

Review

Discussion of the Relation between Initial Time Delay Gap (ITDG) and Acoustical Intimacy: Leo Beranek's Final Thoughts on the Subject, Documented

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Abstract: Current discussions on the objective attributes contributing to concert hall quality started formally in 1962 with the publication of Leo Beranek's book "Music, Acoustics, and Architecture". From his consulting work in the late 1950s, Beranek determined that in narrow halls, the short early delay times were an important factor in quality. Needing a measurable acoustical factor, rather than a dimensional one, he chose to define the initial time delay gap (ITDG) for a specific location near the middle of the hall's main floor. Many acousticians failed to understand the simplicity of this proposal. Beranek had learned that long first delays sounded "arena-like" and "remote", and, thus, not "intimate". This bolstered his belief that ITDG was an important objective factor he decided to call "intimacy". Most acoustical parameters can be directly measured and sensed by the listener, such as reverberation decay, sound strength, clarity. "Intimacy" however is a feeling, and over the past two decades, it has become apparent that it is a multisensory attribute influenced by visual input and perhaps other factors. [J.R. Hyde, Proc. IOA, London, July 2002, Volume 24, Pt. 4, "Acoustical Intimacy in Concert Halls: Does Visual Input affect the Aural Experience"?] Beranek's paper "Comments on "intimacy" and ITDG concepts in musical performing spaces", [JASA 115, 2403 (2004)] finally acknowledged the multisensory aspects of "intimacy" and stated this choice of the word "may have been unfortunate". He further separated the term "intimacy" from ITDG. Documentation of this pronouncement will be provided in the paper.

Keywords: ITDG; Intimacy; Concert Hall

1. Introduction

This paper discusses the controversial 55-year journey of initial time delay gap (ITDG) in the realm of understanding the descriptors of concert hall quality. Another simpler title of this paper could be "Is ITDG a measure of Acoustical Intimacy"?

For a few centuries, people who were interested in the acoustical qualities of performing spaces have discussed which attributes a performing space might or should have in order to function as it is intended. The older literature (19th Century) has descriptions of the interaction of sound with enclosures and the listeners within, often discussed in arcane language. In the early 20th century, W.C. Sabine's criteria [1] for good auditorium hearing were: (a) Sufficiently loud source; (b) no excessive reverberation; and (c) no extraneous noise. While true, the times have changed.

Leo Beranek changed the landscape in 1962 when he published his seminal work "Music, Acoustics and Architecture" [2]. The book indeed started the first modern-day discussion on concert hall design and related acoustical quality. This comprehensive work must be understood in the context of the technology which existed at that time. It focused on a list of design attributes related to the metric of reverberation time (T) and observations regarding the hall's surfaces.

Beranek's book was a thorough and prodigious effort. He will be remembered as the first acoustician to put his "neck on the block" by making direct pronouncements, with his characteristic confidence, about which acoustical and architectural attributes contribute to concert hall quality. This also provided a target for criticism as his pronouncements were not all widely or positively received, but they were a start of the discussion we've been having since that time and are having today. For taking a chance and boldly starting the conversation, Leo Beranek deserves our respect and thanks.

For some perspective of the technical setting in which Beranek made his assessments, we must take a look at the instrumentation and measurement systems of those times in the 1950s when his opinions were being formed. The electronic instrumentation basics at that time were microphones, graphic level recorders, filters and importantly our ears. See Figure 1 for a setup typical of the era.

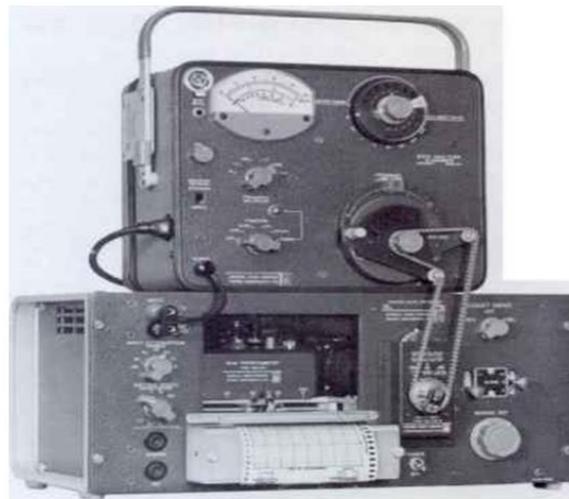


Figure 1. Graphic level recorder and filter set, ca. 1960.

