"ACOUSTIC PROXIMITY" – EXPERIENCE AND NEW CONSIDERATIONS

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1 INTRODUCTION

What makes a sound source appear "close" or "closer than expected" in a concert hall? And what makes us feel that the music is "coming towards us", with the help of the room, rather than having to search for the music "over there"?

"Proximity" and the related concept of "acoustic intimacy" have preoccupied many acousticians, from Leo Beranek to Jerry Hyde, Mike Barron and Tapio Lokki[1] to name but a few – yet it has proven difficult to define the concept and even more difficult to find acoustic criteria that might correlate with subjective proximity.

Through a review of existing research and auditory experiences (in real and simulated halls), it will be shown that acoustic proximity is linked to the information that acoustic reflections tell our brain about the environment we are in.

2 PROXIMITY AND THE MENTAL MAP

2.1 Multi-sensory aspects and the notion of expectation

Some aspects of subjective perception can be better understood if we consider that the input from all of our senses is combined in the brain to create a "mental map" of the space we are in. Our brain creates this cognitive 3D model of our surroundings continuously, and our mental map of very familiar spaces even enables us to navigate in the dark – just like finding one's way to the bathroom at night without switching on the light.

Acoustic reflections from room boundaries tell us something about the space we are in and are used by the brain to contribute to our "mental map". Closing the eyes, even sighted listeners can estimate physical parameters of a room like ceiling height or distance from the rear wall, while the blind develop a more acute ability in this respect, as has been shown by Halmrast[2]. On the other hand, in situations where we know the physical parameters of the room we are in, this creates expectations about the sound we should be receiving and hearing.

Leo Beranek introduced the parameter of Initial Time Delay Gap (ITDG)[3], linking it to the notion of acoustic intimacy. In a discussion with Jerry Hyde and the main author of this paper, Beranek argued (or shall we say admitted) that the main reason for the importance of ITDG is that a longer ITDG shortens the "time interval available for reflections to arrive before the 80ms threshold". At the same time, it should be clear that a long ITDG will indeed indicate a "big room" to the brain, creating the expectation of a weak sound and large distances.

Mike Barron[4] found that vision strongly influences the perception of sound, in his case the perception of (subjective) loudness. Presenting the same acoustic stimulus (recording of an orchestra) either with a photo of the orchestra from a close seat (main floor seating) or with a photo of the orchestra from a distant seat (top balcony seat), the stimulus was judged significantly louder for the more distant visual image: vision and knowledge of the physical distance to the source (orchestra) therefore creates expectations around how loud the orchestra should be. In fact, what Mike Barron finds in his research is that all seats following the Barron curve (as G over distance) are being judged as being equally loud subjectively.

Eckhard Kahle[5], in his doctoral thesis on objective measurements and subjective evaluations of concert halls during live performances found that the answers to the question of "acoustic distance" correlated best with the measurement of "physical distance". No acoustic criterion could be found that correlates better to "acoustic distance" than the measurement of physical distance (measured as time of flight during the measurements).
All participants in these listening tests were sighted people. Given the ability of blind people to effectively understand their surroundings based on listening, we might expect the result to be generally similar for blind people. Obviously, this would be a highly interesting study to carry out.

Considering the above findings, the experimental setup used by Lokki et al.[1] is extremely interesting in that it fixes many parameters while eliminating visual distance cues: for each different concert hall tested, the measured 3D impulse responses used to generate the laboratory listening tests all used an identical physical distance of 12m from the loudspeaker orchestra to the measurement position. Furthermore, no visual cues were given during the laboratory listening test. This actually means that this study investigated "secondary effects" – but nevertheless extremely important effects – as objective (and visual) distances were eliminated as parameters.
Citing the end of the paper's abstract, Lokki et al. found that "even though all halls were recorded exactly at the same distance, the preference is best explained with subjective Proximity and with Bassiness, Envelopment, and Loudness to some extent. Neither the preferences nor the subjective ratings could be fully explained by objective parameters (ISO3382-1:2009), although some correlations were found."

In conclusion: even though – or especially as – the physical distance was eliminated as a parameter in the test, the notion of "proximity" is essential in the analysis of the subjective judgments of concert halls. In Lokki's tests, subjective Proximity was both the "consensus parameter" between two groups of listeners with different preferences and provided the best correlation with preference.

