MORE COMBS

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1 INTRODUCTION

The main research in room acoustics is "energy/time"-based, meaning "how much energy is received during different time intervals". This is of course highly important for the design of auditoria. However, we should also consider the distribution of reflections within these time intervals, which is important for the "timbre". Timbre is the most unclear and badly defined parameter in acoustics. We often think of the more general aspects of timbre, like "bass/treble" "sharp/soft", but from studies in studio engineering, we should learn that more detailed studies of timbre due to combfilter-effects from short reflections are of great importance, as the "timbre"/"sound" is determined in the first part of the sound. The paper will discuss earlier knowledge regarding orchestra platforms combined with the most helpful use of our ear´s early-reflection-analysis; the so-called "echo-localization" used by the blind in order to "see" a room or an object by use of the ears (also for short reflections that do not give a distinct echo, but rather coloration).

2 DIRECT SOUND + ONE REFLECTION

When the direct sound is combined with a reflection (from an object/wall or digitally), some frequencies arrive in phase and give an increase in sound level, while some frequencies arrive out of phase, and will (ideally) give cancellation and zero amplitude for these frequencies. The frequency response of a direct sound and one reflection using a linear frequency scale looks like a comb, thereby the name combfilter. For a single reflection with a delay time of Δt ms, the "Comb-Between-Teeth Bandwidth" (and the peak-to peak-bandwidth) is 1/Δt [1]-[5]. A "short reflection" will give a very broad combfilter, and a reflection arriving "late" will give only small "ripples" in the frequency response. A reflection with a time delay of more than app. 50 ms will be perceived as a distinct echo. This is of course common knowledge when standing more than some 8.5m from a reflecting object/wall giving a reflection with an exceeding sound path of 8.5x2=17m. For such a delayed reflection, we are "in the time domain", and every person with normal hearing would probably soon learn to "calibrate" his ability to determine the distance from an object/wall giving a distinct echo. What happens if the delay is shorter? Blind persons are known to "see" objects with their ears. They often explain that for longer distances, they of course hear the distinct echo, but for shorter distances/delays, they might localise by judging the change of the timbre/"klangfarbe" due to the reflection. Knowledge of such perception of reflections should be important also for room acoustics.

3 BOX-KLANGFARBE

3.1 Investigations in concert halls

Investigations of the acoustic conditions for the musicians on the orchestra platform in concert halls give interesting knowledge of changes of timbre/"klangfarbe" due to reflections. Reflections on the podium are highly important for the musicians "ensemble", both regarding playing in time, and for the intonation. Some orchestra platforms have high ceilings and perhaps sidewalls too far away and/or oriented so that they do not supply the necessary reflections within the orchestra. Measurements of impulse responses and their frequency responses, combined with questionnaires were done in Oslo Concert Hall and on tour with the Oslo Philharmonic, conductor Mariss Jansons to several concert halls in Europe, including Musikverein in Vienna [1]. The results shows that introducing distinct reflections in a certain time delay-region gave a change in timbre/"klangfarbe" sounding like "inside a box". Such a change in timbre was therefore called "Box-Klangfarbe". This change in timbre was most clearly observed when introducing a rather low reflector over the podium, and for measurements with the musicians present on the stage. (Through Orchestra impulse Responses, TOR-measurements) [1].The changes in timbre ("box-klangfarbe") appeared for distinct reflection from a suspended reflector over the orchestra at a height of some 6-8m.

3.2 Coloration and Critical Bandwidth

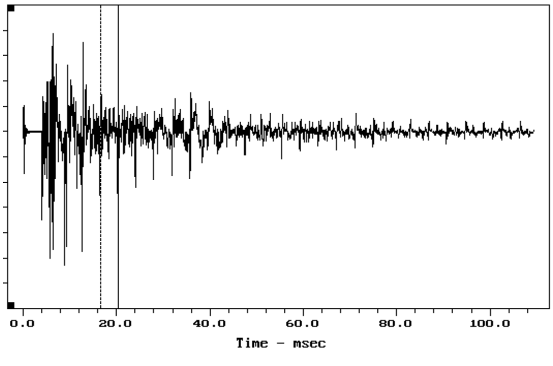
For an orchestra on a platform, Box-Klangfarbe is perceived when a discrete reflection gives a clear comb-filter having a "Comb-Between-Teeth-Bandwidth" that is comparable in size to the Critical Bandwidth. This is indicated as the "**Box-Klang-Zone"** [1]-[5]. The exact borders of this Box-Klang-Zone must be further investigated, but our study shows that a strong, discrete reflection with a time-delay of some 5-20 ms (Comb-Between-Teeth-Bandwidth of some 200-50 Hz) will give Box-Klangfarbe. Adding more reflections in a random order into this Box-Klang-Zone will smooth the **T**hrough **O**rchestra impulse **R**esponse. (TOR) The periodic behaviour of the Short-Time-FFT will then be more "unclear", and the chances of Box-Klangfarbe will be reduced, as in Musikverein in Vienna.