Coincidentally, in 1962, the year of Beranek's benchmark book, the author was a lab assistant for the iconic Vern O. Knudsen (Founder of the Acoustical Society of America, Professor of Physics Emeritus and Chancellor of UCLA) at UCLA. As a young physics student, the author took reverberation chamber measurements using this instrumentation, taking decay curves, drawing best-fit lines through the unique squiggly sound decays and calculating the time (T) for the sound to diminish by 60 dB (See Figure 2). For both those who remember, and those who weren't there, it's important to remind ourselves of the existing level of electronic technology of the 1950s. We, thus, understand that T was the only readily available objective measure of acoustical quality at that time.

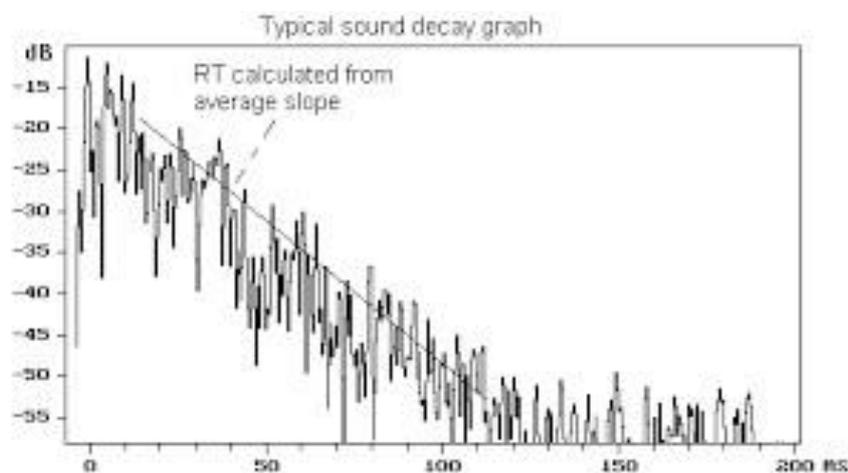


Figure 2. Sound level decay in dB versus time.

2. Acoustical Intimacy as a Concept

The experience of music being intimate had its origin a few centuries ago when it was performed by small groups of musicians in small rooms. In most cases, the attendees knew each other or at the least were known to the patron providing the entertainment. The setting was by definition “intimate”, and the term conjures the feeling of the small size of the performance space and the sound field which exists therein.

2.1. Subjective Acoustical Factors and Common Experience

As terminology along with technology developed over time, important subjective factors which have been determined relevant to the perception of music in concert halls include reverberance, loudness, clarity, spatial impression, warmth, and intimacy (Table 1). Of these six subjective acoustical descriptors, the first five relate in varying degrees to our common experience as listeners in concert halls. The judgment of reverberance, for instance, is a perceivable concept for most people. Another generally understood acoustical term is that of loudness, a concept common to virtually everyone’s daily experience. Evaluation of the value of these factors in a concert hall would easily be made by listeners asked to make such judgments.

Intimacy, on the other hand, does not readily lend itself to interpretation. Whereas, reverberance and loudness are somewhat singular in their experience, intimacy appears to be multidimensional in character in that it is more of a feeling, comprised of a combination of concepts relating what we hear to the perception of the space surrounding the performance and indeed to the observation of the space and the performance itself.

Another way to express the complexity of acoustical intimacy is to say that it is probably not an independent or orthogonal subjective attribute. Rather, as has been suggested by Kahle [3], it may be a dependent factor which is strongly correlated with other subjective factors, as well as with objective geometric and dimensional factors (confirmed both by the ear and visual inspection).

Table 1. Primary acoustical factors of large performing spaces [2,4,5].

Subjective Attribute	Description	Objective Factor
Reverberance	Reverberation	T
Loudness	Sound Strength	G
Clarity	Clarity	C ₈₀
Spatial	Image Broadening	LF _{early}
Impression	Envelopment	LF _{late}
Warmth	Warmth	G _{125 Hz}
Auditory Intimacy	Feeling of Closeness to the Performer	?