2.2 Stream segregation: source presence and room presence

In addition to the notion of the spatial "mental map", the brain is also continually identifying and locating sound sources in our environment and placing them in the mental map. The separation of environment and sources – essentially the "cocktail party effect" – is more generally referred to as "stream segregation" and this notion is helpful in the analysis of the perceptual effects of reflections. Laboratory experiments by the room acoustics group at IRCAM[6] indicated that when listening to music our brain focuses both on the source (the content of the message) and the room (the environment we are in), thus processing the incoming information into two parallel streams. This notion was confirmed in the analysis of the results of the listening tests in real halls[5].

Concerning the question of proximity, the first question is, simply put: which reflections are integrated into the source stream (i.e. are being integrated into source loudness and source presence) and which reflections are integrated into the room stream (i.e. are being integrated in the room loudness and room presence)?

2.3 Experimental observations on early reflections

How do reflections influence our "mental map"? What effects can reflections create?

The answer is “much more than one generally thinks”, and clearly much more than the ISO parameters would indicate. Much of the following discussion would need more controlled experiments to be statistically significant and to be fully conclusive. But there are clear relationships and cohesive aspects of perception that are indicated by these experiences and that should be considered.

- **Ceiling height**: delayed zenithal reflections raise the perceived ceiling height and increase “acoustic openness”.
  This effect can be experienced in concert halls equipped with a movable ceiling of adjustable height such as Stavanger Fartein Valen Concert Hall. It is however most easily demonstrated with a reverberation system: delaying the ceiling reflections[6] of ceiling loudspeakers by 20ms in an active acoustics system creates an increase of perceived ceiling height of approximately 3m (20ms corresponding to 6m flight time).
  In architectural acoustics, the perceived ceiling height for low ceilings can be moderately increased by reducing the strength of the reflection (for example by using convex curved reflectors, or by adding diffusion).
  The observations indicate that both arrival time and strength of reflection influence our spatial perception of the ceiling height – and this indicates that both arrival time and strength of reflection are being processed by our brain.

- **Cornice reflections**: with a delayed reflection from an upper side wall loudspeaker in the Bechstein Hall project, it was possible to create an (acoustic) image of a higher side balcony.
  The image was so strong that when closing the eyes one could imagine a balcony in the space… i.e. creating a visual image that corresponds to the acoustic image…

- **Diffuse side wall reflections**: during a visit to the Elisabeth Murdoch Recital Hall in 2010 during ISRA Melbourne, Tapio Lokki and Eckhard Kahle noted that the highly diffusing parterre side walls of the hall both increased the acoustic distance between the stage and the main floor parterre and weakened source presence.
  Incoherent, non-phase-preserving reflections are not fully integrated into the loudness of the source, as our brain cannot fully recognize this energy as belonging to the source. In the notion of source presence vs. room presence, the energy of diffuse reflections is not fully (or not at all) part of the source presence. This can be advantageous in some rooms like in recording control rooms or small rooms, but certainly decreases source presence in large rooms.

- **Rear wall reflections, temporal aspects**: short-delay reflections from behind are processed by the brain as frontal reflections. This (highly counter-intuitive) observation was made both in physical rooms and with reverberation systems. It seems that reflections arriving from behind within less than 20 to 30ms delay after the direct sound are processed as frontal reflections, leading to an increase in loudness and source presence, but not increasing spaciousness and not creating the effect of “sound arriving from the rear”. This was observed in Stavanger Concert Hall, where in the first rows of the (quite long) first balcony the geometrically optimized reflections from the rear wall arrive sufficiently late and are perceived as “reflections from behind”. On the contrary, in the 3rd to last row of the 2nd balcony the reflections arrive earlier and there was no impression of a reflection from behind. Following this observation, during the commissioning of the reverberation system in the Bechstein Hall project, a deliberate test was done with a variable delay for the rear wall loudspeakers (more or less directly behind the last row of seats): a delay of less than 20ms after the arrival time of the direct sound created a loudness increase but no perception of a reflection from behind, while greater delays clearly added a perceivable reflection from behind and subjectively “pushed back” the rear wall, creating greater envelopment and improved acoustic proximity for the rear seats.

- **Rear wall reflections, spatial aspects**: listening from the balcony of a hall with a highly broken up, large-scale diffusing back wall made from prisms and pyramids, this back wall was surprisingly absent acoustically, even at distances that lead to reflections well above

20ms delay with respect to the direct sound.
Does a reflection from behind need to arrive from a “plausible direction” to trigger the acoustic image of a back wall?

