such aspects as clarity, the most important cues largely lie in the early part of the room response, which might be processed more effectively with adaptation/learning of the room acoustics. Reverberant tail, on the other hand, is likely be important for distance perception and other related characteristics, such as perception of spaciousness, as ADP in reverberant environments has been found to be more accurate than in anechoic or free field conditions[17]. It can be seen that a task (or attention) modulated adaptation (cue weighting) framework provides an intersection for a variety of perceptual phenomena in room acoustics. Particularly intriguing in this respect is the loudness constancy phenomenon[24] which requires a listener to direct attention jointly to both 'what' and 'where'. Loudness constancy and its relation to *intimacy* were also discussed by Hyde[4].

It seems that some sounds, such as musical signals, or speech, tend to pull attention to `what` the sound is and to the early part of response, and only when required the attentional focus shifts from the 'what' to the 'where', for example, `where *in distance*`. It is plausible that when attenting a concert, we are by default focusing on 'what' is being played, 'what' is the phrasing like, 'what' do the musicians look like, 'what' happens on the stage, and 'what' kind of movements the conductor performs, not to mention the facial expressions and other interesting characteristics of the performance. As discussed

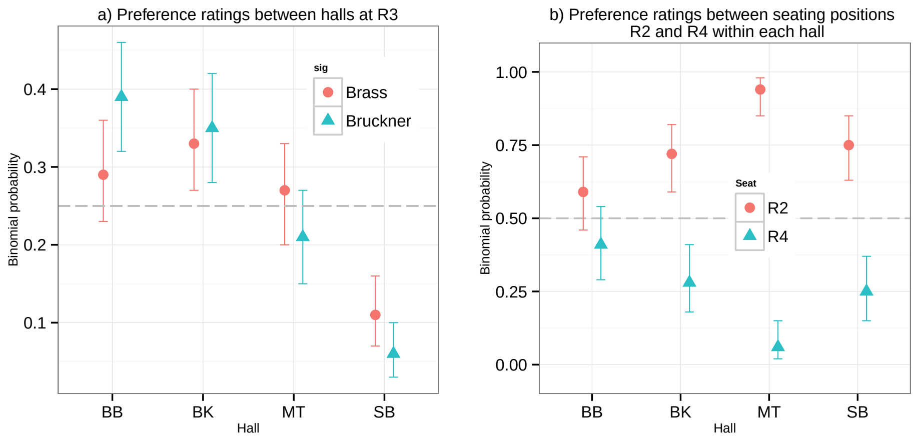

Figure 4 Preference ratings: a) Between halls at R3 (18 m). b) Between R2 (14 m) and R4 (22 m).

by Hyde[4], much is conveyed by visual aspects and the experience is inherently multimodal. Many perceptual aspects like distance perception is dominated by vision when visual information is available. It may be even so, that we have no particular need to attend the spatial acoustic cues when we have a clear view to the sources. Anecdotal example of this is the experience of the first author's mother, who, after attending to a concert in MT, commented that only by closing her eyes, she could hear how the music traveled through the space, because with an unobstructed view to the musicians she mainly followed the conductor and the musicians, and in fact, forgot to listen. Perhaps both the visual attentional focus on the performance and the attentional pull of the music to what is being played undermine the perception of the spatial effects induced by the acoustics of the hall.

Keeping in mind the 'what' and 'where' pathways, we turn to the perception of *intimacy*/proximity with another perspective. From a semantic viewpoint "*intimacy*" has a clear affective dimension as well as the connotation of distance. This duality links us directly to psychology, where affective experiences and the perceptions of distance have been studied extensively. In the present context, we only scratch the surface of this psychological inquiry and consider a recent account on the motivational distance perception[25] which illuminates a number of reasons why some stimuli might be perceived as (psychologically) closer than others. This account fits surprisingly well to our understanding and previous remarks on acoustic *intimacy*.

Basic tenet of this account is that approach orientation is associated with perceived proximity. In other words, stimuli and situations which evoke orientation to approach are perceived as closer than such stimuli that do not evoke such orientation. The appoach orientation can be evoked by both positive and negative stimuli and it happens that the concert experience in a hall can be thought to be composed by both.

Most of all there is evidence that the strongest approach orientations are experienced when both a motive arises and when the motive can be satisfied by an object or stimuli that is present[25]. Regarding live music, it is not uncommon to feel the urge to get little closer - to hear or to see just a little better. In concert halls where we are figuratively tied to our seats, we can not satisfy this motive by moving physically closer, but perhaps it can be satisfied by acoustical means. Music raises the motive to get closer[26], and the acoustics may or may not fulfil this motive. As a result we may or may not perceive proximity. Thus, the differences in proximity between halls can be viewed as the ability of the hall acoustics to fulfil our inherent motive to get closer to music, that is, the orchestra. Considering Beranek's and Hyde's remarks presented in the introduction, it is noted that the motive to get closer is perhaps by default satisfied in a small room, but not necessarily in a concert hall, where the objective might be to get the sound to appear closer by acoustical means.