2.2. Acoustical Intimacy Defined

The traditional definitions of “intimate” expose the difficulty of applying the term to an actual dynamic, physical, multisensory experience involving the perception of the performance of music. There is little reference to intimacy in the listening context prior to Beranek’s seminal 1962 work [2], where he said that “a hall has intimacy if music in it sounds as though it is being played in a small room.” Several references relate intimacy to the perception of the size of the room, whereas others refer to feeling close to the performance.

Barron [4] has defined Intimacy to “one’s degree of identification with the performance, whether one feels acoustically involved or detached from it.” Beranek [5] selected the term intimacy to “characterize the listening attribute of the closeness of communication between the listener and the orchestra” or other sources of music.

In a survey of acousticians, Hyde [6] found the most common definitions of intimacy as being “closeness to the performer” and a sense of “the room sounding smaller.” Moreover, a good discussion on intimacy can be found in a recent 2018 paper by Lokki and Patynen [7] on Auditory Spatial Impression, where they point out that this aural aspect of a concert hall can be described as intimacy, proximity, presence, and engagement. They suggest that they all mean the same perception, which is suggested to have a major positive influence for preference.

3. Leo Beranek and ITDG

3.1. Relating ITDG to Intimacy

While a small hall has acoustical and visual intimacy, a large hall will only hope to possess intimacy if there are surfaces and reflectors which provide the reflections of a smaller space. Thus, Beranek stated that the listener’s impression of the size of a hall is determined by the time delay of the first major reflection after the Direct Sound (ITDG) at a location near the center of the main floor, approximately 2/3ds of the way back from the stage. He further observed that halls known to have intimate acoustics had ITDG values at or shorter than 20 ms and that the shorter the ITDG, the more intimate the experience [6,8,9]. It is notable that, thus far, Beranek has made no mention of the directionality of that first reflection relative to the receiver. This particular omission has led to some less than ideal acoustical designs, including high profile examples.

3.2. Other ITDG Benefits, Issues

Beranek has also said that intimacy relates to “loudness of the overall sound, since the listener assumes that performance sounds louder in a small room than in a large one” [10]. In addition, he states in his last book [11] on concert halls and opera houses (2004) that with a short ITDG, more reflections can occur in the first 80 ms after the arrival of the direct sound, and that more early reflections produce a greater feeling of intimacy. Part of the reason for this result is that more early reflections contribute to greater loudness even in a large room. Finally, he states that others who have used only one or two reflections after the direct sound in subjective lab tests, and have found ITDG not correlated with intimacy, have not performed a meaningful experiment. [9]

3.3. ITDG, a Measure of the Hall, or of the Seat Location within Each Hall?

Importantly Beranek meant ITDG as a factor relating to the overall conditions of each hall. A potential problem with this approach is in allowing one value derived from one location to represent the acoustics of an entire hall on average. However, because of the limited technology at the time of his proposal, this factor became a surrogate for the dimensions of a hall, and in most cases of the best halls, it became a measure of hall width and length. Rather than specify a dimensional design factor, Beranek chose to define the time delay associated with each space. Thus, ITDG defines the general characteristics of the hall, and does not, nor was it intended to, relate to the early delays at the many seats within the hall. Many acousticians failed to note this distinction when analyzing the metric.

Decades later, we can reason that ITDG evolved to be an early surrogate for the Spatial Impression derived from early lateral reflections, not yet defined at that time. Seen in this light, ITDG in its simplicity may well be a measure of concert hall quality.

Barron’s studies [12,13] confirm this from data derived from the judgment of real halls by many listeners during live concerts. He found that the perception of loudness is directly correlated with the objective sound strength, and that intimacy is best correlated to the total sound level. His results found no correlation between “ITDG” and subjective intimacy as a function of seat location. Lokki and Pätynen [7] have also come to the same conclusion, and these results confirm Beranek’s point of the importance of the single measurement location. Barron’s “ITDG” study refers to the delay time of the first reflection at each seat in which a judgment was made (and at which objective data were measured), so Barron’s statistical analysis and conclusion vis-à-vis ITDG (the single hall position measure) isn’t

technically correct. Lokki and Pätynen [7] point out that ITDG ignores the overall level (i.e., perceived loudness) and spatial location of first reflections, resulting in a ceiling reflection and side wall reflection supposedly giving the same intimacy which of course is not true. Thus, when reporting ITDG, one must be clear that it represents the hall in general and does not apply to the array of seating. To be clear, Beranek never said that ITDG applied to all seats—and he was adamant that it didn't.

