Level balance between Self, Others and Reverb, and its significance to noise exposure as well as mutual hearing in orchestra musicians

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Summary

In order to gain more insight in ensemble issues as well as noise issues, it is proposed to analyze the sound at the ears of musicians in three components, namely the Dry Self, Dry Others and Reverb. Simulation in Odeon and several measurement series in different typical situations have been carried out during 2014. Dry Self represents 50-60% of the energy density at the ear of musicians in all situations investigated so far, except for violinists in individual rehearsal, where Dry Self represents approximately 80%. This means that commonly suggested noise and health measures in the musicians' acoustical environment is not effective, but instead are likely to do more harm than good to ensemble conditions. Suggested balance parameters Foreground-Background-Balance and Dry-Reverb balance exhibit consistent results through changing situations. These are interesting features that will be pursued in further work, as they could potentially tie together podium acoustics and rehearsal room acoustics.

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1. Introduction

In orchestra musicians, noise is a complex issue, and more so than in most other occupations. An instrument that in one instant must be clearly heard could in the next instant represent a masker or even a potential threat to the musician's hearing. Sound categories like signal, noise and masker cannot be used in the common way. It is not adequate to understand the noise exposure of musicians by the common definition of noise - unwanted sound. None of the musical instruments can be considered as noise sources, nor can the fortissimo notations by the composer's hand. So far, «noise exposure in musicians» and «mutual hearing conditions in musicians» have been treated in separate sub-disciplines in acoustics – the first being a typical noise and health issue, and the latter being a typical stage acoustics issue. Based on a growing amount of measurements near musician's ears during performance and rehearsal over the past decade, this author recommends that these issues should be considered as closely related. E.g., the same conditions that make it difficult for musicians to hear important musical information, has the ability to drive the musicians to adopt a forced style of playing, resulting in higher and potentially harmful sound levels. As a consequence, ever higher masking levels and more harmful spectra can occur, leading to a vicious circle. The prominent assumption among researchers, that sound level at a musician's ears is dominated by own instrument [1], has far-reaching implications as to the way the aforementioned issues are understood and solved. However this assumption is strictly a hypothesis that needs to be tested. This paper presents data on sound pressure levels of Self, Others and Reverb at musicians' ears during performance and rehearsal, and discusses their possible influence on noise exposure, orchestral sound quality and mutual hearing in orchestra musicians. Level balance appears to be critical in these issues.

2. Components in Ensemble Acoustics

Sound from an ensemble, i.e. a music group of any size N>1 in general and an orchestra in particular, can be analyzed in different ways. One way is to analyze from the individual musician's perspective, see matrix in Table 1, into

Dry Self (= an-echoic sound of own instrument), Dry Others (= an-echoic sound of other instruments) and Reverb (= reverberant sound of own and other instruments). These three components can be combined into the balance categories Foreground-Background and Dry-Reverb.

Table 1 Sound elements and their balance in ensemble acoustics

	Element	Balance 1 FBB	Balance 2 DRB
A	Dry Self	Foreground	Dry
B	Dry Others	Background	
C	Reverb (all)		Reverb

3. Balance between parallel streams

According to the above, information that is considered relevant to the musician, and that needs to be balanced, could be considered parallel streams. Balance 1 describes the balance between the Foreground stream and the Background stream, i.e. the Foreground-Background-Balance, abbreviated FBB. Balance 2 describes the balance between Dry sound and Reverb sound, i.e. the Dry-Reverb-Balance, abbreviated DRB.

4. Foreground-Background

It is assumed that in the ensemble musician's total sound image, the dry component of one's own instrument is in the Foreground stream, while other instruments and reverberant sound are in the Background stream. The Foreground contains important information about the own sound produced by the musicians, while the Background contains important information about the sound of the music created by the orchestra. If either of these components is too weak, i.e. being masked by the other, there is a risk that the individual musician's play is compromised, since the intonation and synchronization of the individual instrument could not easily be related to the rest of the orchestra. When the play of the individual is compromised, problems would accumulate and eventually compromise the performance of the orchestra as a whole. Of course, due to rehearsing, a professional musician would be able to play for brief moments with a bad FBB. However, an ensemble condition with consistently bad FBB is expected to have compromising long-term effects on an orchestra as to its playing style. This is indeed one of the main objectives of the current research project, see sections 7 and 8.

Based on the analysis above, a simple division into Foreground stream and Background stream, the level balance between the two streams could be expressed by the Foreground-Background-Balance as follows. If A, B and C are the energy densities of the respective components, at the ear of the musician, then

$$FBB = 10 \cdot \log(A) - 10 \cdot \log(B+C)$$

In some cases it could be relevant to subdivide the background, considering other instruments in one's own voice group (playing in unison) as Middle Ground, while the remaining instruments are considered Background. However, such subdivision is not applied in this paper.