Based our empirical observations in different halls both in-situ and from listening to the auralizations side by side have indicated that in some halls this proximity effect seems to happen. In some halls the sound field seems as approaching, i.e., as looming, during big crescendos, while in other halls such looming does not occur. (It is likely that this observation is similar to the observations of spatial responsiveness discussed by Marshall and Barron[27] and the spatial impression[28]).

Continuing with the psychological viewpoint, such looming sound may be associated with a threatening situation and consequently to tap into our defensive behavioural system of fight or flight. In the context of motivational distance perception, it has been found that threatening stimuli evoke approach orientation when we are unable to flee from the situation and in such situations, the stimuli are perceived as being close. Attending a performance in a concert hall can be considered as a situation which we virtually can not escape, and if the sound is felt as intimidating it is consequently experienced as being closer than if it is not felt threatening. Thus, if certain acoustics support or promote auditory looming, the sources could be perceived or felt as being closer than when the acoustics does give such support.

Several additional remarks can be made about the looming phenomenon what corrobarate its importance for auditory perception in concert halls. For example, a continuous increase of acoustic intensity is known to be an indicator of looming[29], so a crescendo by default may produce this effect. Stimuli increasing in intensity have also been found to be perceptually louder[30], longer in duration[31] and to change more in loudness than equally decreasing stimuli[29]. Furthermore, there is evidence that approaching sounds are perceived as starting closer and stopping closer than equidistant receding sounds[32], as well as to elicit higher ratings of emotional arousal with musical chords[33]. Anyway the strongest emotional reactions are most commonly felt in dynamic passages of music[34], such as big crescendos. From evolutionary perspective, this bias for looming stimuli has been speculated to promote a selective advantage and an extra margin of safety in respect to potentially threatening objects. Some have even hypothesized that we have a neural network which specifically responds to looming auditory motion and directs our attention to the location and movement of the sound sources[35].

Whether such mechanism exists is not clear, but it seems reasonable that the dynamic variation of the spatial cues including auditory distance, induced by the hall acoustics, promotes an enhanced feeling of being in the same space with performers. Consider that besides Beranek's and Hyde's observations, also Marshall wrote already in 1967 that "for the listener, [the desired quality] generates a sense of envelopment in the sound and of direct involvement in it in much the same way that an observer is aware of his involvement with a room he is in".[28]. This remark again is reflected in the presented psychological account of the perception of *intimacy* and the raised awareness of the surrounding space induced by the acoustical response of the halls, possible with looming or other dynamic variations of spatial cues. Note also that the visual modality can hardly offer such dynamic variation because in the concert we are effectively sitting still. On the other hand, witnessing a more energetic performance may as well influence the overall perception in other sympathetic ways.

With these concepts, we see that the feeling of *intimacy* is enhanced by acoustics which integrates our emotional involment in music to the surrouding space by enhancing the musical expressions with the feeling of spatial movement which satisfy our motive to approach the music. If the hall acoustics induce a perception of looming during crescendos, the experience of *intimacy* would be elevated not only by evoking the approach orientation, but also by the heightened awareness of the surroundings. These observations can further be coupled with the evidence that the spatial response of the hall with the musical excitation of the orchestra on the stage has non-linear consequences for the perceived sound due the shape of the human head and the location of the ears (not to mention auditory processing in the brain)[36]. In the present context, the non-linear consequences may well extend far beyond the frequency spectrum.

4 CONCLUDING REMARKS

Our previous investigations together with literature have highlighted the importance of *intimacy* in concert halls. For many, it may even be most important aspect. The descriptive profiling experiments and a recent experiment on auditory distance perception highlighted the distinction between such analytical and simple perceptions as apparent distance and more complex perceptual aspects like envelopment or *intimacy*. It is beneficial to recognize the nature of the perceptual features in terms of the mechanism of our auditory system. Here we highlighted the distinction between the 'what' and 'where' auditory pathways and suggested a task or attention modulated adaptation (cue weighting) framework, which provides an intersection for a variety of perceptual phenomena in room acoustics.

intimacy is undoubtedly a multimodal experience, and previous discussions have indicated that vision plays a crucial role in this experience. Here we have focused on *intimacy* from an auditory and psychological perspective and viewed it as a dynamic feature, which is heavily influenced by the manner how musical expressions are translated and even enhanced by the acoustics of the hall. If a hall can provide our hearing dynamically varying spatial cues, which for instance can induce a perception of looming during crescendos, the experience of *intimacy* would be elevated not only by a heightened emotional response to the music, but also by a feeling of deeper involvement with the space we are in.

Acknowledgments: We thank Dr. Sakari Tervo and Dr. Jukka Pätynen for discussions, and Jerald Hyde for making inspirational comments while preparing the paper. The research leading to these results has received funding from the Academy of Finland, project no. [257099], Emil Aaltonen's Foundation, and Finnish Foundation for Technology Promotion.

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