WHEN SOURCE IS ALSO RECIEVER

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ABSTRACT

Musicians (and low budget acousticians) often judge the acoustics of a venue for music by clapping, shouting or making other kinds of more or less impulse-like sounds. In such situations, the source and the receiver is (almost) at the same position. This is a different situation than for standard measurements of room acoustics, where there is a (long) distance between the sound source (loudspeakers, pistols, balloons and musical instruments) and the receiver (microphone, ear). The sonic experience must be totally different, but still we trust our clapping and our ears. We probably "recalculate" so that reverberation times etc. judged in such a way "by ear", are often quite correct. How can this be? And: Can we learn from how a blind person uses clicking sounds made with the mouth in order to "see" surfaces and objects by the ears? In both situations the position of the source and the receiver are (almost) the same.

1. INTRODUCTION

Most acoustic characteristics and parameters can be taken from the Impulse Response, which usually is measured by standard methods like backwards integration of sine-sweeps, MLS or more easily understood: approximated by analyzing a recording of a short, broad banded impulsive sound like a pistol shot, the explosive sound of a balloon [1], or even a handclap. Most measurements in venues for music are taken with a source on stage, and receiver positions spread around in the audience area.

For investigations of the acoustic conditions for the musicians, both the source and receiver are positioned on stage [2], often with a distance of typically 1m (for the parameter ST, Support). Gade [3] indicates that 1m from the source is "comparable to the distance from the performer´s ear to his own instrument", which might not be totally correct for hand-held instruments (and of course not for singers). Also, the ST parameter has been somewhat discussed [2]. We can conclude that even for ST measurements, the source and the receiver position are not the same.

Griesinger [4] has analyzed musicians sound of own instrument back to his/hers ears (microphones on the rods of his glasses), but these measurements were mostly for analyzing Running Reverberation, meaning the acoustics experienced by the musician when he/she and other musicians play "continuously".

Cabrera et al [5] gives interesting information about methods for measuring and simulating room acoustics using oral-binaural room impulse responses, but with emphasis on speech as signal, and with little comparison with standardized measurements of reverberation time etc. for the room.

When entering a new hall, every musician claps his hands and shouts, in order to "measure" the acoustics. For such a "measurement", the musician can judge the reverberation and the presence of any distinct echoes. Of course, this clapping method does not give (and is not suppose to give) information of how good the musicians hear each other ("ensemble") nor Running Reverberation.

What happens when the receiver (ear) is in (almost) the same position as the source (hands, mouth)? And what can we learn from the specialists in the art of "seeing" rooms, surfaces and objects by using the ears instead of the eyes, namely the blind, using clicking sounds made by the mouth, in order to *echolocate*?

The measurements were done with Sennheiser "in-ear" microphone MKE 2002 and a small Edirol wav-recorder (44.1 kHz, 16 bits). (Only one ear was used for most of the measurements of room acoustics).

2. HAND-CLAPS AND TONGUE-DROPS

A typical frequency analysis of a (non flamenco) hand-clap is shown in fig.1. (200-20.000 Hz)

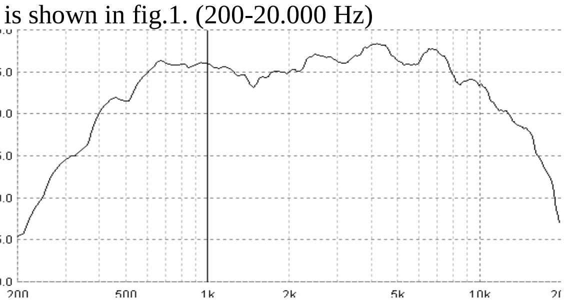

Figure 1. Frequency analysis of a hand-clap

Fig 2 shows a typical "tongue-drop" (performed by the author). The mean frequency can be somewhat changed by shaping the mouth (formant adjustable within approximately 1 octave between 600 Hz and 1.3 kHz for adult men).