5. Dry-Reverb-Balance

Results from simulations [2] and measurements [15] on violin and violin sections have shown that the balance between the anechoic (Dry) sound stream and the reverberant (Reverb) sound stream can be consistent throughout very different spaces for different purposes in the range from individual rehearsal to orchestra performance. In contrast, the Dry-Reverb-Balance DRB would tend to deviate whenever the room acoustics was not adequate for the actual use. Hence, the potential of DRB as a possible "indicator of proper acoustics" is to be investigated in further work. Dry-Reverb-Balance could be expressed as follows.

$$DRB = 10 \cdot \log(A+B) - 10 \cdot \log(C)$$

In the simplest case, an unobstructed point source, the DRB would be equal to the commonly used Direct-to-Reverberant level D-R.

6. Data acquired during 2014

Ensemble acoustics data acquired in 2014 includes,

- Odeon simulations for violinist in four situations, orchestra source model calibrated to fit with long term equivalent levels reported by O'Brien (2008) [1], presented in detail [2]; FBB and DRB from selected rooms with preferred acoustics presented in Table 4.
- 1st measurement series: Violinist playing f-ff parts of total 217s duration from Swan Lake in four situations, including orchestra pit. Measurement method and analysis procedure was presented in detail [15]; FBB and DRB presented in Table 4.

- 2^{nd} measurement series: Violinist playing Beethoven's 5^{th} , first movement, in three situations, including stage
- Students project, measurements on violinist, oboist and trumpet player, in individual rehearsal and on concert hall stage

Table 2 Balance parameters from Table 1, based on energy average at left and right ears. Comparable results from simulations in Odeon, preferred [7] rooms selection, in paranthesis.

Balance parameter	Reh. Room	Big Reh. Room	Orch. Reh. studio	Orch . Pit
FBB (avr{L+R}) (Odeon simulation)	6 (6)	16 (16)	0 (2)	-1 (-)
DRB (avr{L+R}) (Odeon simulation)	6 (6)	16 (16)	6 (7)	8 (-)

The measurement series with a violinist playing the first movement of Beethoven's 5^{th} symphony in 3 different situations, carried out in September 2014, followed the same method and procedure as the Swan Lake series referred to above. Even the violinist was the same in 1^{st} and 2^{nd} series. Instead of an orchestra pit session, the performance-like situation was the dress rehearsal on the stage of the opera hall. Rehearsal room and Orchestra Rehearsal Studio was the same as in 1^{st} series reported above. An orchestra shell was present in the session on stage.

Table 3 Balance parameters from Table 1, based on energy average at left and right ears. Comparable results from 1^{st} and 2^{nd} measurement series with violin musician and simulations in Odeon, 3 different situations. (*) indicates orchestra pit situation. Big hall is a 14000cbm opera hall.

Balance parameter	Series	Reh. Room	Orch. Reh. studio	Big Hall
FBB avr{L+R}	1^{st} 2^{nd} Odeon	6 8 6	0 1 2	-1* 1 2
DRB avr{L+R)	1^{st} 2^{nd} Odeon	6 8 6	6 6 7	8* 8 7

It is to be expected that the energy density distribution of the 3 ensemble acoustics components, and thus their balance parameters, will be different in orchestra musicians playing other instruments than those reported her for violinists.

Recently, the research has been extended with measurements of oboe and trumpet in rehearsal

