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THE SUPPORT PARAMETERS FOR MEASUREMENT OF SOUND REFLECTIONS ON CONCERT HALL STAGES

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ABSTRACT

Four decades ago, this author came up with the idea of describing the sound reflection energy on orchestra stages by means of the Support-parameters. Since 2009 the measures ST_{early} and ST_{late} have been included in the ISO 3382 standard on room acoustic measurements – as the only parameters specifically designed for this purpose, and they are often being used by scientists and consultants alike. Still, other acousticians have – for good reasons - suggested modifications or alternatives to the ST-measures. However, the ST-parameters seem to survive the "competition". Therefore, it might be relevant to review their purpose, their limitations and to describe in which situations we have found them useful. In this context it is also relevant to discuss which values can be considered favorable or the opposite. Also the ratio between ST_{early} and ST_{late} might be relevant as a certain element of clarity on stage is necessary for precise communication between the musicians. The discussion will be based on comparisons between measured objective data and musicians' subjective responses from a number of halls.

Keywords: *stage acoustics, reflections, measurements*

1. INTRODUCTION

In spite of many attempts during the last four decades, it has not yet been possible to find objective acoustic parameters of general value for description of musicians' evaluation of concert halls (or rehearsal studios). The author's suggestions, ST_{early}, and ST_{late} as well as all other objective parameters suggested (see reviews e.g. in [1], [2], [3] and [4]) seem to fail when used on a new group of halls evaluated by orchestra musicians. As discussed in [1], one reason for this might well be that the number of halls in each investigation was small compared to the large number of ways in which halls may differ, whereby the number of degrees of freedom in the analysis becomes insufficient to reveal any statistically significant relationships. Another reason – revealed by the same investigations – might be that musicians have difficulties in distinguishing between the different subjective aspects such as "support", "ease of ensemble" and "overall impression" in their evaluations. Besides, musicians do not always agree on what they hear or prefer due to individual preferences and instrument-related differences. Still, the author has found the ST parameters useful and in line with the musicians' evaluations when testing acoustic changes on the stage e.g. in connection with a planned renovation of a specific hall. In experiments limited to one single hall, the number of possible independent (uncontrolled) variables will be much lower whereby fewer degrees of freedom are required for the analysis to reveal significant results.

After recalling the definitions of ST_{early} and ST_{late}, and a look at their purpose and theoretical limitations, we will describe results from case studies where both measured ST data and musicians' evaluations were available. Most of these cases involved only one hall each. The purpose is to see whether the results from these cases can illuminate to which degree these parameters are useful and perhaps give an idea about optimal ranges for ST_{early} and ST_{late} (valid for description of symphony orchestra stages).

2. MEASUREMENT OF SUPPORT PARAMETERS

The original intension behind the Support parameters was to record reflection energy on stages assuming that this would have an impact on musicians' judgement of their

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acoustic surroundings. The inspiration came from musicians reporting two halls in Copenhagen to have large acoustic differences. In one of the halls, most of the stage is surrounded by an orchestra shell in a stagehouse, while the stage in the other is exposed in the wide, fan shaped auditorium as seen in the photos below.

Figure 1. View towards the stage in the Tivoli Concert Hall (left) and in the old Danish Radio Concert Hall (right).

The obvious geometrical differences between the two indicated that the amount of early reflection energy returned to the musicians would be very different and a likely reason for the judgements of "ensemble" being difficult in the old Danish Radio but easy in Tivoli. (Reverberation time in the two halls are about the same, ca. 2.1 – 2.2 Sec. empty and 1.4 – 1.5 Sec. occupied.)