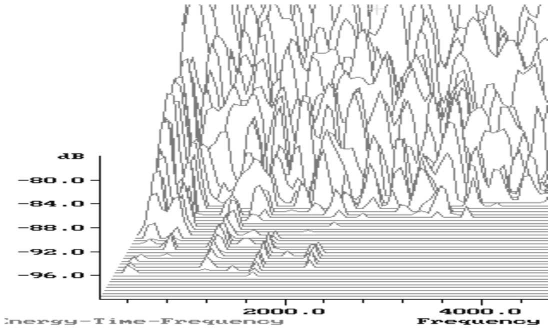
3.3 Comparisons with psycho acoustical studies

Atal et al [6], Bilsen [7],[8] and Salomons [9] have investigated coloration in listening tests for broadband noises with delays. These investigations all conclude that coloration effects are generated in the early part of the received sound, defining "Short Time Spectrum" which confirms our use of combfilter- investigations taking the FFT of the early part of the Impulse Response. They also defined an Autocorrelation Weighting Function to describe the hearing organ. A broader discussion about whether to use a frequency-domain or time-domain criteria for coloration, or if they are equivalent, is given in [6]-[9]. Here we will just point out for which region of time-delay (/quefrequencies) this Autocorrelation Weighting Function has it highest values, indicating that coloration is most likely to appear. Salomons [9] shows that there has been some uncertainty about this Weighting Function for short delay times. Our results and the psycho-acoustic studies agree that coloration is most likely to appear for discrete reflections within some 5-20 ms after the direct sound. For shorter time delays the comparison is good for the results from Bilsen [7], but not for the investigations of Atal [6] and Salomons [9], who reports coloration also for shorter time-delays than what is given for our musical study indicated as the Box-Klang-Zone.

3.4 Investigations in a corridor

Corridors are interesting with respect to acoustics. The length of a typical corridor is often within the "time domain", giving a (short) echo. However, if we look at the cross section of the corridor, the dimensions are much smaller, leading to more interesting acoustical effects, as an extreme case of "close reflections". In [5] is presented observations and measurements of the acoustics of a corridor, investigations of comb-filter effects and examples of how even modest "diffusion" treatments of the sidewalls changes the perceived acoustics. The time-delays of the (repetitive) reflections are within the "box-klangfarbe-"region (left figure):





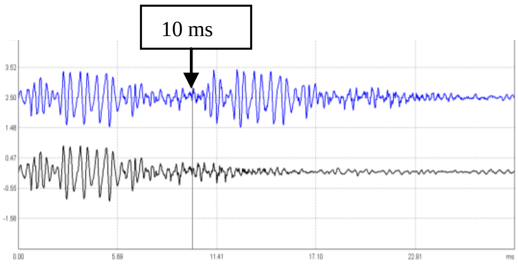
The frequency-response/-waterfall-curves show resonances giving the almost "ringing" sound observed when walking through the "naked" corridor. In [5] it is shown that even modest "scattering" treatment placing paintings/"posters" on the sidewalls reduced this combfilter/resonances and the "box-klangfarbe".

Corridors have a history in music recording. When Elvis Presley changed to the bigger recording company RCA, they went through a lot of work trying to reproduce the special timbre/"klangfarbe" of his first recordings in Sam Phillips´ Sun Studio in Memphis, and they actually placed Elvis in an adjacent corridor. Sam Phillips, however, used two tape recorders with a slight delay [10] (and presumably some feedback).

