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Live concert or headphone listening? The binaural signal and the musical experience.

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Localization, Source Broadening and Envelopment are among the listening aspects necessary to achieve excitement and engagement when listening to a live classical music performance. A playback of a binaural recording in headphones can quite accurately reproduce the sonic impression from the concert. In contrast, common stereo recordings techniques are very different from those used for binaural recordings. Newer generations seem to enjoy all kinds of recorded and streamed music in headphones. Can a good recording provide binaural signal qualities equivalent to those of a good live event? For newer recordings the answer seems to be no. Older recordings seems to be more similar to live, as far as the IACC-comparisons in this investigation can tell. However, a full similarity test would need more detailed investigation. Considering the nature of common practical recording techniques, similarity with live listening is not possible.

1 Introduction

Localization, Source Broadening and Envelopment are among the listening aspects necessary to achieve excitement and engagement when listening to a live classical music performance. These spatial, perceptive aspects are again related to certain features in the binaural signal arriving at the listeners ears. A playback of a binaural recording[1] in headphones can quite accurately reproduce the sonic impression from the concert. In contrast, common stereo recordings techniques are very different from those used for binaural recordings. Newer generations seem to enjoy all kinds of recorded and streamed music in headphones. This paper will compare features of the binaural signals from live classical performance with high-quality stereo recording of the same piece of music when listened to in headphones. Can a good recording provide binaural signal qualities equivalent to those of a good live event, or does the classical concert venue have something unique and irreplaceable to offer newer generations? What difference does room acoustics make to binaural signal in facilitating a musical experience? These are key questions to be addressed in this paper.

Since 2011, this author has run the Binaural Project, aiming to explore the nature of the binaural signal through measurements in live music performances with symphony orchestras. The basics of the projects are described on the project's web page[2].

In this paper, the problem complex introduced above is approached by to the question:

What differences and similarities between live concert listening and headphone listening can be seen in the binaural signals presented to the ears in the two cases?

Specifically: Would the difference between the sound in one concert hall and the sound from a record be bigger or smaller than between the two concert halls? Here, "a record" in 2020-terms would mean a wide range of available recording and reproduction formats, from traditional recording to modern streaming by YouTube, Spotify, etc.

To address the specific question, the following method was chosen.

2 Method

2.1 Data and formats

A direct method was chosen. Binaural signals from live music listening was compared with the exact same pieces of music, although played by different orchestras, reproduced via different media and played back in earphones. The binaural signal measurements were made with tiny microphones in the ear canal according to the procedure in the Binaural Project description. This technique allows the measurement objects, i.e the signal input reaching the entrance of the ear canal of the listener, to be changed without changes in the measurement signal chain. In short, the differences heard are the differences measured. Thus, any difference in perceived sound has the same cause as any difference in the binaural signal reaching the recording device. All the binaural signals forming the raw data in the investigation reported in this paper have been recorded with the one and same H2 Zoom wave-recorder, at 16-bit rate, 128 bit/s, sampling frequency 44.1kHz, and stored in the common wave-format with file extension *.wav.

2.2 Inter-aural cross-correlation IACC

Inter-aural cross-correlation IACC is a common quantity in research and findings in binaural hearing, as well as in the binaural cues and parameters in concert hall acoustics. Thus, it was natural base the investigations in the Binaural Project on IACC. The algorithm used to convert the binaural signal pair from the left and right ears, to a sequence of IACC-values can in short be described as follows

- Filtering, from each signal producing a set of 6 signals, one for each octave band 125Hz to 4kHz
- Dividing the signal into a sequence of 100ms periods, each with 441 samples
- From each 100ms period and each octave band compute the normalized cross-correlation function IACCF(i) for the 47 different lags from i=-23 samples lag, to i=+23 samples lead[1], taking values in the range [-1.0,1.0]
    - Inter-aural coherence IC=IACCF(0), is the special case i=0, with neither lead or lag, which would be the inter-aural cross-correlation from sound arriving from a source up front, i.e. a source in the median plane; in an-echoic conditions a source in the median plane would ideally produce IC=1.0
- In each 100ms period above, the highest value of IACCF(i) returned from calculations with the 47 different lags, define each term in the IACC(t) sequence in each octave band
- IACC(t)=max {IACCF(i)}, where t belongs to any sequence $t=t_0+n\cdot 0.1$s, where n=0,1,2,….

Note that the normalization of the IACCF cancels out any differences between left and right ear as to biased SPL or gain differences in the measurement chain.

2.3 Examples of IACC

In an-echoic conditions a sound source would cause the inter-aural cross-correlation function to take the value IACCF(i)≈1.0 for one of the sample-lags i, depending on the direction of arrival. Our IACC(t) is not intended to tell us in what direction the source is, it just tells us how strong cross-correlation is in the direction where the highest value is detected.

In reverberant conditions, or in any presence of noise or other sound that is not correlated with the direct sound, we would observe lower values than IACC(t)=1.0. How low depends on frequency, for the following reasons.

When sound arrives from a source at one side of the head, sound would need to take a longer path around the head to the ear on the far side ear than to the ear on the near side. From the mid-frequency (MF) range, octaves 500 and 1000Hz, und upwards, the extra path length would cause a phase difference between the two ears. In these octaves, even a single sample lag could cause a noticeable difference in the IACCF, and in common hearing models, phase differences provide the dominant ques for sound source detection and the listener aspect of Localization. Above 1500Hz, our hearing would also take cues from the inter-aural level-differences (ILD) caused by the sound shadow on the far side of the head when sound arrives from off-axis.

In the low-frequency (LF) region, towards zero frequency, the IACC(t) would approach 1 regardless of the direction of the source, since the human head is too small, and the wavelengths of the acoustic signal too long, for there to be a difference between the signals at the two ears. Examples: Figure 1; In diffuse conditions in 125Hz we observe average values around IACCL=0.90 in the late reverberant decay, i.e. after 80ms. In the early part of the binaural impulse response, we have statistically IACCE=0.93.