2.1 Definitions

In ST_{early} and ST_{late} the amount of reflection energy is calculated from impulse responses recorded on the stage with a 1 m distance between the acoustic center of an omni directional loudspeaker and a ditto microphone as follows:

$$ST_{early} = 10log\frac{\int_{20}^{100} p^2(t)dt}{\int_{0}^{10} p^2(t)dt} \qquad (1)$$

$$ST_{late} = 10log\frac{\int_{100}^{1000} p^2(t)dt}{\int_{0}^{10} p^2(t)dt} \qquad (2)$$

ST_{early} and ST_{late} detect the amount of reflection energy returned before and after 100 ms respectively relative to the level of the direct sound emitted. The 1 m distance is of the same order of magnitude as the distance between the musicians' ears and the acoustic center of his/her instrument. Thus, the parameters measure how much "support" the hall returns to the musician relative to the sound produced by his/her instrument.

2.2 Measurement details, time windows and positions

To represent realistic heights of instrument and listening musician, both transducers are placed 1.0 m over the stage floor. With such a moderate height, it is not possible to separate in time the floor reflection from the direct sound. Since the floor's reflection coefficient will be the same in most halls (wooden stage floor without a carpet!), we can just choose to include this in the direct sound reference, which is the reason why the integration interval in the denominator is 0 – 10 ms. On the other hand, the 10 ms limit requires that we move any furniture or other reflecting elements on stage at least 2 m away from the transducers. Otherwise, reflections from these items will create random errors in the direct sound estimation. Likewise, starting the integration in the numerator at 20 ms means that the transducers should be at least 4 m away from any of the surfaces whose reflections we wish to detect. The upper integration limit in ST_{early} was set to 100 ms more or less in accordance with the upper limit for reflections contributing to "clarity" which also means that walls/ceiling surfaces up to about 17 m from the transducers can contribute, i.e. most of the surfaces surrounding a normal, large orchestra stage.

The only calibration needed is that one must make a correction for the possible difference between the power response and the pressure response of the loudspeaker in the chosen position of the microphone (1 m from the source center). Consequently, one should mark and always choose this same position of the microphone relative to the spherical coordinates of the source.

Our practice has been to average over the four 1/1 octave bands 250 – 2000 Hz and over minimum 3 position pairs on the stage as shown in Figure 2. S1 represents the soloist, S2 is the middle of the string section stage right, S3 is the left end of 2nd row of woodwinds (bass clarinet) and P1 is 1st oboe. P2 and P3 are mirrors of S2 and S3 respectively in the long axis of the stage.

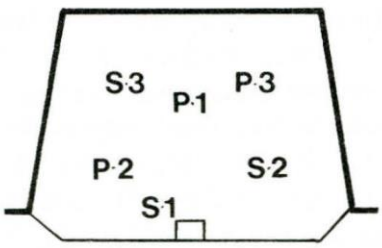

Figure 2. General layout of transducer positions for acoustic measurements on orchestra stages. See text.

As a minimum, ST_{early} is measured in S1 - S3, but more positions are preferable, of course. We also measure EDT between pairs of S and P positions (denoted EDTp). The stages are furnished with chairs and music stands, but without musicians, during the measurements.

All ST-data presented in the following are arithmetically averaged over the four 1/1 octave bands 250 to 2000 Hz and over positions.

3. USE AND LIMITATIONS OF THE ST PARAMETERS

3.1 What can ST_{early} be used for?

Early experiments [5] indicated that in many halls, reflection energy arriving before 100 ms could easily be masked by the direct sound from the musician's own instrument.[1] However, when sitting in an orchestra playing in a single hall subject to different modifications, strong correlation was found between ST_{early} and "ease of hearing others" [6]. Consequently, the author has continued to use this measure in investigation of halls - often in connection with consulting jobs. In most of the cases where variation in early reflection energy was tested within the same hall, we have found agreement between "ease of ensemble" responses averaged over musicians and the position averaged ST_{early} as described in section 4. We have also found this parameter to be robust and repeatable [7].

That a parameter like ST_{early} measured only 1 m from the source should be able to detect ensemble between musicians sitting far apart is a paradox. On the other hand, we only intend to measure the effect of early reflections on musicians' acoustic conditions in general, i.e. comparing the position averaged ST_{early} with the musician averaged response. In spite of its simplicity, ST_{early} should be feasible for that purpose.