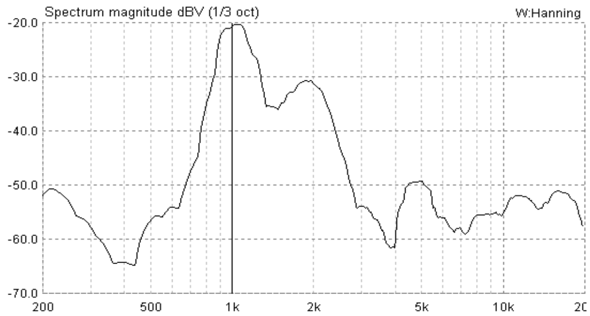

Figure 2. Frequency analysis of a tongue-drop

We see that the signals are of mid-frequency, so the can of course not be used to detect room acoustics below some 250 Hz. They might give information in most of the melodic range for music, but not low bass. (Such a restriction of course also goes for the ISO-standardized frequency range for building acoustics).

Hand-claps and tongue-drops are short signals, but of course not as short as an ideal Dirac pulse. How to indicate the duration of such decaying impulse sound are not standardized, but for both the hand-clap and the tongue-drop a duration of some 7 ms for a decay of some 15 dB is common (see fig.3, measured anechoic).

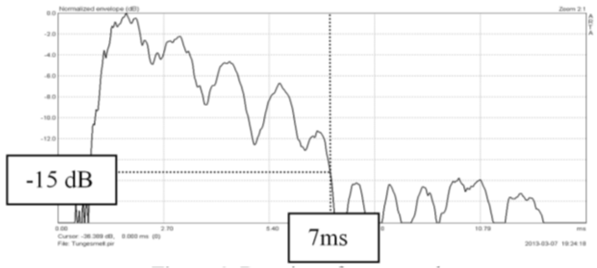

Figure 3. Duration of a tongue-drop

The Energy-Time-Curve (ETC) and the Schroeder-curve (backwards integration) of a hand-clap recorded in the clappers own ears in a room typically look like fig.4:

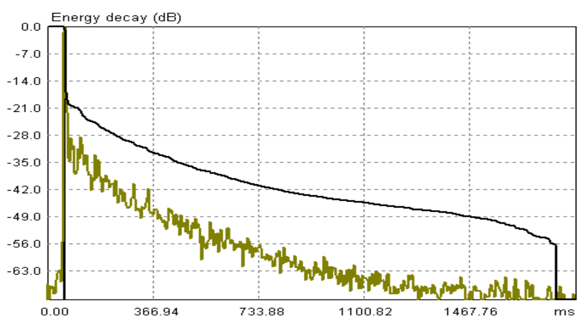

Figure 4. Typical “In-Ear” Energy-Time-Curve in a room.

We see that the drop of the sound energy (and the Schroeder-curve) in the start of the curve is much more abrupt than common for “long-distance” standardized reverberation time measurements. If we make a very rough reverberation time calculation from this figure (calculated from 0 dB), we get strange results, somewhat depending on how long decay we included in the calculation.

One default calculation method implemented in a quite good room acoustic computer program gives T60=0.02 s and EDT=0.012 s, C80=24 dB and C50=21 dB. The measurement in fig. 4 is taken on the stage of the new Stavanger Concert House, (see later). Musicians and acousticians on stage suggested some 2 s by such a “clapping-test”, which is actually close to the value measured using more standardized methods and longer distances between source and receiver. How can it be that the musicians and acousticians judged their clapping so correct? We did measurements i three room, a big, reverberant foyer, a concert hall, and a small living room/ music room.

3. MEASUREMENTS IN A BIG FOYER

The Foyer of the Institute of Physics at the University of Oslo is a big, reverberant, almost empty room with a rectangular main volume and extensions to each side.

Figure 5. Section, Plan and Photos from the Foyer

Measurements of Impulse Responses (fig. 6) were done with 1) Ordinary distance (app. 9m) between source and receiver (lower, in black) and 2) Clapping using “In-Ear”-microphone (source=receiver) (in blue).