The significance of IACC in the LF-region is unclear, and in this paper the observations in LF will only be briefly mentioned. In the following, the octaves 500-4k will be emphasized.

[1] 23 samples lag is 0.52 ms, the delay from a 17.7cm detour around the head. In common binaural hearing models, a signal arriving from left would arrive at the right ear with approximately 23 samples lag relative to signal arriving at the left ear. With i the number of sample lags, $\tau=i/44.1$kHz, IACC(i) converts to the common form IACC(τ).

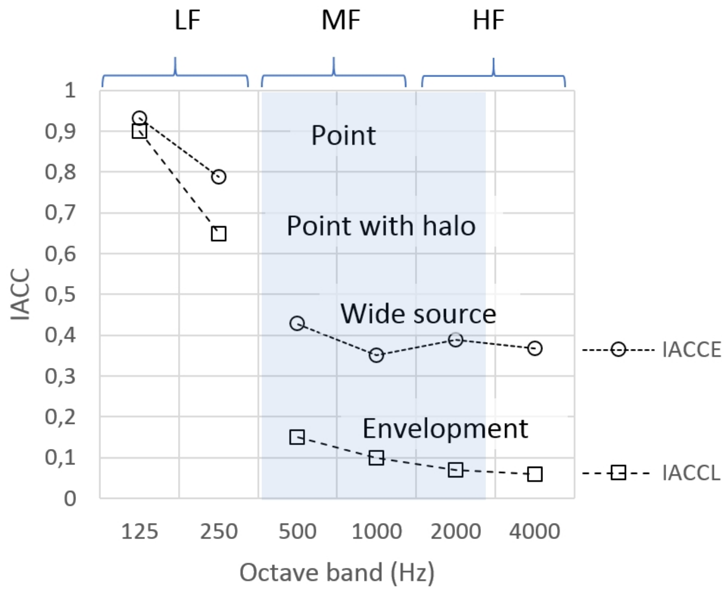


Figure 1: Left, examples of common IACC-values and typical corresponding listening aspects; Right, example of optical halo around a light source, the moon, to which the acoustical halo around a sound source is an analogue.

2.4 Interpretations of IACC in reverberant conditions, 500Hz – 4kHz octave bands

When reverberant sound is weak, i.e. with direct sound dominating and direct-to-reverberant ratio d/r>>1, IACC would take values close to 1. The point source would be perceived as point-like.

In the limit where d/r=1, if the reverberant sound is relatively diffuse, IACC would be close to 0.7. A point source would be perceived as moderately broader than at IACC=1. Some listeners would describe the broadening as a halo around the point source. If the reverberant sound is dominated by lateral reflections, the value would be lower than 0.7, while higher than 0.7 if vertical reflections dominate. The halo would be perceived as bigger for lower values of IACC.

As d/r decreases below d/r=1, e.g. if the listener moves away from the source, IACC would decrease due to weaker direct sound. The perceived halo would grow bigger and wider and eventually be perceived as a broad sound source, hence source broadening. In the average concert hall, IACC from the first 80ms of an impulse response, IACCE, would be close to 0.4 in the octave bands 500-4k, Figure 1. 1-IACCE is commonly used as a metric for apparent source width, ASW. If lateral reflections are dominating over vertical reflections, IACC would take lower values than if vertical reflections dominate over lateral reflections.

When sound comes from a group of instruments distributed over the stage, e.g. from a symphony orchestra, IACC would naturally take lower values than when sound comes from a single instrument. Consistently, like with source broadening of a single instrument, a physically broad source would in general produce a lower IACC than a point source.

When d/r approach zero, IACC could approach the values seen in the late part of the impulse response in the classical, rectangular concert halls, like those in Vienna, Amsterdam and Boston, where IACCL in the range 0.15 in 500Hz down to 0.06 in 4kHz, the lower curve in Figure 1. In this low limit, the sound image is diffuse, without any frontal emphasize.

Here, it is important to keep in mind that during a music performance, IACC(t) hardly stabilizes to a constant value, but instead fluctuates vigorously around a floating average. Instead of producing a series of discrete, ever-changing listener aspects, the merging in our hearing convert a sequence of IACC values into continuous parallel streams of listener aspects in the range between localization and envelopment, see Figure 1. This means for example that a point source could be localized and perceived with a halo, while being and enveloped, all at the same time. The floating average would depend on radiation characteristics of the musical instrument, listener distance, and properties of the room acoustics of the hall.

Example 1: Figure 2, left part. During an oboe-solo in a symphony orchestra performance in a good concert hall, IACC could fluctuate around an average of 0.60, with brief instants below zero and up to 0.98, upper quartile around 0.85 and lower quartile around 0.40. This means that 25% of the instants have values in the range 0.85 to 0.98, with strong cues of Localization. In the other end of the scale, 25% of the instants have values in the range 0.0 to 0.40. More than 80 dots below 0.20 can be counted, more than twice per second, providing strong cues of Envelopment. The mediate range between 0.40 and 0.85 would have ques of Source Broadening.

Example 2, Figure 2 right part. When the cello section repeats the melody of the oboe solo, a more compact distribution around a lower average is observed, with a naturally broader sound image from a distributed, broader source like the cello section actually is. Still, as many as 40 dots (500Hz) above 0.70 can be counted between 1140 and 1170s, on average one per second, being brief instants of point-like localization, as if the individual instruments have fluctuating directivity. In optical analogy, the cello section is sparkling.