3.2 Limitations of ST_{early}

Of course, there are obvious limitations in using position averaged ST_{early} as a measure of ease of ensemble. The most obvious ones are:

1) With a source-receiver distance of 1 m, it does not measure the actual transmission of ensemble information between specific positions on stage,
2) It cannot measure the effect of different riser configurations used to improve the direct sound propagation.
3) It does not consider instrument or listener directivity.
4) Position averaging of measurements taken with only 1 m source-receiver distance means it is impossible to describe correctly the effect of reflectors oriented to transmit reflections between specific groups of instruments.
5) Measuring without musicians on stage means that the effect of vertical surfaces creating purely horizontal reflection paths can be overestimated because the attenuation by the musicians themselves will be absent.

3.3 Properties of an "ideal" parameter for measuring "ease of ensemble"

An objective parameter correctly considering the variables determining musicians' ensemble conditions between specific positions would be nice to have – at least in theory; but it would probably require the parameter correctly considering:

a) the level, directivity and orientation of each of the different instruments in the symphony orchestra,
b) the attenuation effect of musicians sitting between source and receiver (unless the measurements are done with the musicians on stage),
c) information about the directional sensitivity of the hearing of the musicians playing different instruments (see [8]),
d) the desired level of balance between self and others,
e) the influence of reverberance (dependent on the presence of both musicians and audience in the hall and therefore being measurable only when occupied).

Some of these factors have been included in computer model studies [3] and in laboratory simulations [4]; but it seems far too complicated to consider in a practical measurement situation. Besides, if many of these

[1] In the same publication, another parameter, EEL "Early Ensemble Level", intended for measurement of the sound transmitted between the musicians, was also tested but was found to have very low correlation with musicians' evaluations of concert halls.

parameters were included, the measurement result would probably be valid only for one specific orchestra setup and orchestration and not as a general descriptor of whether the acoustics of the hall and of the stage in particular are favorable or not. Therefore, our pragmatic approach in research and consulting has been to use ST_{early} as an overall - and easy to measure - objective parameter. Of course, it must then be supplemented with a qualitative consideration of the other position/instrument dependent factors such as cross stage communication between the weaker string sections on both sides of the conductor, a need to improve the hearing of the weaker instruments (strings and wood winds) and moderating the levels of loud brass and percussion for the rest of the orchestra.

3.4 What can ST_{late} be used for?

While most of the early reflection energy being returned to the musician from his own instrument is masked, it seems possible that ST_{late} can describe the effect of the later part of the room response. It is likely that the amount of late energy is used by musicians to judge the "fullness" of the hall, whether it "supports" the sound she/he produces and probably also whether it helps the musicians to balance and blend their sounds.

The information to be transmitted between musicians must also possess clarity. There is a risk that too much late sound can mask the early. Therefore, the balance between ST_{early} and ST_{late} may be relevant to look at. Also, EDT measured on stage: EDTp may be used. EDTp should likely be lower than EDT in the hall as already suggested by Jordan [9].

4. DATA FROM PRACTICAL CASES

In the following, some of our experiences from measuring ST parameters and collecting musicians' evaluations in different halls will be described. Similar results from a couple of halls in Australia are also mentioned.

4.1 The Danish Radio and Malmö Live concert halls

In his MSc project from the Technical University of Denmark, Jakob Wincentz [10] compared the stage acoustics of the two new concert halls for symphonic music located in Copenhagen, Denmark and Malmö, Sweden respectively, but only about 30 km from each other.

The Danish Radio concert hall (DR) is of the vineyard type with 1800 seats and the stage being surrounded by elevated terrasses. Malmö Live (ML) has a shoe box shape seating 1600 and the stage placed near the rear wall between nearly parallel side walls. In DR, a canopy is placed about 15 m above the stage floor, while in ML wide reflector panels are placed between 8 and 10 m above the floor. Occupied mid frequency RT in DR is 1.9 Sec. while it is 2.05 Sec. in ML. With these differences there are large possibilities for the acoustic conditions on the stages to be different. As can be seen in Fig. 3, both stages have circular risers promoting efficient direct sound transmission between the musicians.