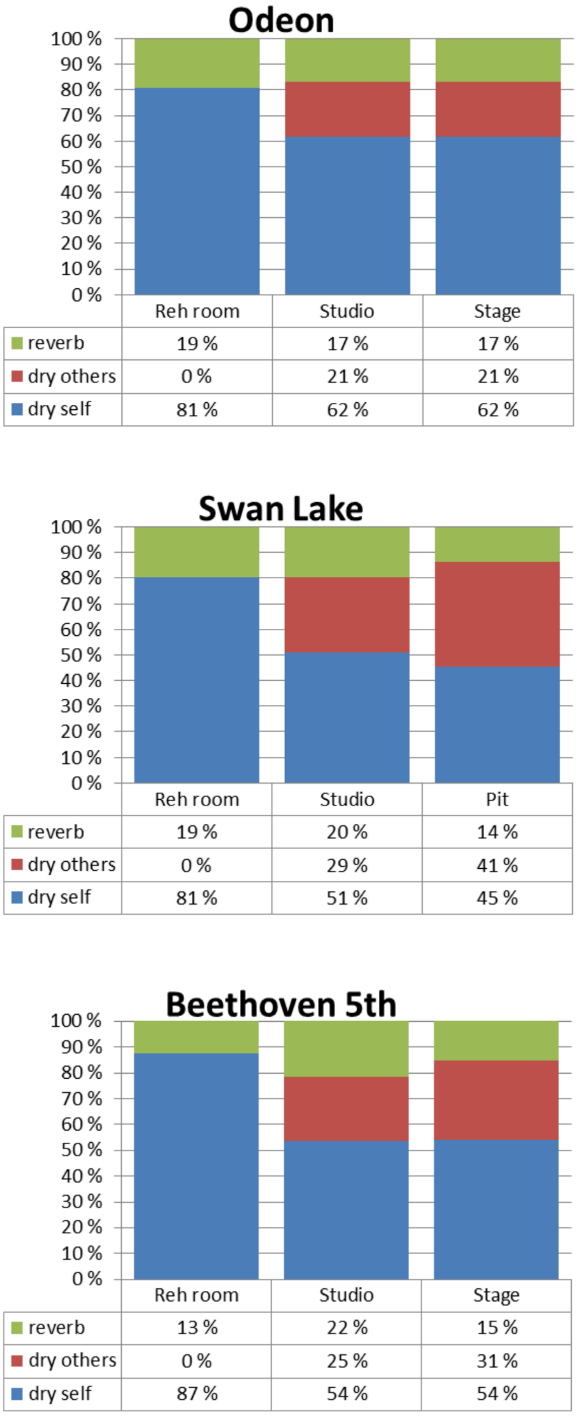


Figure 1 Energy density distribution of the Dry Self, Dry Others and Reverb, as heard by the violinist in 3 different situations; Results from Odeon simulation and 2 measurement series

room and orchestra stage. Based on the measurement results in a student project at NTNU in Trondheim, the computed energy density distributions are given as averages of each instrument in Figure 6.

An important result from the measurements is that in ensemble play, approximately 50% of the energy density at the violinist's ears is an-echoic sound energy from own instrument (Dry Self). Results from recent measurements in a student project shows that this is the case also for oboe and trumpet. Simulations resulted in 60% Dry Self for violinist. In measurements as well as simulations, the energy Dry-Reverb-Balance (DRB) appears to be a possible indicator of proper acoustics in very different situations. However, preferred values are expected to be instrument dependent. Indeed, the student project results indicate that for trumpet players, DRB are much higher than for oboists and violinists, while the latter two have statistically equal DRB. For oboe and trumpet players, Foreground-Background-Balance (FBB) is quite consistent, exhibiting 95% confidence intervals [0.2;1.6]dB in individual rehearsal rooms and [-1.5;0.5]dB in ensemble play on stage. The latter overlaps with measured FBB for violinists in ensemble situations, namely [-0.6; 1.3]dB.

In contrast, FBB in violinists is 6-8dB in individual rehearsal rooms. Higher FBBs can be expected in individual rehearsal from any instruments that are played with shorter apparent distance to the musician's ear, and in this matter the violins are quite exceptional.

7. Critical implications to Noise and Health

As long as FBB is not considerably smaller than zero, noise exposure at the musician's ear cannot be effectively reduced by reducing the level of Dry Others and Reverb. This means that commonly suggested measures like screens, increased distance between musicians, sound absorption and redirection of reflected sound is not relevant to Noise and Health. On the other hand, screens can, with proper design and placement, be used to adjust FBB, since screens can be designed to attenuate sound from a selected part of the orchestra. However, screens are hardly able to reduce sound exposure levels as long as Dry Self dominates. On the contrary, measurements by this author indicated that in practical use, screens tended to make little difference to, or even increased, the noise exposure on the user of the screen. If necessary, noise exposure should be reduced with ear plugs, but with no more than the attenuation required to satisfy the noise dose limit.