(The difference in arrival time for the direct sounds is not important, and is kept for a clearer view)

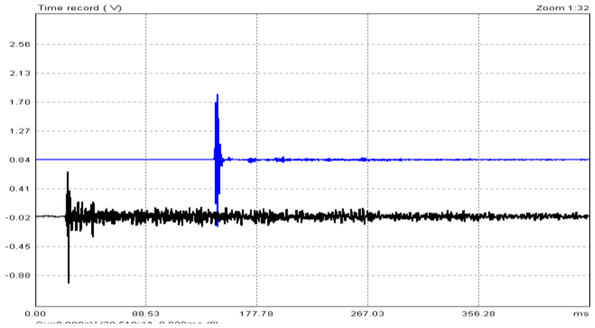

Figure 6. Impulse Responses:
Upper (blue)=Handclap, In-Ear-Mic
Lower: Standardized measurement

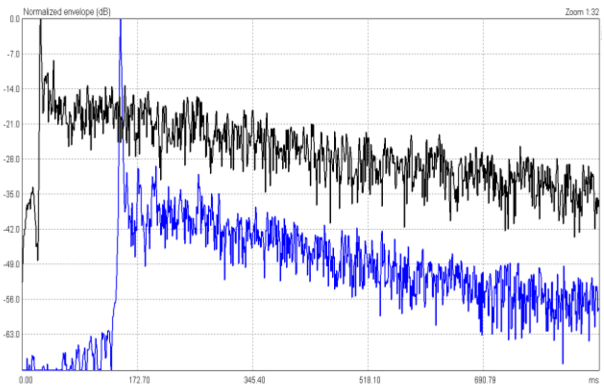

Figure 7. ETC-curves. Foyer.
Upper (black): Standardized measurement
Upper (blue)=Handclap, In-Ear-Mic

Even if the Impulse Responses look quite different we see that the decay after the strong direct sound of the “in-ear” measurements is actually (totally) parallel with the decay in the standardized measurement (see fig.7). This is not very surprising, but interesting, as the “in-ear”-measurements include also the “HRTF-filter of the head and many other disturbing effects.

The measurements with tongue-clicks also show similar good agreement. Fig. 8 shows the comparison of the ETC-curve of a hand-clap and a tongue-drop.

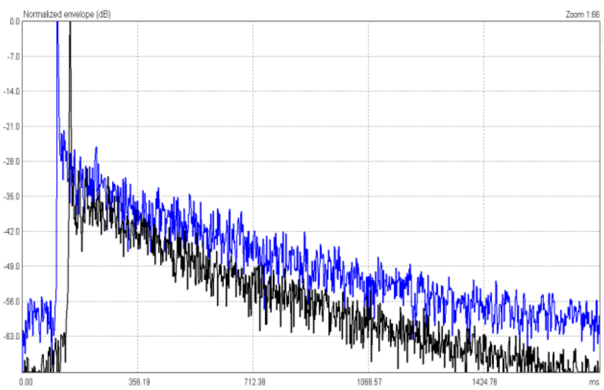

Figure 8. ETC-curves. Foyer. In_Ear-Mic
Upper: Handclap, Lower: Tongue-drop

The Schroeder curves of the three measurements are perfectly parallel (se fig. 9).

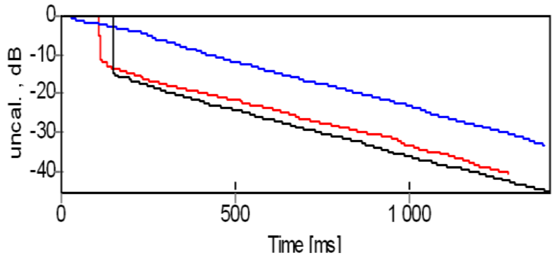

Figure 9 Schroeder-curves. Foyer. Comparison Standardized Measurement and two In-Ear-Mic.
Upper (blue): Standardized measurement
Middle (red): Handclap, Lower (black): Tongue-drop

This indicates that our ear is capable of eliminating the strong direct sound when clapping our hands when judging the reverberation of a hall.

4. STAVANGER CONCERT HALL

Stavanger Concert House opened autumn 2012, and has already got the reputation of a very good concert hall combining long reverberation and clarity. The measurements were done on an empty stage w/chairs and music stands, in an empty hall.