Along with objective measurements, musicians' opinions were collected by questionnaire forms filled in by nearly 50 musicians from the two resident orchestras in DR and ML respectively. Fortunately, many of these musicians had played in both halls, whereby direct comparison of the subjective ratings of the halls was possible with high significance.

Figure 3. Views towards the stages in DR (left) and ML (right) respectively.

Tab.1 shows the measured results of ST_{early} and ST_{late} from the two stages along with results of EDTp, (measured with a distance between source and receiver of about 5 – 8 m). Also, the difference between ST_{early} and ST_{late} is listed, since this represents the ratio between the reflection energy arriving before and after 100 ms, likely to represent the perceived "clarity".

Table 1. Objective data from the DR and ML halls.

Vol. [m3]	Hall/ Config.	ST early [dB]	ST late [dB]	early-late diff. [dB]	EDTp [Sec.]
28000	DR	-16,6	-18,6	2,06	1,71
22000	ML	-13,5	-17,4	3,9	1,62

Analyses of the musicians' responses showed significantly higher evaluation of both "ease of ensemble", "support" and "reverberance" in ML than in DR. This is in line with the values of both ST_{early} and ST_{late} being higher in ML than in DR, although the difference in ST_{late} is only 1.2 dB. That

ST_{early} is 3 dB higher in ML than in DR also has the effect that the early-late difference is higher in ML – probably indicating that the higher "reverberance" is obtained without sacrificing "clarity". This is also indicated by EDT_p being lower in ML than in DR – in contrast to the fact that in the auditorium, the RT in ML is higher than in DR! The sound in DR is judged to be more "analytical" than in ML, which is liked by many members of the DR orchestra. This is probably the reason why the overall evaluation indicated that members of each orchestra like their "home" hall best in spite of ML getting the highest scores for both "ease of ensemble", "support" and "reverberance".

4.2 Two halls in Odense – one with modifications

In 2023, it was considered to move the Odense Symphony Orchestra concerts from its present home hall, the Carl Nielsen Concert Hall (CN), to a new venue next door, the Odeon (OD). CN is a rectangular "shoe box" concert hall with about 1060 seats distributed on a rather steep main floor seating (on a telescopic riser system), a single rear balcony and a shallow choir balcony behind the orchestra stage. OD is a slightly fan shaped hall with about 1700 seats distributed on main floor and a single level of rear and side balconies. OD has a proscenium opening and a large stage tower, and the first six rows can be removed to give place for an orchestra pit. The pit floor can also be raised to form an extension of the stage into the auditorium. RT in CN is about 2.0 Sec. occupied, while it is about 1.5 Sec. in OD.

To test whether the orchestra members could use OD for their concerts, a series of experiments were made where the CN hall was compared with OD fitted with a temporary orchestra shell in different configurations to accommodate either all musicians on the stage behind the proscenium opening or with part of the orchestra on the pit raised to stage level. For each of these two, also two different total depths of the stage floor and shell were tested, since there is often a request from woodwinds and strings to get further away from the loud brass and timpani. The appearances of the stages in CN and in OD (both behind and partly in front of the proscenium) are shown in the photos in Fig. 4. In both halls, winds and percussionists sat on their custom-made riser boxes.

Objective measurement data and evaluations by most of the Odense Symphony Orchestra members (more than 50 responded) were collected from all five cases. An overview of the objective data are shown in Tab. 2. Where "stg" is added to "OD" in the second column, it means that the entire orchestra was placed on stage behind the proscenium, whereas "pit" represents the exposed position partly on the raised pit. Likewise, "deep" indicates the extended depth of the (partly open) orchestra shell to allow for larger distances between brass/percussion and the rest of the orchestra.