The above examples clearly indicate that acoustic reflections – both natural and virtual – contribute to our “mental map”, sometimes to a degree of creating auditory and mental objects that do not exist in the visual reality, and sometimes even removing visible real-world objects (such as a rear wall) from our mental map.

2.4 Projection and the connection between stage and hall

In Casa da Música Concert Hall in Porto, during optimisations of the stage acoustics, the inclination angle of the convex curved, inflatable canopy above the stage was changed from “horizontal” to “projecting towards the audience”. Listening from the same seat in the hall (about row 10) the acoustic proximity was strongly increased (subjective reduction in distance) and source presence increased. Other listeners indicated that the “music is now coming towards me” rather than “me having to find the music on stage in front of me”.

In Stavanger Concert Hall, the smaller but equally convex curved reflectors above the stage were also angled towards the stalls for better projection. While this had a relatively small influence on the early reflection coverage back to musicians (due to the convex curved underside), the musicians instantly noted a large perceptual difference as they could hear a much stronger hall response: “we can hear much more of the reverberation of the hall” was their main comment.

In Salle Ansermet, a 200-seat chamber music hall in Geneva with an array of convex reflectors both over the stage and over the audience, changing the angle of one line of reflectors above the first row of audience members produced a strong acoustic change on stage – even though the reflectors were several meters in front of the stage position and could/should not create any early reflections directly to the musicians on stage. The subjective impression on stage was that “contact” to the hall was improved.

It can be hypothesized that acoustic projection is linked to energy exchange between the stage enclosure and the audience chamber and that an improved energy exchange will change both the mental map and enhance acoustic proximity. Optimally angled reflectors can also act as a “mirror” of the hall sound, improving the connection of the hall acoustic back to the musicians on stage.

2.5 Effects of spatial distribution of late reverberation

The spatial distribution of late acoustic energy and reverberation also has a strong effect on proximity.

Frontal reverberation – and especially reverberation from around the source – has a tendency to increase subjective distance and to reduce both proximity and clarity. Reverberation from behind, on the other hand, can increase proximity.

This can be explained using the notion of room presence and our expectation of where we are in a room based on the spatial balance of reverberation: if the “centre” of the reverberation is around or behind the listener, subjectively the acoustic cue is that the listener is close to the source, while the listener is subjectively further away from the source when the acoustic centre of the reverberation is in front (of the listener). Most likely this relates again to expectations: in situations where the room is more “active” acoustically around and behind the listener, the listening position is typically closer to the source (and vice versa).

This is graphically demonstrated by the following image from Tapio Lokki's study on rooms for speech[8]: frontal reverberation increases subjective distance and reduces clarity.

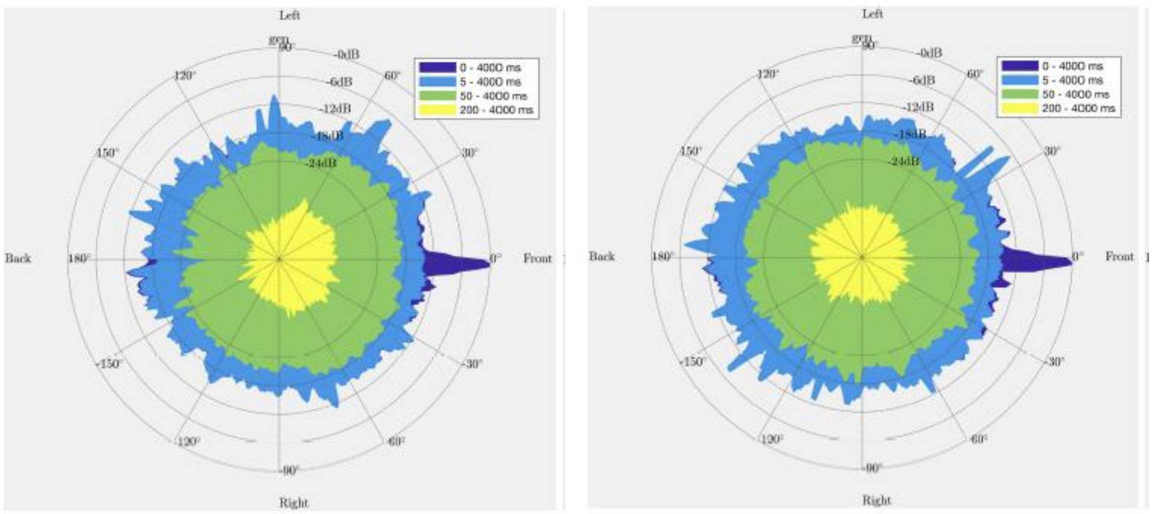

Figure 1: spatial map of frontal reverberation (wall behind speaker reflective, wall behind audience absorbing, left side) and isotropic reverberation (wall behind speaker absorbing, wall behind audience reflective, right side). Already visually one can imagine that the source is subjectively further in the left image, as there is "more happening in front of us", creating an increased perceived acoustic distance.