Figure 10. Stavanger Concert Hall

Fig.11 shows the comparison between a “standardized” long-distance (>10m between source and receiver) measurement on stage, and handclapping recorded with the “in-ear”-microphone,

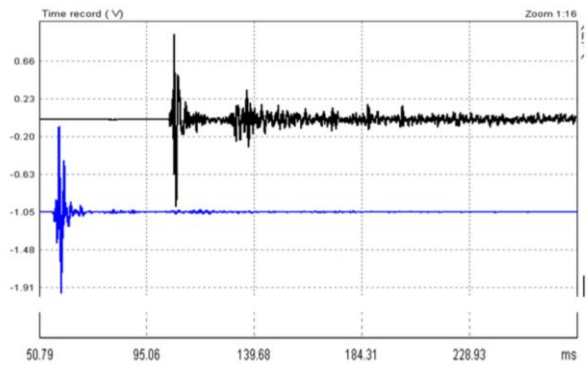

Figure 11 Impulse Responses in Stavanger.
Upper (blue): Standardized measurement
Lower: Handclap, In-Ear-Mic

and the ETC+ Schroeder curves (fig. 12):

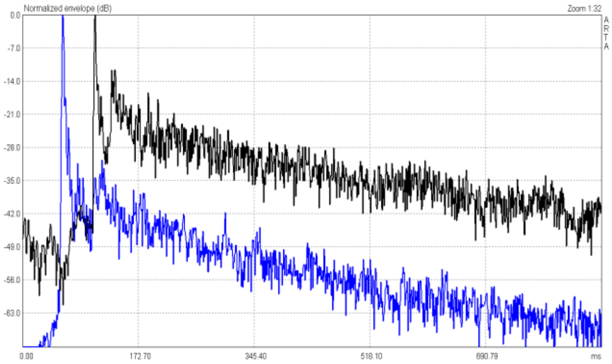

Figure 12. Energy-Time-Curves in Stavanger.
Upper (blue): Standardized measurement
Lower: Handclap, In-Ear-Mic

Again we see that the decays after the direct sound (plus some reflections) are parallel.

Such clapping/ clicking/ shouting is a very flexible test method, and because our ears (and our mouth) are directional, this type of measure ornaments can easily be performed in different directions. Fig 13 shows a comparison of handclaps recorded with “In-Ear”-microphones in Stavanger. The black curve (starting as the upper curve from 200 Hz) is taken with the face pointing outwards towards the audience, while the blue curve (which is the highest only around 2000 Hz) is for the face turning backwards towards the choir balcony/organ.

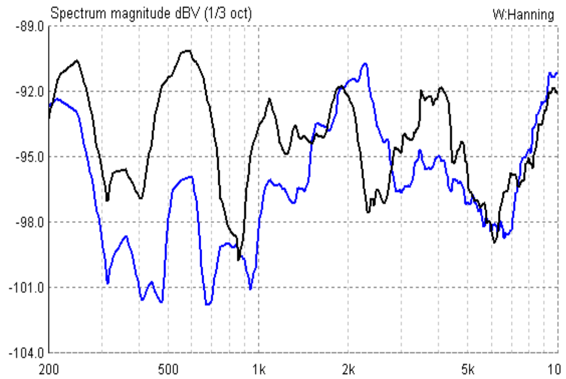

Figure 13. Frequency analysis og handclap, In-Ear.
Black= towards audience
Blue=towards organ

Such analysis is important to check that the acoustic response from the rear of the stage is not to dominating compared to the response from the main hall.

5. SMALL LIVINGROOM/MUSIC ROOM

Measurements in a small living room/music room also gives that the decays after the direct/attack sound are parallel for the standardized “long”-distance measurement and the “In-Ear”-recordings of hand claps (fig.15).