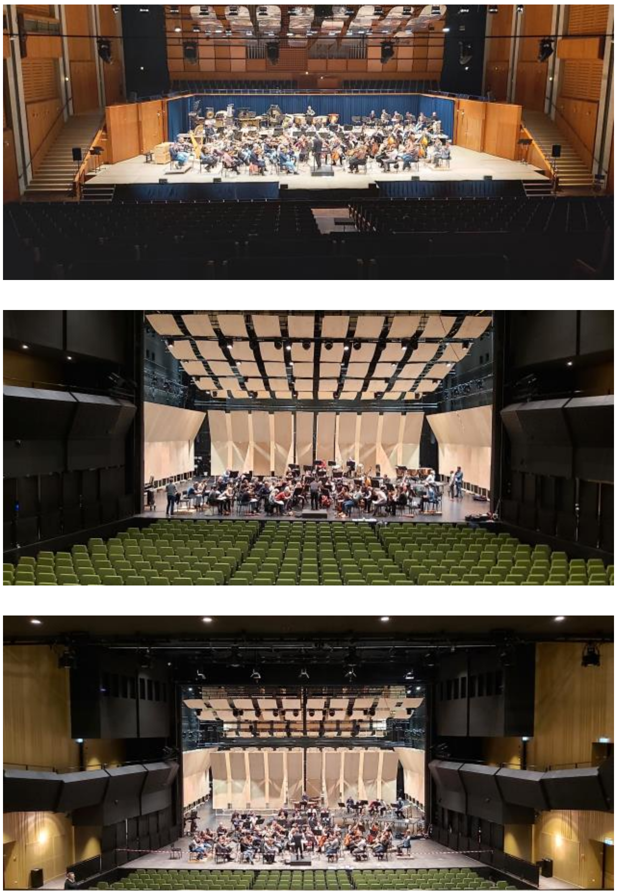

Figure 4. Views towards the stages in CN (top) and in OD with orchestra stage on stage or partly on raised pit.

The musicians clearly judged "support" in CN to be better than in OD, which was felt too "dry" in accordance with the very low values of ST_{late} in all four OD configurations. On the other hand, all OD configurations were judged better for "ensemble" than CN, which is also mirrored in the higher (but not impressive) ST_{early} values. "Ensemble" in CN is poor and the sound was described as "muddy" as also indicated by the early-late ratio being negative and EDT_p being very high. The two configurations with increased depth of the orchestra shell were not judged to be significantly different from the configurations without extended depth. Still, ST_{early} shows small but consistent reductions in the extended depth situations due to a larger stage volume. ST_{early} is also lower when the orchestra is exposed on the raised pit; but overall, these two configurations were preferred due to slightly better contact with the modest reverberance in the auditorium (not indicated by ST_{late}, but by EDT_p).

Table 2. Objective data from two halls in Odense.

Vol. [m3]	Hall/ Config.	ST early [dB]	ST late [dB]	early-late diff. [dB]	EDTp [Sec.]
14000	CN	-17,1	-17,0	-0,1	2,03
18000	OD stg	-14,7	-19,5	4,8	1,40
18000	OD stg deep	-15,4	-19,7	4,3	1,40
18000	OD pit	-15,7	-19,8	4,1	1,52
18000	OD pit deep	-16,2	-19,8	3,5	1,52

4.3 Attempts to improve the CN hall in Odense

Following the experiments in Odeon, a series of experiments was organized to test whether improvements could be made in the Carl Nielsen Hall. The main problem for the orchestra in this hall is excessive sound exposure levels; but our hypothesis was that if the poor conditions for "ensemble" can be improved, then the orchestra – with the help of a devoted conductor – will be able to develop a more refined playing style with more emphasis on nuancing in the lower end of the dynamic range. Among the physical parameters tested were different geometries of the portable risers, screens or floor absorption in front of the loud instruments and reduction of absorption behind the stage (the blue curtains in Fig. 4). However, the main tools were introducing the tilted wooden reflectors seen in Fig. 5 and reducing RT in the hall with drapes mounted along the walls in the auditorium.