3.4. ITDG Proclaimed as a Major Factor in Concert Hall Quality

Beranek's evaluation and determination of hall metrics were basically informed in the 1950s through his experience with large venues where he improved the acoustics with the application of overhead acoustical panels. One criticism of his systematic evaluation of halls was that he relied mostly on his relationships with conductors, management/musicians and music critics. Musicians and conductors don't hear the same room as the audience and evaluation from acousticians, and a knowledgeable public was largely absent from his analysis. However, at that time, Beranek worked with what he had.

The Tanglewood [2] project is his prime example of taking a large, 5000-seat fan-shaped space with poor acoustics and significantly improving it by adding overhead reflectors, within the reverberant volume, and thereby reducing the delay time of the first reflections significantly to around 20 ms. There were several other halls where overhead panels were used to improve the acoustics by this approach, and they were the genesis of his early pronouncements of the prime importance of the ITDG in concert hall design. However, this did not take into account the directionality of the first reflection at the listener, seen by many as a flaw in its use alone as an important objective factor.

3.5. Beranek's 1962 Hall Quality Rating Scale

In 1962, Beranek chose eight factors to define hall quality, each of which is given a percentage contribution to the whole. These factors were assigned the percentage ratings given in Table 2. Intimacy, as defined by the ITDG, was allocated a whopping 40% of the entire hall quality index—nearly three times more weight than any other factor. Note that these factors are only based upon the measurement of T and on observation of the space. ITDG was measured with a ruler from architectural drawings. By the time of his next work on hall quality in the 1990s, with the advent of measurement technology, this list below and several of its factors were severely modified.

Table 2. Beranek's 1962 acoustical factors regarding concert hall quality (100 pt. rating system) [2].

Factor	Method	% Rating
Intimacy (ITDG)	Ruler	40%
Reverb. Time (T)	Measured	15%
Warmth (T_{LF}/T_{MF})	Calculated	15%
Direct Loudness Not too Loud Not too soft	Distance by Tape Measure or Ruler	10%
Reverb.Loudness $\approx K \cdot (T/Vol.)$	Calculated	6%
Balance/Blend	Observation	6%
Diffusion	Observation	4%
Ensemble	Observation	4%

4. Multisensory Integration—Auditory and Visual Input

4.1. *Perceptual Phenomena and Psychology of the Integrated Experience [14]*

All experience is fundamentally multisensory. That is, we have evolved as a species by integrating converging sensory input in order for the information to make the most sense and be the least ambiguous. The product of these integrative processes is called “perception” [15].

There are significant differences between “seeing” and “hearing” as opposed to the perception of an event which uses both senses. Generally, the visual modality predominates. Where the intensities of stimuli are similar, the visual effect on aural perception is greater than the effect of sound on visual perception [15]. The ventriloquism effect is a well-known example.

Since sensory systems have evolved to work together, the synergy between auditory and visual systems are generally evident in our experience. One common example is the perception of speech in a noisy room. Visual cues significantly enhance the processing of auditory inputs providing the functional equivalent of altering the signal-to-noise ratio of the stimulus by up to 15 to 20 dB [16] depending on the “stimulus set” and context of the information (for instance, if the words and phrases are commonly known to the listener). The extreme of this processing example is that of lip-reading, where there is no aural signal, yet the information is transmitted and perceived via visual stimulation. Further to this, MRI brain studies [17] show that the sight of lip movement alone actually stimulates activity in the auditory cortex. The sight of a conductor leading an orchestra may well do the same.

There are many examples in cognition psychology where seeing a source actually affects what we perceive we hear; in other words, with visual input, the brain process actually alters the perceived frequency content of the source. A well-known example of this is the McGurk effect [18,19] where the brain’s multisensory integration system actually modifies the signal of the aural input. This is a palpable example of receiving one signal yet “hearing” a different event depending upon what one sees. One would expect that this sort of sensory integration would happen in the concert hall context where the visual aspects of the event are of similar intensity as the aural.