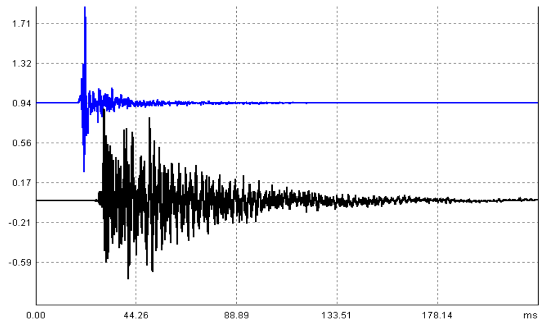

Figure 14. Impulse Responses. Living room

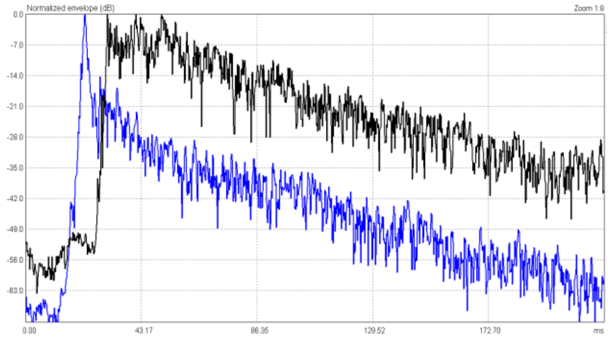

Figure 15. ETC-curves. Living room
Black=standardized
Blue=”In Ear”-mic, Hand-clap

6. REVERBERATION TIMES FROM “IN-EAR”-MEASUREMENTS

Taking the decay from 0 dB will, as mentioned, give strange, low values of T60 for “In-Ear”-measurements of handclaps and tongue-drops. However, calculating reverberation times from 0 dB is seldom used also for measurements also when using standardized, longer distance between source and receiver. Often T30 is used, measuring the time for the decay between -5 and -35 dB (and multiplying this time value by 2, to make T30 comparable with the 60 dB decay defined by Sabine).

If we look closer into the first part of the decay in the Foyer, we find that the parallel decay of the In-Ear-measurements start some 25 dB lower than for the standardized measurement.

(Cabrera et al [5] indicates the limits: -10 dB and -30 dB, for measurements with speech as signal, which might seem a bit too optimistic, and this study is without comparisons to reverberation times measured by standardized methods for the same rooms).

Some computer programs for room acoustic include the possibility of indicating the limits of the decay in a more flexible way than just choosing one of the standardized sets of limits. If we calculate the reverberation time for the In-Ear measurements from their decay between -20 and-35 dB and compare with standardized T30 measurements at longer distance, we see the following result (fig. 16).

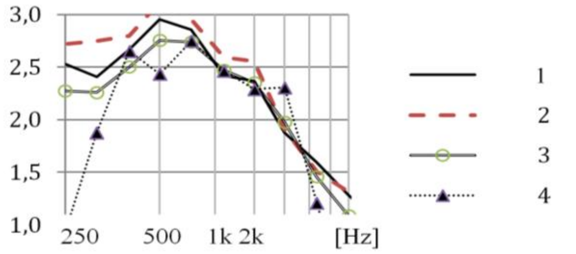

Figure 16. 1)Standardized measurement of RT (T30).
2)Same long distance measurement (-20 to -35 dB)
In-Ear: 3)Handclap, and 4)Tongue-drop (-20 to -35 dB)

We see that all types of measurements agree reasonably well for the middle (and high) frequencies. (Remember the deviation between measurements at different positions, also for standardized measurements). The tongue-drop disagrees the most, especially for frequencies below 500 Hz. This is because of low signal level of the tongue-drop. (For other measurements, tongue drops have shown to be somewhat stronger for these mid-/low frequencies. This of course depends on the actual "performance"/"formant shaping" of the tongue drop).

<u>We judge the reverberation time in a room by eliminating the direct sound when listening to our own handclap</u>. If we calculate the reverberation time from the decay between some -20 dB and -35 dB, we get the same values of reverberation time as for a standardized measurement with a longer distance between source and receiver. Can we use parts of the decay closer to the direct sound, to improve the Signal/Noise ratio? (Closer to common standard reverberation time settings, T30 etc). For the measurements in the Foyer, there are few reflections between arrival of the direct sound (0 dB) and the -20 dB chosen for the start of these calculations of reverberation times for the "in-ear"-measurements. This means that we might "dare" to start the calculations before -20 dB. For the measurements in the Foyer, taking the common T30 (-5 dB to -35 dB) also for the In-Ear measurement, gives reasonable good agreement (fig.17).