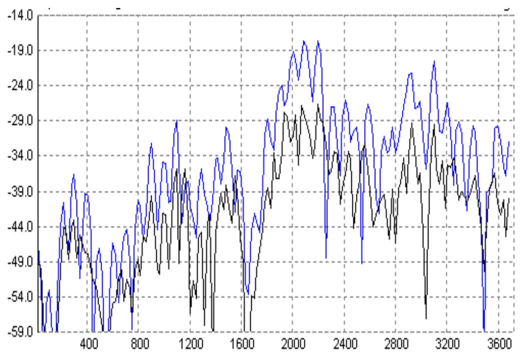
4 "SEEING WITH THE EARS"

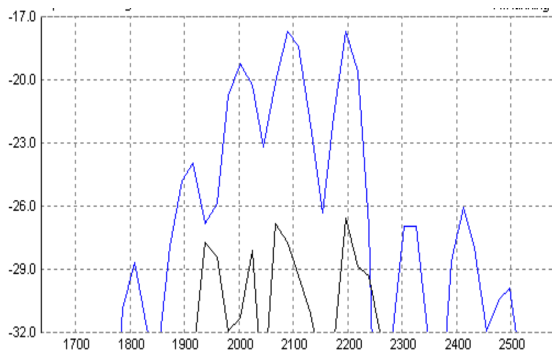
The blind uses several sound sources for the localisation of objects or walls: "clicking" with the tongue, or kicking with their stick. (Sometimes even ordinary background noise is used). All these techniques are often called "echolocalization", even if the object/wall is so close that the reflection is not perceived as a distinct echo. The techniques are well described regarding how "echolocalization" should be performed [12], [13], but what happens, acoustically and psycho acoustically, is not very well described in the literature. In 1964 Basset et al [11] concludes: "The best sound would seem to be a white noise containing essentially all frequencies at equal intensity. The preliminary observations indicate that even a narrow band containing many random frequencies will produce the effect". Most used signals for "echolocalization" are rather high-pitched. We will concentrate on the "clicking" sound produced by a short "release" of the tongue. These signals are somewhat "personal", and can be modified somewhat depending on the practical situation, but most of the ones we have analysed have a frequency peak around some (1)-2-3-(4) Hz, the most sensitive frequency region for human beings.

Click Type A. The following figure shows a "tongue- click", and the same signal with a delay of 10ms, corresponding to an exceeding sound path of 3.4m, as from a wall 1,7m away from the blind person:



In the blue, upper curve, we see the 10ms delayed reflection that gives a combfilter with "comb-between-teeth- bandwidth" of 1/10ms=100 Hz. A zoom-in shows this even more clearly:

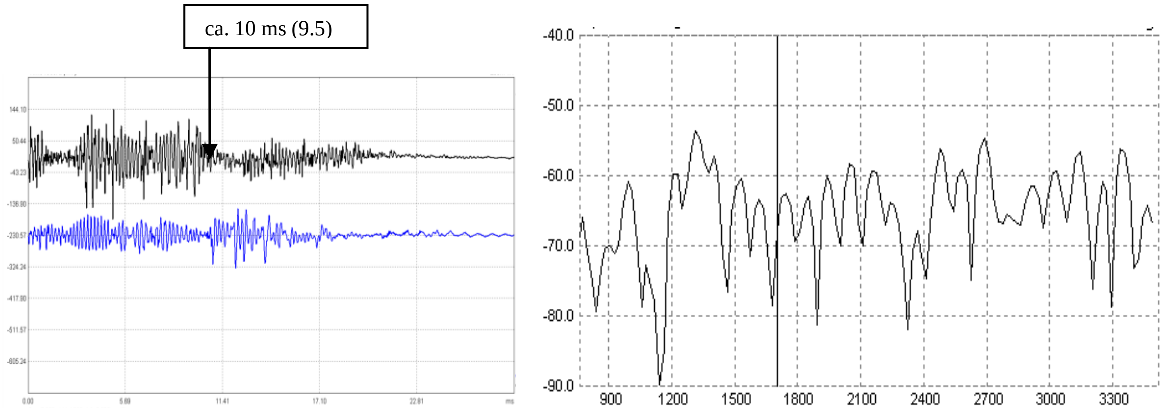




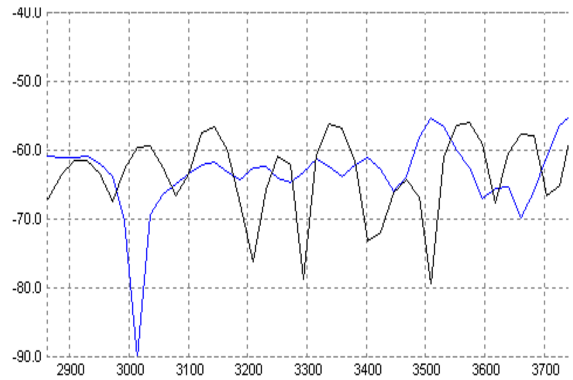
The same test were done with the delay 3dB and 6dB below the original source level, to simulate the reduction of sound level due to distance and (minor) absorption on the surface of a reflecting wall/ surface. This means this tongue-click has a total signal-bandwidth that is broad enough to give coloration when combined with a reflection with a delay of some 10ms, which would be a typical/practical value for the distances to objects/walls in indoor practical life. Our investigations shows, however, that there are several personal types/"dialects" of clicking with the tongue.

Type A was performed by an "amateur" and the delay was added electronically. The next type of clicks were performed in the anechoic chamber with/without a reflecting plate size some H=2.1m, W=0.7m.

Type B is a type of click used by the blind person who is said to be "the best echolocator in Norway". The following figure shows recordings of this type of click, for two situations in an anechoic chamber: (The upper curve (black) shows the situation With a reflecting hardboard plate at a distance of some 1,7m, intended to give a delay of 10ms.)



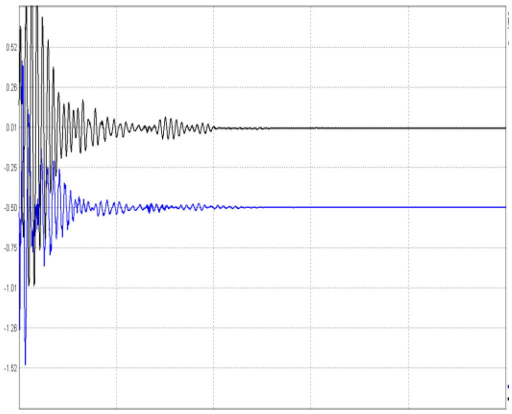
The clicking was not performed in exactly the same way in these two recordings (and the levels are not normalized). Looking at the frequency response above, we see a comb for the situation with the reflecting plate. The following zoom-in shows the frequency response With reflecting plate in Black, giving the comb, and Without reflector, showing no comb.

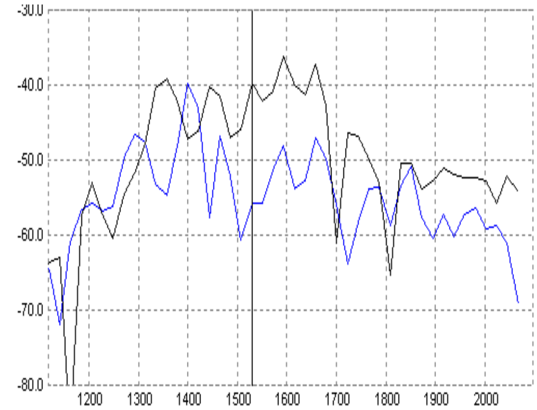


(When we look more in detail into the curves, we see that the Comb-Between-Teeth (or peak-to peak) is somewhat higher than the intended 100Hz. This actually shows that the exact delay was not 10ms, but some 9.5ms, and the position was measured again afterwards, giving some 1,65m instead of 1,7m.)

In both A and B, the sound is produced somewhat to both sides of the mouth, and the signal is "longer" and with a "broader" frequency range than the following type of click:

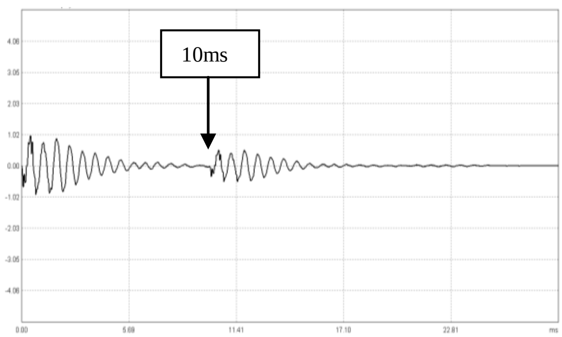
Type C is a short click performed with the front of the tongue. Here the reflecting plate is placed to the side of the blind person:

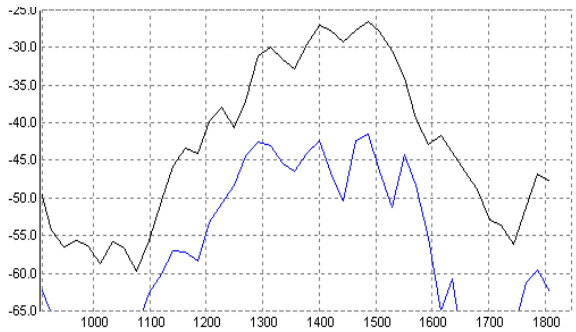




The frequency responses with/without the reflecting plate give some indication of comb, but not clear.

For a frontal recording of this Type C click, with a 10ms delay (3 dB down) added (electronically) to simulate the reflecting plate we see this response:

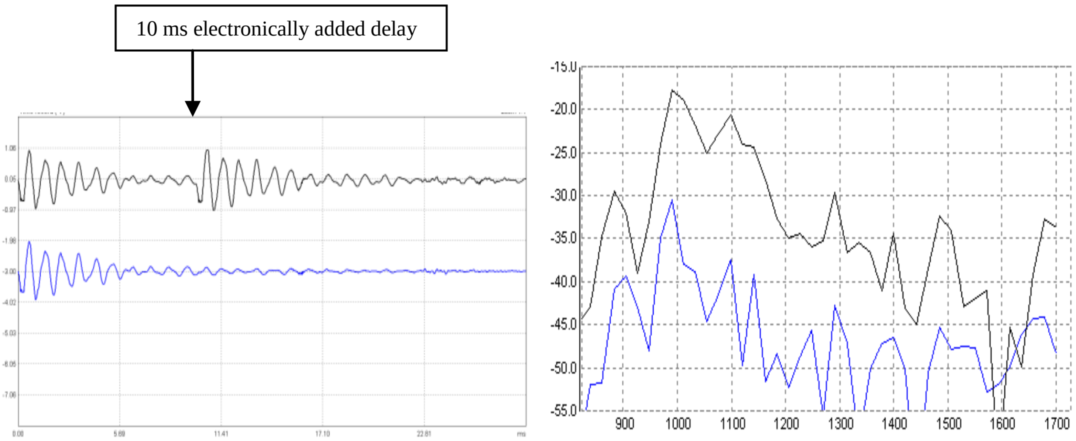




Here we see some comb-like structure for the upper curve (with delay), but not as clear as for type A and B. Also listening to Type C clicks with/without delay/reflector does not give as clear change in timbre as A and B, but the (very small) additional length is actually perceived!

Type D is almost the same type as C, but by another performer, giving a somewhat higher centre pitch. As for type C, a comb due to a reflection is not really clearly visible.

Tongue-Drop. Included in the tests was also a “Tongue-Drop”, produced by “vacuum/ release” of a broader part of the tongue, sounding more like opening a wine bottle.



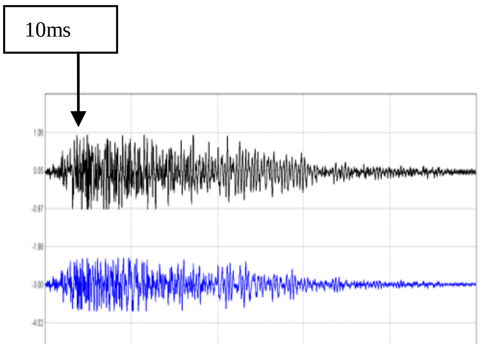
We see that the “centre frequency” of the Tongue-Drop is somewhat lower than for the Click Type A and B. There are signs of Combs for the Tongue-Drop, but perhaps not as clear as for Clicks Type A, B and C.

Piano Cluster. Investigations also included the recording of a piano cluster with/without an electronically added delay of 10ms.