4.2. *Perceptual Aspects of the Concert Hall Experience*

To acousticians, the aural experience is generally the singular issue of concern in the evaluation and study of performing spaces and indeed in their enjoyment as well. Also, subjective laboratory tests rarely include concomitant visual cues. Of course, attending a concert or opera is entirely a multisensory experience, and the visual aspects of it are hypothesized as being important and even relevant to the evaluation of overall acoustical quality.

Visual input in the performance space context is comprised of both static and dynamic queues. Visual static input relates to the perception of the room’s boundaries, their size and orientation, lighting, texture and color, the framing of the performance area and, to the individual, the physical relationship of the observer to the boundaries, as well as relationship with the performance, including distance, degree of elevation, and degree off the room’s axis. Visual dynamic input relates to the movement of the performer, including the conductor, the synchronicity of movement and cadence of string and other players and the movement and expression of the soloist. The degree to which an observer integrates and uses this information depends on the amplitude of movement and the size of the dynamic image which is inversely related to distance.

Indeed, it can be argued that it is the magnitude of the visual input relating the source-receiver distance that determines the amount of “information” and the magnitude of the experience transferred to the observer. As with speech, music is produced in rhythmic patterns often with a low frequency modulation spectrum of about 4 to 5 Hz, corresponding to articulation peaks on the order of 200 ms. The observer’s degree of exposure to the cadence, magnitude of movement, even the location of actual instruments which produce the different sounds, may be said to enhance the experience by adding visual information coherent with the acoustical field. It is hypothesized here that this distance

related effect of dynamic visual input is closely related to the concept of intimacy on the basis that source-receiver distance is a bimodal factor.

Both static and dynamic visual stimuli relate to distances and boundaries and therefore to major architecturally important issues producing the acoustical field. Thus, the fundamental issues of size and volume of the enclosure determine acoustical properties, such as the direct sound level, early sound field, and reverberation time. Further design related acoustical properties include sound strength G through the room constant (highly dependent on the number of seats), and the degree and direction of early and late reflections.

4.3. Survey of Opinions on Auditory-Visual Aspects of the Concert Hall Experience

In the same survey reported above [6], acousticians were asked to give their opinions as to whether the visual relationship between the listener, room and the performance affects the perception of certain acoustical factors. Figure 3 shows the results of this survey of prevailing opinion, where there is near unanimity that intimacy is “definitely” influenced by visual stimuli. All acoustical factors in Figure 3 except reverberation are thought to at least “perhaps” be influenced by visual input by over 70% of the respondents. Several respondents felt that all factors were visually influenced. Second to intimacy itself, “overall acoustical quality” was considered to be highly influenced by visual stimuli. While this is clearly not a scientific study, it indicates that acousticians knowledgeable in our field believe that visual stimuli play a significant role in the perception of sound in a concert hall.

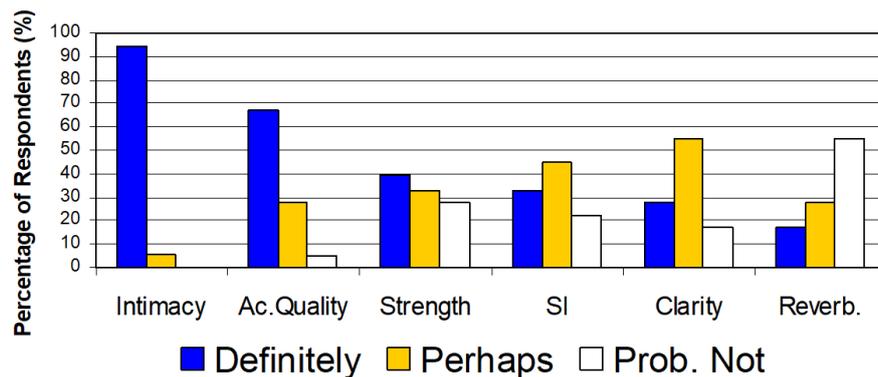


Figure 3. Opinion survey of visual influence on sound field perception (SI = Spatial Impression).