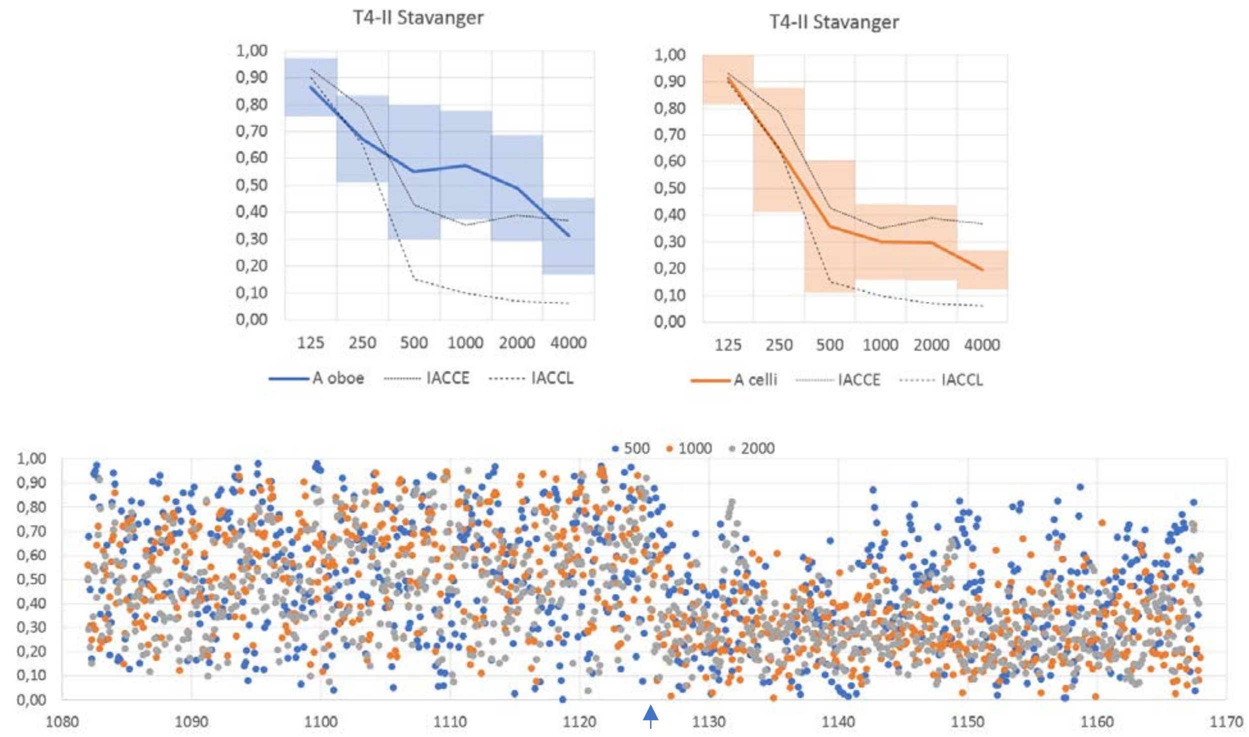


Figure 2: Lower diagram, IACC(t) in 500, 1000 and 2000Hz plotted over time between 1080s and 1170s during Tchaikovsky's 4th Symphony in Stavanger Concert Hall, beginning of 2nd movement Andantino. 1080s to 1125s is an oboe solo, while 1125s (arrow) to 1170 is the same melody repeated by the cello section; Upper diagrams are statistics from the same parts, oboe to the left, and cello section to the right, solid curves are average IACC, shaded area span between lower and upper quartiles (25p-75p), and dotted curves the references for IACCE and IACCL.

2.5 Comparison method

Differences and similarities between the various material presented below, are measured by comparing statistics from the IACC(t) data of the material. The music is divided into parts after musical category or because they are observed to have different statistics. Examples of such categories are musical categories like solo parts, string section parts, tutti parts, parts with brass, strong, soft or medium strong parts, melodic themes, and so on. Some comparisons would be estimating to what degree a transition from one part to the next happens with the same change in IACC in when comparing to versions of the same music. In particular, we would like to know whether a solo part has higher IACC than a full string section part in a recording, like it does in a live performance. For this purpose, the second movement of Tchaikovsky, abbreviated T4-II, is divided into 36 parts, T4-IV in 20 parts, and Prokofiev's violin concert in 51 parts.

Spectrograms are useful in detecting transitions between parts with significant differences, like the one in Figure 3.

IACC-profiles of each case from various material was computed. Examples of IACC-profiles of T4-II, is presented in Figure 4. In the results section below, systematic comparisons of all the investigated material, in all octave bands are carried out with a regular correlation algorithm.

In live listening, the fluctuating IACC-values typically exhibit gaussian distribution. In recording, d/r may be chosen so high that the upper tail in the gaussian distribution is forced to be truncated, which would mean a significantly different perception of music than the live listening case.

Some results call for more detailed investigation, and thus ad-hoc analysis methods.

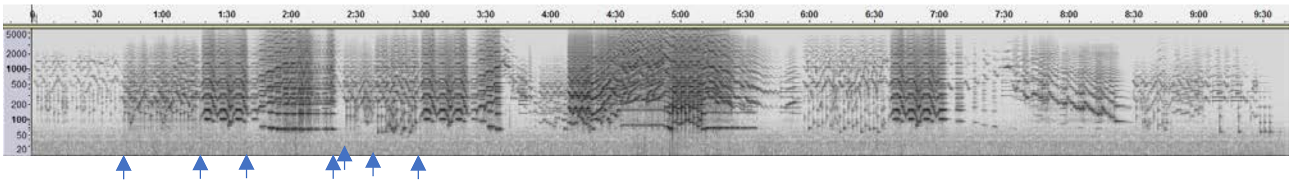


Figure 3 Spectrogram of T4-II recorded with Oslo Philharmonic in 1984; Arrows indicate some of the transtions of interest between parts with significant differences; The first arrow indicate the transition between the oboe solo and the repetition in the cellos, corresponding to the arrow in the middle of Figure 2