A highly interesting aspect of the listening tests carried out during the investigations on the perception of anisotropic reverberation by Penot et al.[9] was that the main differences were not always concerning the spatial aspects of the sound field. While listening to recorded music over headphones (with head tracking), frontal reverberation sounded dull while the same excerpt with increased reverberation from behind sounded more interesting and engaging – and better played. The most striking differences were observed with an overture by Mozart: with increased late reverberation from behind, the recording sounded more musically interesting and with increased clarity and definition, a highly significant subjective effect due to a better separation between source and room presence.

Listener comments concerning the case with increased frontal reverberation included: "distant", "less airy", "compressed", "confined", "unclear" and "nasal". Listener comments concerning the case with increased rear reverberation included: "closer", "more open", "more explosive", "more presence", "cleaner" but sometimes as well "too detached", "too separated", "better source-hall separation", "echo".

What is interesting to note in this context is that the reference (anchor point) for the study by Penot was isotropic reverberation – while in concert halls, very often the spatial distribution of energy is not isotropic. This is due to a number of factors including Barron's revised theory of sound level distribution (late sound level also decreases with increasing source-receiver distance), back-scattering of sound from seats and audience towards the stage and the fact that most of the (absorbing) audience is located in the back of the hall, leading to increased absorption in the back of the hall. This means that typical concert halls will rarely reach the state of isotropic reverberation, and many seats in concert halls may well fall into the category of "frontal reverberation", leading to a reduced perceived proximity.

For this reason, many of the best sounding concert halls have features such as choir seating, an organ and variable absorption in the rear part of the stage enclosure, which provide sound absorption in the stage area and front part of the hall to counterbalance the audience absorption and avoid the spatial reverberation balance from tipping too much towards the stage/frontal direction[10].

2.6 ISO parameters

The above discussion of detailed effects of early reflections and the spatial distribution of the late acoustic energy shows why it is not surprising that Lokki et al. found no good correlations between the notion of “subjective proximity” and ISO parameters.

There are several perceptual and acoustical aspects that are neglected or not sufficiently taken into consideration in the ISO parameters with their clearly defined, static and frequency-independent time intervals:

- Phase-coherent reflections are more easily “understood” and better integrated by our auditory-cognitive system into the source presence than diffuse reflections;
- Integration of reflections into source presence or room presence not only depends on time of arrival, but equally on direction of arrival and probably also on whether a particular reflection is masked or not. Audible acoustic “events” are processed differently compared to random energy by our brain;
- Direction of arrival and localisation of late energy can have strong effects on source presence, clarity and proximity;
- Time intervals of our auditory system are frequency dependent. A recent study on low frequency reflection integration, following the investigation of Raphaël Penot, seems to indicate that for frequencies below 200Hz the integration time of early reflections is significantly longer than for mid- and high frequencies – up to 150ms if not 200ms for low-frequency reflections on a timpani attack and roll.

Rather than thinking about strict time intervals and global integrated energy, additional details need to be taken into consideration when evaluating whether a reflection will be integrated into the source presence and source loudness or not. This is why current ISO parameters fail to fully account for key subjective attributes such as proximity, source presence and clarity.

3 CONCLUSIONS

The notion of the “mental map of a space” is helpful when analyzing the effects of both early and late reflections. Individual reflections and spatial variations in acoustic energy create cues and “events” for the brain to work with in creating and refining this mental map.

Subjective proximity is closely related to the mental map of a space. Strong, identifiable early reflections from the frontal hemisphere seem to enhance the connection between the listener and the source and therefore enhance the feeling of proximity.

On the contrary, reverberation perceived as coming from around the stage reduces the sense of proximity, by increasing the perceived acoustic distance.

The current acoustic parameters (ISO parameters) are only a very basic approximation when studying the perceptual effects of early and late sound. For a more a detailed analysis, the direction of arrival, the effective audibility of individual reflections, as well as the frequency content and the temporal envelope need to be taken into consideration.

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