8. Critical long-term effect on orchestra play

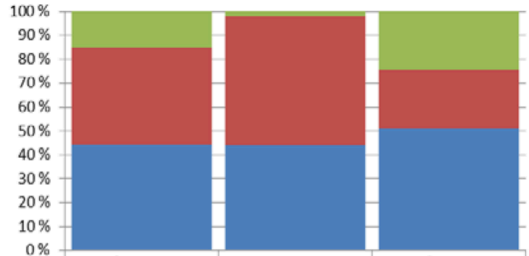
Even if Dry Self dominates the loudness at the musician's ear, the weaker Dry Others and Reverb may be key parts in the mechanisms that have long-term effects on development of sound levels, playing style and noise exposure in an orchestra. From the simulations with models of rooms, single musician, group of musicians and full orchestra ensembles referred to above, it was concluded that even where reverberant sound has little direct effect on the sound pressure levels at the musician's ear, they could indeed have an important indirect effect by driving the musician to play louder. In practice, louder means forced playing style, which in turn leads to more high frequency content in maskers, making them more effective maskers. Due to their alternating roles as information sources and maskers, Dry Self, Dry Others and Reverb and their internal balance is critical and delicate [2][3], and thus FBB and DRB are sensitive measures in this context. This means that improper balance of FBB and DRB could have unwanted long-term effects on playing style, not only from a music-esthetical view point, but also in terms of too high noise exposure.

The significance of masking and the listening conditions of orchestra musicians have been suggested by authors, though not very comprehensively. Two statements emphasizing balance and masking are quoted below:

"The results from the orchestra collaborations indicate that the following are of most concern for players regarding acoustic conditions: hearing all other players in the orchestra clearly and having sound from others well balanced with the sound of their own instrument and the acoustic response from the main auditorium. These subjective aspects appear to relate to complex perceptual effects like the precedence effect, masking effects and the various cocktail-party effects. When relating these effects to physical conditions, a narrow and high stage enclosure with the stage highly exposed to the main auditorium appears most beneficial.[5]"

"The art of designing good on-stage acoustics boils down to providing just enough early energy to help

with coordination, but not so much as to mask audibility of the late-energy room response. [6]"
Attention has indeed been drawn towards the problems of hearing balance and masking in musicians' listening conditions. Thus, the paradigmatic shift from the aspiration for sufficient hearing of others, to the aspiration for "just sufficient", is to be expected. "The more the better" is contradicted by "less is more" and ultimately replaced by the optimum "not too little, not too much". However, the fact that one instrument (or group) that is being a masker in one instant can be unwantedly masked in the next instant, makes the hearing balance much more delicate than previously understood.



	Oboe Stage m	Trp Stage m	Vln Stage m
reverb	15 %	2 %	25 %
dry others	41 %	54 %	24 %
dry self	44 %	44 %	51 %

Figure 2 Energy density distribution of the Dry Self, Dry Others and Reverb at the ear of an oboe player, a trumpet player and a violinist. Average fromf-ff parts.

9. Conclusions and further work

As a part of the investigation of acoustical conditions for the orchestra musician throughout 4 typical, but very different situations, measurements at the ears and other relevant positions around the musician are to be carried out. Two measurement series and a simulation series in Odeon has been completed for violin, with very similar results. One critical result is that in all measurements and simulations, 50-60% of the energy density at the musicians' ears is an-echoic sound energy from own instrument (Dry Self), except for violinists in individual rehearsal rooms, where the Dry Self part is even higher. This means that commonly suggested measures like screens, increased distance between musicians, sound absorption and redirection of reflected sound is not relevant to Noise and Health in these cases. Instead, noise exposure should be adjusted by ear plugs, but only if necessary to not exceed the noise dose limit.

In measurements as well as simulations, Dry-Reverb-Balance (DRB) appears to be a possible indicator of proper acoustics in very different situations. However, preferred values are expected to be instrument dependent. Except for violinists in individual rehearsal, measured Foreground-Background-Balance (FBB) is quite consistent in oboist, violinist and trumpet player. Interestingly, FBB is on average 1.4dB higher in individual rehearsal than in ensemble situations, which is expected to be advantageous in gradual preparation towards performance.
Ideas about the relationship between information sources and maskers, and the alternating roles of one and the same source, have been presented for discussion.

10. Further Work

In further work, measurements are to be extended to include instruments from different voices and sections of the orchestra. Situations with less suitable acoustics should be included, as well as situations with suitable acoustics. Significance of the two balance parameters, DRB and FBB, will be tested and subjective differences associated with differences in balance parameters will be investigated. The orchestra model used in simulations is a composition of 4 surface sources representing the sections String, Woodwind, Brass and Percussion, each defined by their respective empirical long-term-average sound power emission. Statistical variance and level distribution is another instrument- and section-specific property, which is to be established empirically, and will be implemented in the orchestra model. Simulated Dry Self component is very sensitive to the apparent distance r' between ear and source, which is another instrument specific property to be determined in further work. Because DRB is very similar to Direct-Reverberant ratio, the relationship between critical radiuses r_c, critical listening distances, internal ensemble distances and ensemble size is likely to be important. These aspects are to be studied further.

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