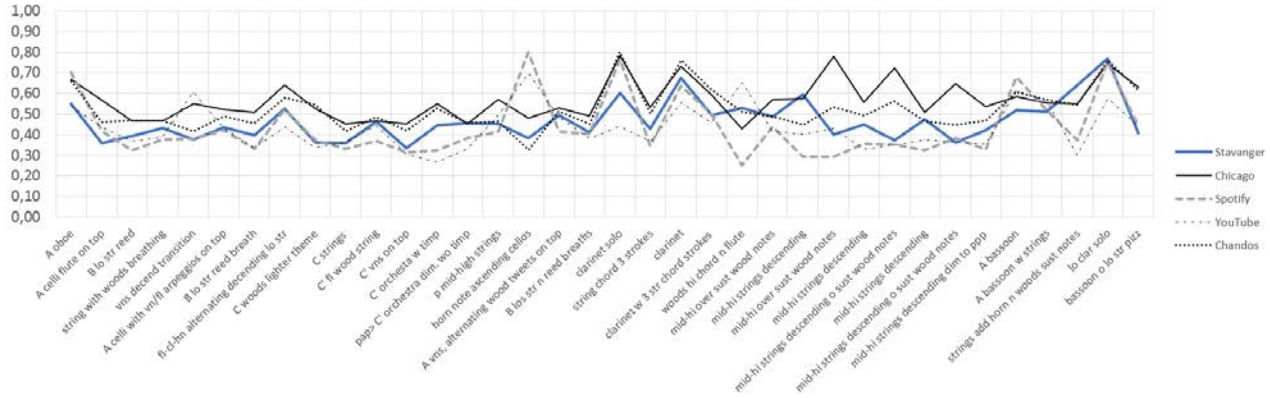


Figure 4: IACC-profiles in the 500Hz band, averages from 36 parts of the 2nd movement of Tchaikovsky's 4th Symphony, for comparison between live listening in Stavanger and Chicago, Spotify listening, YouTube listening and listening to a wave-file from a traditional recording (Chandos). Letters A, B and C are arbitrary notations by the author, to identify different themes (melodies). The leftmost parts "A oboe" and "A celli" correspond to the examples in Figure 2.

2.6 Inherent limitations in non-binaural recording techniques

In natural binaural signals, inter-aural time-differences (ITD) and inter-aural level-differences (ILD) come in pairs[3]. E.g., in an-echoic conditions a source in the median plane would come with ITD=0 and ILD=0, and a source off-axis, i.e. located at an azimuth angle greater than zero, would come in certain value pairs where ITD and ILD are both different from zero. In playback of a binaural signal, localization would be decoded by our brain. In contrast, in common stereo recording techniques, phase information is lost. E.g. with overhead microphones spaced far apart, unnaturally long ITDs would cause randomized phase differences, confusing to our brain.

2.7 Data material

Two live concerts with Tchaikovsky's 4th symphony (T4), performed by two different orchestras in two different countries, in two different years offered a starting point. From these it is possible to get an idea of differences and similarities that can occur within from one concert to another. A selection of different available down-loadable recordings of T4 was chosen from the top hits in google, when searching the expression "Tchaikovsky's 4th symphony", one bought from Chandos, one free-version from Naxos, one top hit version from YouTube, and one version from Spotify. A list of the data material in given in Table 1

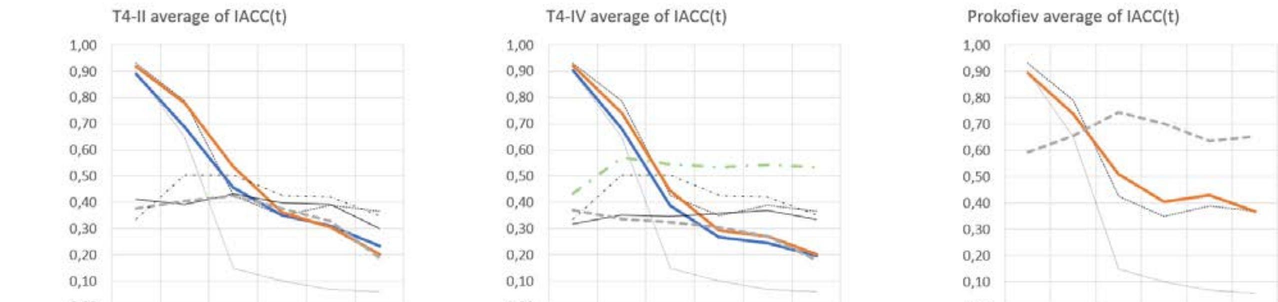
Table 1 List over the data used in the current investigation

Music	Orchestra	Conductor	Binaural recording from	Year
T4 mov II and IV	Chicago Symphony Orchestra	Richardo Muti	Live performance in Orchestra Hall, row L, Chicago	2014
T4 mov II and IV	State Achademy Symphony Ochestra St.Petersburg	-	Live performance in Stavanger Concert Hall, row 15	2012

T4 mov IV	Poland National Radio Symphony Orchestra	Adrian Leaper	Wave-file[4] in headphones	2005
T4 mov II and IV	Oslo Philharmonic Orchestra	Mariss Janssons	Wav-file in headphones, recorded in Oslo Concert Hall [5]	1984
T4 mov II and IV	Wiener Philharmoniker	Herbert von Karajan	YouTube with headphones, recorded in Musikvereinsaal, Vienna [6]	1980?
T4 II and IV	San Fransisco Symphony Orchestra	Michael Tilson Thomas	Spotify in headphones, recorded in Davies Hall, San Fransisco[7][8]	?
Prokofiev Violin Concerto, mov 1	Janine Jansen and Leipzig Gewandhaus Orchestra	-	Live performance in Leipzig Gewandhaus, row K [9]	2010?
Prokofiev Violin Concerto, mov 1	Janine Jansen and London Philharmonic Orchestra	Vladimir Jurowski	Wave-file in headphones, recorded in Henry Wood Hall, London	2012

3 Results

This section presents the results from the investigation, according to the methods described above. Average of IACC(t) in Figure 5. Basic differences and similarities are also evaluated by the correlation between IACC-profiles of each listening cases in Table *2* , by the histograms Figure *6*, and the IACC-dynamics ratio diagrams in Figure *7* and Figure *8*.