To give a musical indication of how fast 10ms is, we could look at the musical notation:

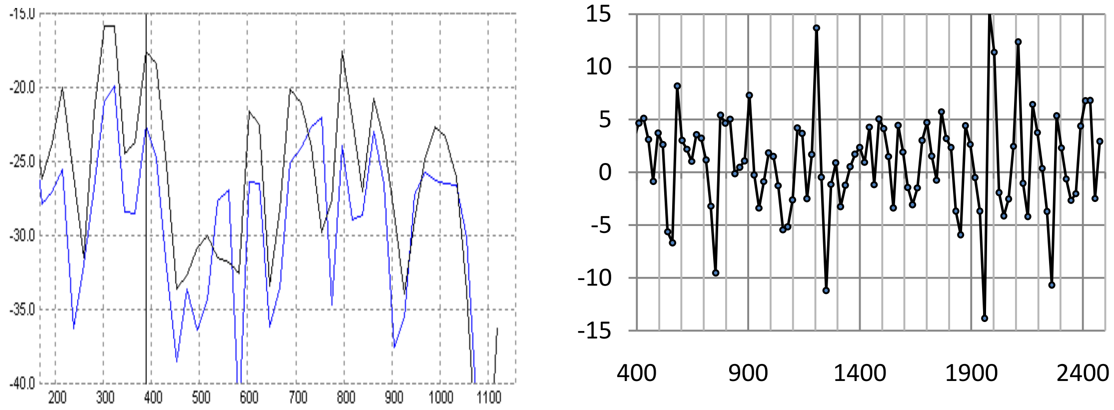
Such a rapid “repetition” in a high tempo (200!) is so fast that even the “state of the art” music notation programmes are not able to secure playback. (The example above gives a repetition time of 9.375 ms

This figure shows the recording of a piano cluster with artificial delay 10ms (upper curve, black), and original recording without delay (lower curve, blue):



The piano cluster is of course longer due to the “reverberation” of the instrument itself (some 200 ms), and somewhat broad banded (600-1200Hz in our example), (and of course build up of discrete frequencies, so not really “white”).

The following figure shows the frequency response of the piano cluster with/without the delay of 10ms (figure left). If we take the difference between the frequency response of the analysis With and Without the delay, we see a clear “rhythmic” behaviour showing the 100Hz comb (figure right):



The following table summarises the types of signals and how they were “observed” aurally and by investigation of “rhythmic” behaviour in the linear frequency response (“Combs”):

Signal	**Duration**	**Freq.**		**Delay**		**Observed Yes/No**		**Level**
	ms	**Max kHz**	**Range kHz**	**electronic**	**real wall**	**comb**	**time**	**dB rel. Speech**
Click A	6	2.0	1.7-3.1	10		Y	?	-11
	-«-	-«-	-«-		10	Y	?	
B	12	2.2	1.9-4.2	10		Y	N	
	-«-	«	-«-	5		Y	?	
C	3	1.3	1.0-1.6	10		N?	Y	-8
	-«-	-«	-«-		10	N?	Y	
D	3	2.1	1.2-4.0	10		?	Y	
Drop	10	1.0	1.0-2.0	10		?	?	
	-«-	-«	-«-	5		?	?	
Pno-clust	200	0.7	0.6-1-2	10		Y	N	

The sound pressure levels are lower than for usual speech, some 8-11 dB lower than the person introducing the recordings

5 CONCLUSION

The measurements both on orchestra platforms and in corridors, together with the clicks used by the blind show that (discrete) reflections from rather close objects/walls will give changes of timbre/”klangfarbe” shown as combfilters with a “comb-between-teeth” (or peak-to-peak) bandwidth in the order of the Critical Bandwidth. This gives “Box-klangfabe” on the stage of a concert hall, and is detected by persons in corridors and by the blind using “clicking” for orientation of such (close) objects/walls. For the auditive localisation of non-sounding objects/walls at closer distances than some 8m, the ear does not detect the reflection as a distinct echo, but rather as a change in timbre of a broadband source. It is shown that tongue-“clicks” used by blind persons, with energy around some 1-4 kHz, is a good signal for the localisation of objects/walls. However the Tongue-drops with somewhat lower centre frequency do not give as clear combfilters when adding a delay of some 10ms, and for very short clicks with a somewhat narrower frequency range the reflection is probably not perceived as a changing of timbre/”klangfarbe”, but as a small increase in perceived length of the signal. For broadband musical signals (like a piano cluster) the timbre/”klangfarbe” are clearly changed when introducing a 10ms delay/reflection.

How the blind perceives reflections is fascinating, and should give understanding of finer elements of room acoustics and sound production.

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