Figure 5. Views towards the stage in CN with tilted reflectors suspended over both sides of the stage.

Due to slight differences in orchestra layout including changed risers and more absorption around the stage (besides normal measurement uncertainty, of course), the first line of data in Tab. 3 (named "St.curt.") is not fully identical to that in Table 2. However, the positive effect of the reflectors on ST_{early} in the two following lines marked "Refl." is clearly seen.

Table 3. Objective measurement data from three configurations of the CN hall in Odense.

Vol. [m3]	Hall/ Config.	ST early [dB]	ST late [dB]	early-late diff. [dB]	EDTp [Sec.]
14000	St.curt.	-17,4	-16,9	-0,4	1,97
14000	Refl.	-15,9	-16,6	0,7	1,74
14000	Refl. + Abs.	-15,8	-16,7	0,9	1,66

The musicians judged "ensemble" to be improved by the added reflectors; but ST_{early} and the early-late difference are probably still too low. Reducing RT in the hall also improved "ensemble" slightly; but then some musicians missed the reverberance they were used to!

4.4 Experiences from halls in the UK

During projects related to improvement of the conditions for some of the BBC's orchestras in the UK, we have made measurements and obtained musicians' responses from the following halls/studios: The new Philharmonic Studio in Salford Quays (SF), The Maida Vale Studio 1 (MV) and the Watford Colosseum (WF).

The Salford Studio is a box shaped room with a very high ceiling, suspended reflectors and several moveable absorbers mounted in and on the walls as seen in Fig. 6.

Figure 6. The Philharmonic Studio in Salford, UK.

SF was tested in two configurations: low reflectors and max. absorption (SFabs) or high reflectors and minimum absorption (SFrev).

Maida Vale Studio One is also rectangular but with a quite low ceiling. Still, reflectors are suspended underneath. Watford Colosseum (WF) is a rectangular hall with a large rear balcony and a fixed stage. While SF and MV have only 100-200 seats for audiences, WF has a seating capacity of about 2000. Unfortunately, the fixed stage in WF was too small for the BBC Concert Orchestra. Therefore, the musicians were placed on the flat floor in front of the stage. The objective data for SF in the two configurations, MV and WF are listed in Tab. 4.

Table 4. Objective measurement data from three halls in the UK used by BBC orchestras.

Vol. [m3]	Hall/ Config.	ST early [dB]	ST late [dB]	early-late diff. [dB]	EDTp [Sec.]
10500	SF abs	-11,6	-15,4	3,8	1,49
10500	SF rev	-12,2	-14,2	2,0	1,80
6200	MV	-12,0	-14,4	2,4	1,49
11000	WF	-15,9	-15,5	-0,4	2,09

In short, “Ensemble” in SF is judged to be better with low reflectors and absorption. Without absorption, reverberance is excessive. “Ensemble” is better in MV than in WF.

4.5 Data from halls in Australia

Peter Exton has kindly shared his data from similar investigations he has made in halls in Australia, see Tab.5.

Table 5. Objective measurement data from three halls in Australia; “BR” in 4 configurations.

Vol. [m3]	Hall/ Config.	ST early [dB]	ST late [dB]	early-late diff. [dB]	EDTp [Sec.]
7500	BR L+A	-13,2	-15,9	2,7	1,09
7500	BR H+A	-15,9	-17,4	1,5	1,13
7500	BR H-A	-15,6	-14,1	-1,5	1,52
7500	BR M+0.5A	-13,5	-14,6	1,1	1,29
11600	WT	-14,6	-13,9	-0,7	
2300	MC	-11,7	-13,8	2,1	

BR is the rehearsal hall of the Queensland Symphony Orchestra in Brisbane, which was tested in four configurations: low overhead reflectors and full absorption (L+A), high reflectors and full abs. (H+A), high reflectors and no abs. (H-A) and medium high refl. plus half abs. (M+0.5A) [11]. The latter was preferred to the three other variants – probably due to better blend and moderate reverberance rather than due to changes in “ensemble” [12].