T4-II	125	250	500	1000	2000	4000
IACCE	0,93	0,79	0,43	0,35	0,39	0,37
IACCL	0,90	0,65	0,15	0,10	0,07	0,06
Stavanger	0,89	0,69	0,46	0,35	0,31	0,23
Chicago	0,92	0,78	0,54	0,36	0,31	0,20
Spotify	0,41	0,39	0,43	0,40	0,39	0,30
YouTube	0,38	0,41	0,42	0,38	0,33	0,19
Chandos	0,33	0,50	0,51	0,43	0,42	0,35

T4-IV	125	250	500	1000	2000	4000
IACCE	0,93	0,79	0,43	0,35	0,39	0,37
IACCL	0,90	0,65	0,15	0,10	0,07	0,06
Stavanger	0,90	0,68	0,39	0,27	0,25	0,20
Chicago	0,92	0,74	0,45	0,29	0,27	0,20
Spotify	0,32	0,35	0,35	0,36	0,37	0,34
YouTube	0,37	0,34	0,33	0,30	0,27	0,18
Chandos	0,33	0,50	0,51	0,43	0,42	0,35
Naxos	0,43	0,57	0,55	0,54	0,54	0,53

Prokofiev	125	250	500	1000	2000	4000
IACCE	0,93	0,79	0,43	0,35	0,39	0,37
IACCL	0,90	0,65	0,15	0,10	0,07	0,06
Gewandhaus	0,89	0,74	0,51	0,41	0,43	0,37
Decca	0,59	0,66	0,74	0,70	0,63	0,65

Figure 5: Average of IACC(t) over octave bands 125 to 4000Hz, all investigated materal. Diagrams and tables from left to right, Tchaikovsky 4th symphony 2nd movement, Tchaikovsky 4th symphony 4th movement, and Prokofiev violin concert.

Table 2 Correlation between IACC profiles in different listening conditions, where Stavanger, Chicago and Gewandhaus (Leipzig) are live listening cases, while the others are headphone listening to different recordings and reproduction media. The 500Hz column in the upper two tables (T4-II 36 parts) correspond to the diagram in *Figure 4*. High degree of similarity between live listening and listening to record is indicated by values in bold. IACC3 is average of 500-2kHz.

T4-II 36 parts	125	250	500	1000	2000	4000	IACC3
Stavanger	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Chicago	0,54	0,15	0,44	**0,87**	**0,77**	0,02	0,69
Spotify	-0,73	-0,28	0,50	**0,73**	0,74	0,09	0,66
YouTube	-0,56	-0,31	0,33	**0,81**	0,68	-0,06	0,61
Chandos	0,10	0,33	**0,71**	**0,74**	0,63	0,15	0,70

T4-II 36 parts	125	250	500	1000	2000	4000	IACC3
Stavanger	0,54	0,15	0,44	**0,87**	**0,77**	0,02	0,69
Chicago	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Spotify	-0,50	-0,32	0,47	0,67	0,69	0,69	0,61
YouTube	-0,42	0,29	0,16	**0,90**	0,70	0,63	0,59
Chandos	0,38	0,07	**0,74**	**0,81**	**0,72**	0,44	**0,76**

T4-IV 20 parts	125	250	500	1000	2000	4000	IACC3
Stavanger	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Chicago	**0,77**	0,03	**0,67**	**0,87**	0,52	0,28	0,68
Spotify	-0,62	0,42	**0,71**	**0,87**	0,57	-0,10	**0,72**
YouTube	-0,24	0,48	0,70	**0,88**	0,67	-0,06	**0,75**
Chandos	0,04	0,57	0,63	**0,80**	0,26	0,02	0,56
Naxos	-0,46	0,19	0,73	0,22	-0,33	-0,64	0,20

T4-IV 20 parts	125	250	500	1000	2000	4000	IACC3
Stavanger	0,77	0,03	0,67	**0,87**	0,52	0,28	0,68
Chicago	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Spotify	-0,19	0,55	**0,73**	**0,88**	**0,82**	0,55	**0,81**
YouTube	-0,18	0,29	**0,83**	**0,91**	**0,88**	**0,81**	**0,87**
Chandos	0,16	0,11	**0,77**	**0,87**	0,60	0,63	**0,75**
Naxos	-0,27	0,75	0,64	0,49	0,51	0,25	0,55

Prokofiev 51 parts	125	250	500	1000	2000	4000	IACC3
Gewandhaus live	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Decca record	0,33	-0,18	0,00	0,32	0,54	0,52	0,29

Histograms of the Prokofiev violin concert reveal one of the critical differences between the live listening and the recording, both with violin soloist star Janine Jansen, as explained in the caption of Figure 6. While the use of close-up microphone allows for strong control with balance and signal-to-noise ratios, the IACC can easily become statical, and very high – much higher than what would be common, not to mention possible, in live listening.