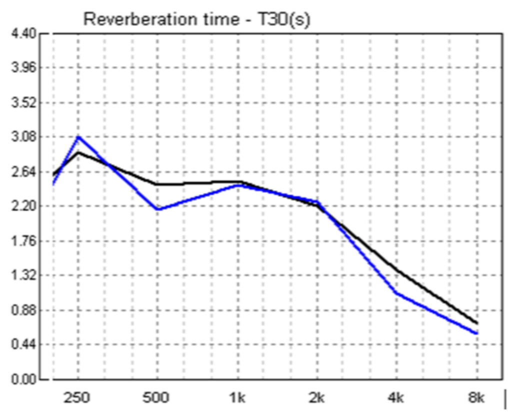

Figure 17. Common T30 (-5 to -35 dB) calculations, Foyer:
Upper: Standardized, long distance measurement
Lower: Handclap, In-Ear measurement

For Stavanger, however, we find that taking ordinary T30 calculations also for the "In-Ear"-measurement, we do not get the same value as for the "long distance", standardized T30 (se fig. 18).

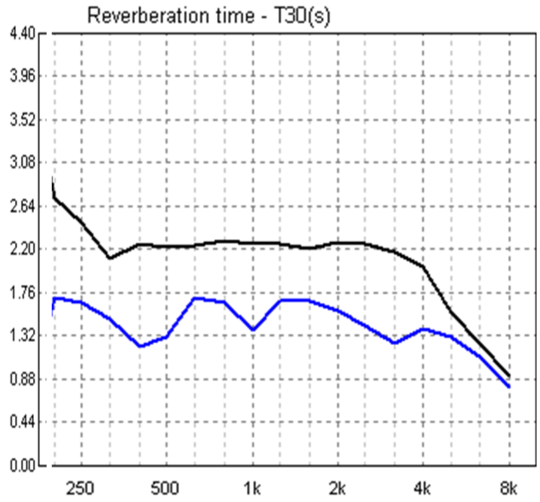

Figure 18. Standardized T30 (-5 to -35 dB) calculations
Upper: Standardized, long distance measurement
Lower: Handclap, In-Ear measurement
Stavanger

This is because there are several reflections arriving within "-5 and -20 dB" of the decay in Stavanger.

This is found also for the small living room/music room, and we should not use the T30-standadized "-5 to -35 dB" decay here, but "-20dB to -35 dB), (if the Signal/Noise ratio permits).

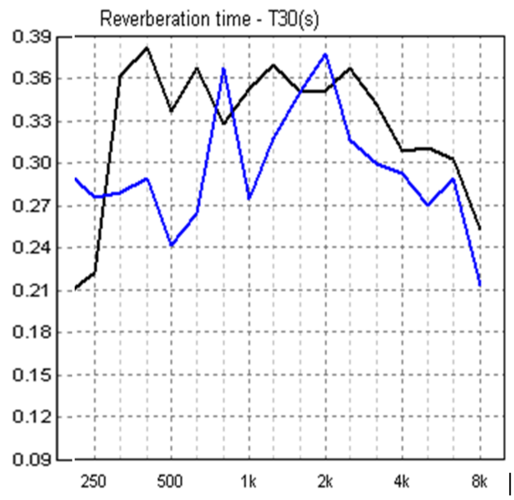

Figure 19. Standardized T30. Living room
Black=standardized distance
Blue="In-Ear"-mic

<u>We must inspect the Impulse Response in detail before starting the calculations earlier than at some -20 dB in the decay of an "In-Ear"-measurement.</u>

For the measurements in Stavanger, we can find the following difference between reverberation times (from -20 to -35 dB) face forwards towards the audience, and backwards towards the choir/organ wall:

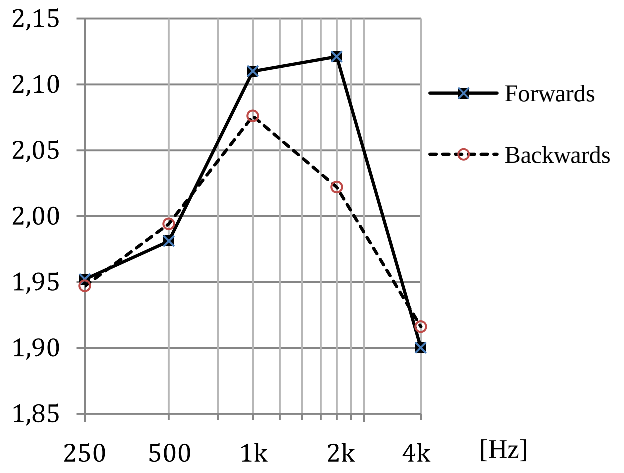

Figure 20. Comparison of reverberation times (-20 to -35 dB)

We see that our “In-Ear”/“source=receiver”-method makes it easy to check if the reverberation backwards is not longer than the reverberation forwards, (which might be the situation if the audience occupies a too big solid angle seen from the stage).