5. Beranek Changes His Position on ITDG as a Descriptor of Intimacy

After the publication of his paper on Multisensory Integration [6] at the 2002 London IOA conference, the author contacted Leo Beranek to discuss the multimodal issues raised in the paper along with results from the survey of acousticians (of whom he was one). In 2003, the author proposed to the ASA to organize a special session on Multisensory Integration and the Concert Hall Experience at the upcoming 75th Anniversary meeting of the ASA in New York in May 2004. Beranek was one of the noted invited speakers in the Session organized by the author [20], which included researchers in perceptual psychology.

In his New York ASA Paper, Beranek revealed his evolved view of ITDG and its origins related to intimacy going back to the 1950s.

5.1. Comments from Beranek’s 2004 ASA Paper in the Session on Multisensory Integration

Leo Beranek’s paper at the New York ASA meeting [21] was titled “Comments on “Intimacy” and ITDG concepts in musical performing spaces” and included the following statements:

“The purpose of this paper is threefold, (1) to document the original reasons for introducing the concept of ITDG, and relating it to the word “Intimacy,” (2) to show in a hall with

excellent acoustics what a short ITDG implies, and (3) to analyze in detail the acoustics of the Tanglewood Music Shed in which suspended panels are employed.”

“Based upon subjective judgments and then measured data . . .” it was determined that “. . . a short ITDG is necessary to ensure excellence in a concert hall, but it alone is not sufficient to create it.”

From his 2004 book [11]:

“. . . it is shown that in the best halls the ITDG is less than 25 ms.” “Because, in 1959, there were no such parameters as the Lateral Fraction and the Binaural Quality Index, greater importance was placed on ITDG than would be the case today.”

“The next question faced in 1962 was what to call ITDG. Because the sound in the original Tanglewood Music Shed and the Arie Crown Theatre both gave the impression of “remote,” it was decided to call it “intimate.”

“The ITDG is important. A short ITDG in a hall generally indicates an important contributing factor to acoustical quality . . .”

The number and strength of the reflections before the 80 ms mark are highly important contributors to acoustical quality. The reflectograms measured in rated concert halls indicate that for the best acoustical quality not only should the ITDG be short, but the reflections between the ITDG and the 80 ms marker should be large in number, relatively uniformly spaced and not too different on strength. Thus, the important parameter is not when the first reflection occurs, but whether there are a sufficient number and quality of reflections between the first reflection and the 80 ms mark. It should be noted that Beranek’s latter-day remarks, of course, imply that the first reflections are lateral.

5.2. Documentation of Beranek’s Dissociation of ITDG from Intimacy

After five decades of an ever-evolving world in the analysis of concert hall quality, Leo Beranek changed his position of ITDG being the physical correlate of acoustical intimacy. Shown here is his Email to the author in its original form (Figure 4), sent after the ASA New York 2004 conference intended to set his pronouncement for the record. Leo Beranek rarely deviated from his preferred line of thinking, but with his acceptance of new ideas, he had this change of heart on ITDG.

From: Leo Beranek [beranekleo@ieee.org]
Sent: Sunday, June 27, 2004 4:12 PM
To: Jerry Hyde
Subject: ITDG

Dear Jerry: It was good seeing you in New York. When I gave my paper on ITDG I changed one paragraph from what I sent you before the meeting. The change is as follows:

In the light of the information presented at this meeting and elsewhere, which shows that intimacy is a dual subjective judgment involving both vision and sound, this choice of word may have been unfortunate. Perhaps, at the present time, it would be best to refer to the initial-time-delay gap simply as ITDG and say that it and “texture” taken together constitute an important factor in acoustical quality. In other words, I am saying that I am quite willing to separate the word “intimacy” from “ITDG.” At this time, I shall not try to propose any objective means for estimating the subjective parameter called “intimacy.”

I send this change to you because you might want to refer to my paper in something you are writing. Best, Leo

Figure 4. Email from Leo Beranek to Jerald Hyde, June 2004.

Leo Beranek was a gracious, thorough and detailed man. At the Sabine Centennial 1994 Meeting of the ASA in Cambridge, U.S., in his acceptance speech for his Honorary Fellowship in the ASA, he told the assemblage to “be kind to young acousticians”! The author has been honored to have been the conduit of this information, and to have received his kindness and to count him as a friend, as well as a colleague. We should all be grateful for his service to our craft and profession.

Conflicts of Interest: The author declares that there is no conflict of interest.

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