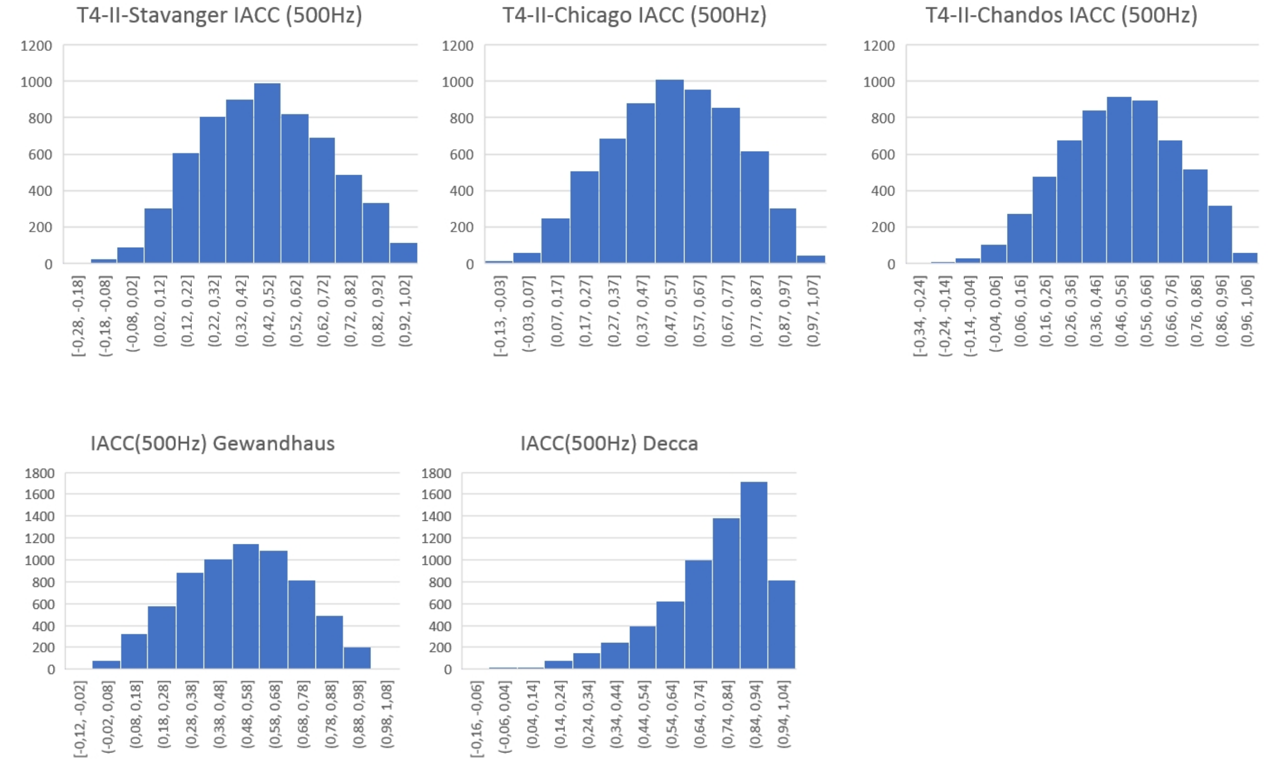


Figure 6 Histograms of IACC in the 500Hz octave; Upper row is Tchaikovsky's 4th Symphony, 2nd movement, where Stavanger and Chicago are live listening, and the rightmost "Chandos" is headphone listening to a recording from 1984 with Oslo Philharmonic Orchestra in Oslo Concert hall, all of which exhibit gaussian bell-shapes with slighly different skews. Lower two diagrams are Prokofiev's violin concert, where the leftmost, Gewandhaus, is live listening, exhibiting a bell-shape similar to those in the upper row. The rightmost, Decca, is a recording with the same violinist, exhibiting a truncated bell-shape in the high end of the IACC-scale.

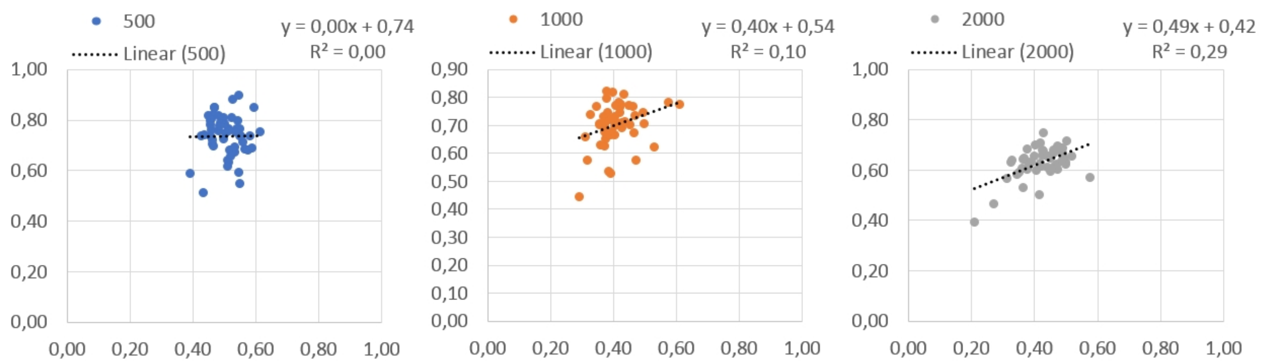


Figure 7: IACC dynamics in Prokofiev; IACC in 51 parts in live listening in Gewandhaus (horizontal axis) plotted against IACC in the same parts while listening to a Decca recording with the same violin soloist. R^2, and the factor *a* in y=*a**x indicate the similarity between IACC dynamics in live listening and IACC dynamics in the recording. R^2 =1 and *a* =1 would indicate full similarity, while R^2 =0 and *a* =0 would indicate no similarity.