7. ECHOLOCALISATION CAN WE LEARN FROM THE BLIND?

Most people can teach themselves to judge the distance to a wall or an object by sending an impulse sound and receiving a distinct echo, if the wall/object is far enough away so that the delay is (much) longer than the duration of the signal, and, of course, longer than the integration time of our hearing. Blind persons often use their ears to “see” objects and walls much closer than this. We are in the middle of a project studying echolocalisation [6], and here we will present some preliminary results.

We can divide Echolocalisation into two methods, one using the Time Domain (as for detecting the distinct echoes) and the other using Frequency Domain (as for changes in timbre/klangfarbe). We will look at the last method first.

7.1 Echolocalisation. Frequency Domain

When a broadband noise is reflected from a surface Xm away, the total delay of the reflection back to our ear will be 2X, and this gives a comb filter with 343/2X Hz between each maximum, or between each dip, called **“Comb-Between-Teeth-Bandwidth” CBTB** [7].

For a reflecting surface far away, this CBTB will be very many and very narrow, so there is almost no perceived coloration (but the reflection is detected as a distinct echo in the time domain). When the reflecting wall/object is very close, the CBTB will be very broad, and the coloration is perceived like a simple bass/treble control on a radio. (Often giving a rise in the bass for music).

These outer regions of distances do not give very interesting coloration (changes in Timbre/Klangfarbe), but when the reflecting wall/surface is at a distance typical for rooms, we get more interesting effects. For instance, if a person is placed some 1.7 m from a reflecting object/ wall, the CBTB will be ca 100 Hz. (Or more exactly 1,715 m, assuming the speed of sound of to be 343 m/s).

Such coloration is easily heard when the signal is broadbanded and of a certain duration, example: water fountains, background noise from ventilation. The noise of (hard) shoes on shingle is human controlled, and a favourite by many blind.

7.2 Echolocalisation. Time domain

The echo limit of some 50 ms commonly used for speech signals is of course not relevant to short impulse-like signals. Jens Blauert [8] suggests “less than 2ms under some circumstances“ as a limit of detection of reflections, called “echo threshold” by Blauert, a name that might be discussed. Using “blind-clicks” as a sources in A/B test we find that “with good will” one might hear difference when adding a delay of down to some 1,5 ms. Of course we do not necessarily perceive this as two sonic events (distinct echo), perhaps more like a somewhat longer click, perhaps with a coloration as described above.

7.3 Echolocalisation. Clicking with the mouth

Our research shows that clicking for echolocalisation is a very personal thing, as each of our test persons has their own way of producing the signal. We have been introduced to one excellent “clicker” who is almost deaf on one ear so binaural listening is not necessarily important. Another good “clicker” has some kind of damage in his mouth region so that he cannot produce clicks the same way others do. Most used clicks are of course rather short and of middle-/high frequency, but they differ both in duration and frequency content from one “clicker” to another.

We recorded several blind persons making their “clicks” in the (semi-) Anechoic Room at the Inst. of Physics at the University of Oslo, with and without reflecting surfaces placed at different angles. The recordings were done binaurally with the mentioned Sennheiser “In-Ear”-microphones. For most of the recordings the reflecting object/”wall” was placed 1,7m from “clicker´s” face (middle between moth and ear). In this way we could more easily detect any 100Hz CBTB in the frequency analysis of the recorded click + reflection. We will not go details, only present some preliminary results that might be important for this paper.

7.4 **Preliminay results for Echolacalisasion**

1) When the “click” in fig. 21 is not too short and not to narrow in frequency range, we see Combfilter coloration in the frequency response (fig. 22), indicating how the reflection is perceived in the frequency domain.