Wintrop Hall (WT) in Perth is a rectangular hall which is judged to have “muddy” sound and poor “ensemble”, while the small hall at Melbourne Conservatory (MC) seems to be well liked by musicians [12].

5. DISCUSSION

5.1 Justification for measuring ST_{early} and ST_{late}

The cases described here indicate that musicians need early reflections from the stage surroundings to help them hear their colleagues, and ST_{early} seems able to describe this objectively in cases of a hall being modified or when comparing two halls.

Musicians also need late reflections/reverberation from the auditorium. It is believed that this energy helps them judge the degree of “support” they get from the room and probably also how well they balance in level and timbre with the rest of the orchestra. In consultancy, we have found promising correlation between ST_{late}/EDT (on stage) and musicians’ judgements of reverberance.

For description of “clarity”, which is also important for musicians’ “navigation”, the difference between ST_{early} and ST_{late} and EDTp (EDT measured on stage) seem to be of value as well. In the data reported here, mutual correlations between the four parameters presented were very low.

5.2 Optimal values for ST_{early} and ST_{late}

All data from the cases presented are condensed in Fig’s 7 and 8. Blue arrows have been inserted, indicating directions of improvement in each case. Although the different tests cannot be directly compared, it is hoped that patterns indicating favorable ranges of values for each of the parameters may appear. The suggested ranges are marked in green. Some arrows stop outside the green areas, indicating that the end results may not be fully satisfactory.

The cases above suggest that the author’s earlier recommended range for ST_{early} , -13 to -11 dB [6] could be extended to -14 dB or even -15 dB in large halls with large stages. In particular, this may be true if half-circular risers are used, so that the direct sound will propagate well between the musicians.

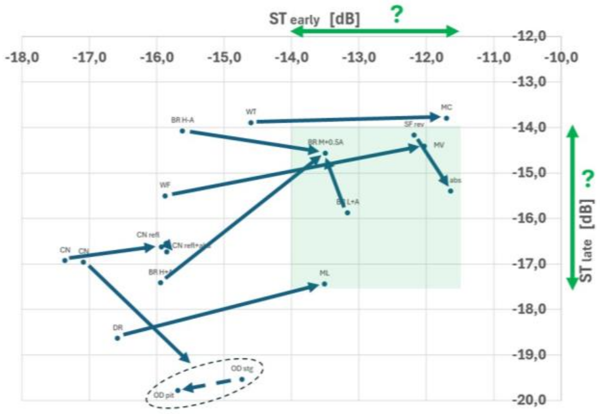

Figure 7. Comparative values of ST_{early} and ST_{late}.

All cases suggested that ST_{late} should be lower than ST_{early}, resulting in a range for ST_{late} perhaps as shown in Fig. 7. Likewise, EDTp should be lower than EDT in the auditorium, which could result in a suggested range as seen in Fig. 8.

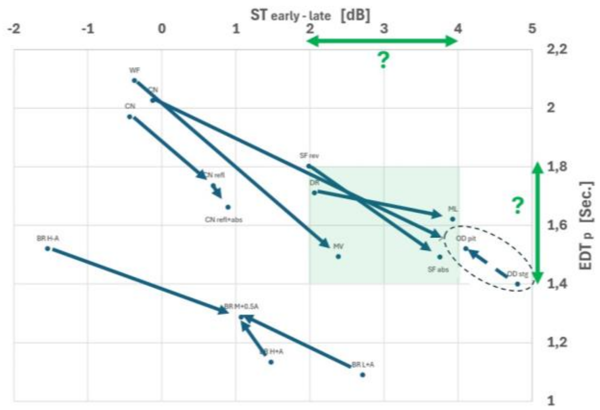

Figure 8. Comparative values of ST_{early} - ST_{late} and EDT_p

The ranges presented here should be regarded as our suggestions as of tody, not as final conclusions!

6. ACKNOWLEDGMENTS

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