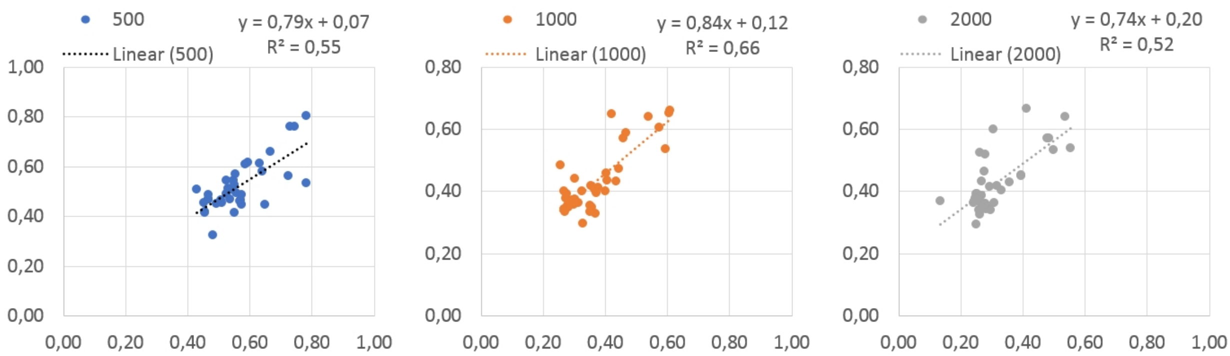


Figure 8: IACC dynamics in T4-II; IACC in 36 parts in live listening in Chicago (horizontal axis) plotted against IACC in the same parts while listening to the Chandos recording. High values of R2 and the y/x ratio indicate high degree of similarity in IACC between the two cases. When IACC increases in Chicago it would increase in the Chandros record. E.g., this means that parts with sharp Localization in Chicago would also have sharp Localization in Chandros. Conversely, when Source Broadening increases in Chicago, it will increase in Chandros.

4 Comments and conclusions

Varying degree of similarity between live listening and listening to records in headphones is seen in the results. In the Tchaikovsky cases the similarity between live listening in Chicago and headphone listening to Chandos (OFO 1984) is bigger than the similarity between live listening in Chicago and live listening in Stavanger. The Naxos recording from 2005 is an example of the opposite, similarity with live listening is poor. The poorest similarity in the material is seen between the Decca record of Prokofiev with soloist Janine Jansen in 2012 and the live listening with the same music and soloist in Leipzig Gewandhaus, row K a year or two before the recording. In general, the similarities between live and recordings are bigger in the fourth movement of Tchaikovsky than in the second movement. This author explains this by the second movement having a bigger dynamic range in the IACC, making it more difficult to emulate with common recording techniques. The diagrams in Figure 7 demonstrates why an excessive use of direct sound from close microphones creates overall high IACC-values, making it impossible to recreate the dynamics of IACC, so important to the live listening experience. This problem also manifests in the truncated bell-shape in the histogram in Figure *6*.

Some recording engineers have suggested that there is a trend towards more d/r ratio in recordings, inevitably causing problems with higher IACC and loss of IACC dynamics. In this investigation at least, this seems to be the case. The older recordings are found to offer headphone listening more similar to live listening than the newer ones.

The perceptive effect of un-natural low and random-like IACC in 125Hz and 250Hz like those seen in record listening in this material, while not in live listening, is unclear.

This investigation has been limited to use of IACC, which indeed carries information of how the degree an instant source is point-like or broad, but unlike the IACCF it ignores in what direction the source is. Any mismatch between ITD and ILD that would potentially affect the listening experience will not be included in the assessment of similarity in this paper. In common recording techniques, so-called panning (ILD control in intensity stereo) could e.g. localize the high frequencies of the violin section to the left, while their fundamental frequency could be anywhere in the sound image, since the latter is detected by ITD and its phase-differences. In a more complete assessment of similarities in future work, these issues will need to be investigated.

5 Discussion: What to expect from recorded orchestra music

While the three listener aspects of Localization, Source Broadening and Envelopment are appreciated by recording engineers, the challenges in combining them all in one and the same recording are well known. Ideally, a binaural recording, e.g. with a dummy head in a good audience position would preserve all three aspects. It would be a pure reproduction of the signal that reaches the ears of a listener at the actual position. However, a range of practical issues inevitably lead to a series of compromises. For one, the recorded sound would depend a lot on the acoustics of the recording space, and this is not always wanted. Moving the microphone position closer to the orchestra could reduce the relative influence of the room acoustics and allow freedom to add artificial reverb on demand in the post-processing. But the microphones would need to fly above the orchestra to avoid being closer to some instruments than others. While a dummy head or even a mannekin with a binaural microphone pair hovering above the orchestra could be possible, a less visible solution is chosen, often as a permanent installation in the concert venue.

A purist approach, mimicking the binaural recording conditions could be a pair of cardioid microphones in an ORTF[10] configuration, with 110 degrees between axis and 17cm between microphone membranes. Localization would be preserved, but from the above perspective the sound image, or mapping, of the instruments would very different from the one in a listener perspective in the hall. Even if existing room acoustics or the distorted perspective in a given case was accepted, a number of other problems are found important to avoid. Once the recording is done, there is no way to change the sound balance between instruments, voices, soloists and groups.

Multi-track recording technique has provided the option to add any number of microphones in well-planned positions to secure great freedom to adjust balance in the post-processing phase. Together, the demand for control and freedom, time and cost restrictions, and the possibilities from technological development has resulted in a common practice very different from the binaural approach. Basically, the introduction of more microphones inevitably leads to higher direct-reverberant ratio and loss of localization cues used by our brain from the very short path-length differences in binaural hearing. Moreover, techniques involving multi- and close-up microphones introduces issues like interference problems and a musical instrument sound at 1-2m distance that differs qualitatively from the one at common audience distance.

Some examples of compromises and the mechanism and priorities leading to them in the development of recording practice over the decades, is given in the following paragraphs.