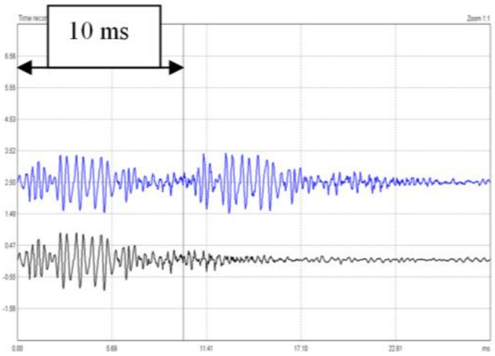

Figure 21. Impulse Response of Echolocalisation Click
Upper (Blue): with reflection 10 ms (distance 1,7m x 2)
Lower (Black): without any reflection (anechoic)

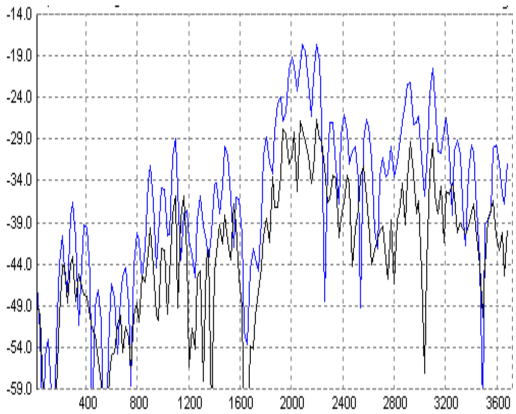

Figure 22. Frequency Response of the same Click
Upper (Blue): with reflection 10 ms (distance 1,7m x 2)
(100Hz Comb-Between-Teeth-Bandwidth)
Lower (Black): without any reflection (anechoic)

The same figure, zoom-in, is shown in fig. 23:

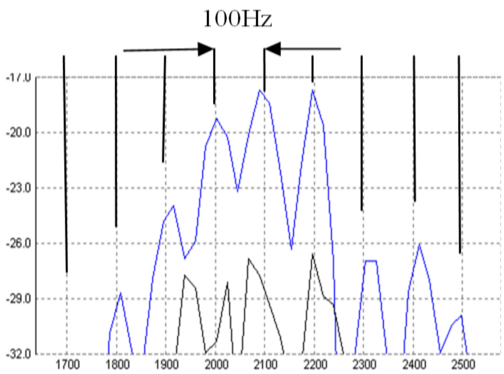

Figure 23. Zoom-in of the same frequency response.
Observe the 100 Hz CBTB

2) For very short clicks, often of higher frequency however, there are problems perceiving the change of frequency content. This indicates that also some Time Domain effect is included (see above).

3) Playing back the “In-Ear”-recordings of the clicking echolocalisation with headphones to the same person, in a “blindfold-test (sic!)” indicates that the “clickers” had big problems hearing the difference with/without reflections, even from their own recordings. When testing “live” you can turn your head and focus on any interesting sound effect.

8. DISCUSSION

Our measurements indicate that also musicians should continue to produce the test signal themselves in “real time” in order to find details in the acoustics of a room. Such “measurements” is faster than standardized measurements, and most important: The “measurements” can quickly be performed also with musicians present (Trough Orchestra Response, TOR [6]) since they do not produce harmful sound pressure levels and need no rigging time. A common drawback is, of course, low Signal/Noise ratio.

9. CONCLUSIONS

We can judge the reverberation of a room/hall by clapping or making other impulsive signals, so that both the source and the receiver are at (almost) the same place, because our hearing “neglects” the first strong direct sound. Our measurements show that the decay after the direct sound (after the abrupt fall of some 20 dB drop in the Energy-Time-Curve) is (exactly) parallel to the decay measured with more standardized methods with a distance between source and receiver.

Our investigations on how the blind echolocate show that we are much better in making judgements of the acoustic reflections when we are making the signal ourselves in “real time”, compared to listening to the same recorded Impulse Response.

Judging the acoustics of a hall by clapping and making tongue-clicks is a much more serious method than one might think, and can easily be done in different directions.

Acknowledgments

“Echolocalisation” is a research project in Statsbygg (Norwegian Directorate of Public Construction and Property), in collaboration with Huseby Center for the Blind, Anders Buen (Brekke Strand Acoustics) and Jens Jørgen Dammerud (NISS).

Kahle Acoustics was the acoustic consultant for Stavanger Concert Hall, with Statsbygg/T.Halmrast as client acoustical adviser.

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