The so-called Decca-Tree is an example of a successful overhead microphone array that produced good recordings and was frequently used from the 1950s. However, compromises were inevitable, localization ques were lost, as five times Grammy-winner sound engineer John Pellowe put it [11]:

> "The reason we did this and consistently did it, and got away with it, and got wonderful reviews and many, many awards, was simply that the localisation cues were missing, but the sound was fantastic."

After 500 records over the last 50 years, sound engineer Alf Christian Hvidsteen has noticed a tendency away from the pure two-mic stereo microphone approach towards use of more close-up microphones, leading to higher direct-reverb ratios in the final mix of recordings[12].

Even if the producer, conductor and recording engineer started out with a back-to-basics approach with a stereo-pair, the demand for adjusting the balance between voices would come up in the post-processing. At that stage, to gather the ensemble for a new take is not an option in the real world.

In the recording industry, there are numerous good reasons to comprise if accepting that the binaural listening aspects cannot all be maintained.

As a conclusion, the live listening experience cannot be replaced by playback from streaming or from a record, as long as any other recording technique than dummy head or ORTF from audience position is used. Decca-3, x-y, a-b and the use of close-up microphones would not be able to maintain the ITD- and phase information so crucial the detailed localization in our brain during live listening to a concert with a symphony orchestra.

6 Afterword, March 2021

This paper was originally written and submitted ultimo February 2020 because of the deadline for the proceedings to BNAM2020. Since then, the Covid-19 pandemic has made the content of the paper even more relevant. Due to health restrictions and lockdowns with severe impact on symphony orchestra concerts, many planned concerts were streamed or broadcasted to the audience instead. After listening to several concerts broadcasted on radio, this author noted that in addition to the listener aspects studied in this paper, reduced dynamics[2] from compressed levels in the audio signal turned out to be a critical variable. The compression issue and reduced dynamic range in radio broadcasting and streaming is well known, and frequently related to the so-called Loudness War[13].

For instance, in a concert attended by this author the Oslo Philharmonic performed Bolero (Ravel) with 22dB difference between the L25% level and the L75% level. In the broadcasted recording from the exact same performance, the level difference was merely 7dB. Bolero is often used as an example of music with extreme dynamic range.

In Figure 9 the statistics of Level and IACC in the binaural signal from live attendance and binaural signal from headphone listening to radio broadcast are compared. Note that while dynamic range is very different, the average level spectra are quite similar. IACC in 100Hz and 2000Hz are quite similar in live and radio broadcast, while considerably higher in

[2] Dynamics is here defined as the range of listening levels occuring in the 1/10s windows of the signals

250Hz and 500Hz, indicating better localization of woodwinds in live listening. In 4000Hz, IACC is much lower in live listening than in radio broadcast, which could be either a real difference in the signals or caused by noise in the live signal.

In future studies of differences between live listening and headphone listening to recorded or streamed symphony orchestra concerts, the aspect of dynamics should be included.

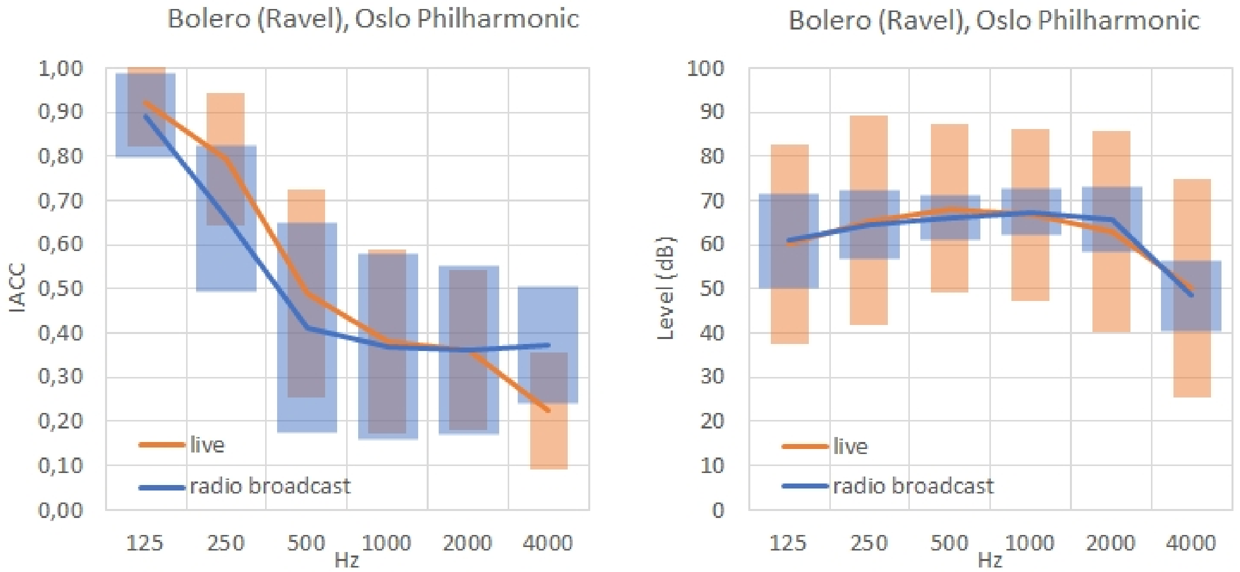


Figure 9: Comparison of statistics from two binaural signals features, IACC and Level, during 1) live attendance and 2) headphone listening from NRK radio broadcast of the exact same performance of Ravels Bolero, by Oslo Philharmonic Orchestra in Oslo Concert Hall, February 2020. Here, the radio broadcast levels are arbitrarily adjusted to match with the average spectrum of the live performance. Bars in IACC diagram are standard deviation (67% within the shaded area), while bars in Level diagram are the interval between L25 and L75 (50% of levels within shaded area).

Link redirecting to online BNAM 2021 presentation at the AKUTEK web site

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