



# PROJECT ANCIENT ACOUSTICS PART 4 OF 4: STAGE ACOUSTICS MEASURED IN THE ODEON OF HERODES ATTICUS AND THE THEATRE OF ARGOS

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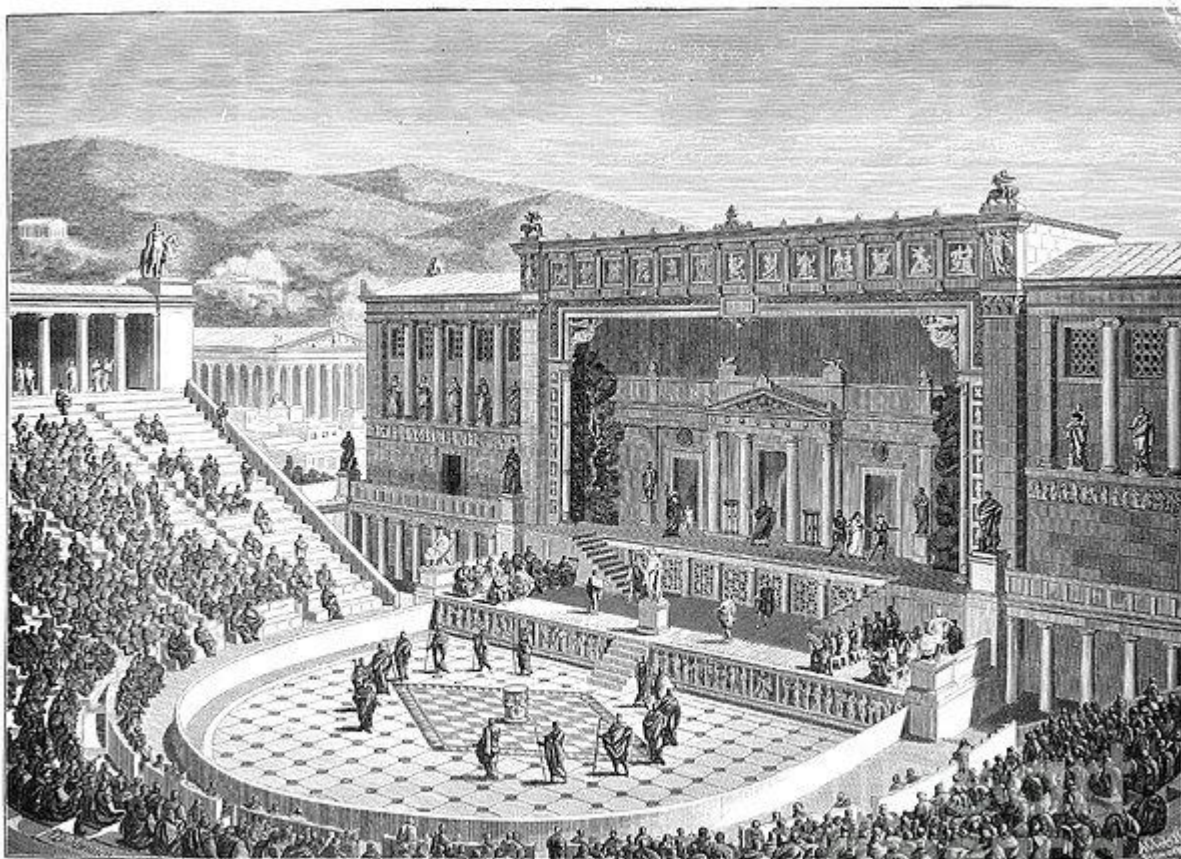
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The stages of ancient theatres can be characterized by their circular shape called the ‘orchestra’, in front of a rectangular elevated stage with a highly decorated back wall. During some performances, a group of musicians was located in the circular shape, while actors were positioned on the elevated stage. In modern concert halls or theatres, acoustic support from the room is required for such performers to be able to play together properly. It can be assumed that in the ancient theatres, acoustic support must have been beneficial for performers as well. As part of the Ancient Acoustics project, stage acoustic measurements have been carried out in the Odeon of Herodes Atticus and the theatre of Argos. The goal of this paper, is to study the behavior of the early and late reflected sound level on ancient stages in their current state, measured by the extended early and late support parameters  $ST_{early,d}$  and  $ST_{late,d}$ . Comparing the two stages is particularly interesting, because in Argos the back wall is missing. However, the absolute value of the parameters might have limited value because both the audience area and stage were unoccupied during the measurements. Also, the theatre of Argos has a severely damaged seating area and the back wall has not been restored, and at Odeon Herodes Atticus, the stage floor was missing. It is well known that the typical concentric shape of the audience area gives focused reflected sound back to the stage. This can be confirmed by the measured results that show a strong increase in reflected sound level when the source and receiver are positioned point-symmetrically along the center of the circle. This might have had an effect on performers, but whether the extra ‘support’ was beneficial is uncertain, because the ‘chirping’ and focussing of the reflected sound can cause colouration and poor balance.

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## 1. Introduction

The stages of ancient theatres can be characterized by their circular shape called the ‘Orchestra’, in front of a rectangular elevated stage (‘Proskenion’) with a highly decorated back wall (‘Skene’) [1]. During performances, a group of musicians would be located in the circular shape, while actors were positioned on the elevated stage. The musicians could consist of singers and dancers (‘chorus’) sometimes accompanied by instruments like strings, flutes and percussion [2]. Only some clues are available to the preferred positioning of the musicians. For instance, in the Dithyramb plays, dedicated to the god Dionysus, a chorus consisting of up to 50 singers would be dancing in a circular shape [3]. However, these plays did not involve any actors and developed before the time of the theatres. In the theatre the exact centre of the ‘orchestra’ was commonly occupied by an altar, which would be used during ceremonies and not necessary during plays. It is likely that the chorus has been dancing around this centre in the theatre too. Figure 1 shows a sketch by J. Buhlmann [4] depicting a scene of a play taking place at the theatre of Dionysos in Athens. In the sketch a circular 12 person chorus and the altar in the middle of the ‘orchestra’ can be recognised. The Proskenion is occupied by a number of actors at random positions.



THEATRE OF DIONYSOS AT ATHENS.

Restored from recent excavations.

Figure 1: Theatre of Dionysos Athens, sketch by J. Buhlmann [4].

In modern concert halls or theatres acoustic support from the room is required for musicians to be able to play together properly [5, 6]. Feedback from the room is necessary for the synchronisation of music and for playing in tune. For symphonic music, a proper amount of reverberation is desired with sufficient loudness to be audible during playing. Among others, this is important to get an idea of how the music sound the audience area. Some room acoustic parameters have been defined that aim to predict the perception of the acoustic conditions by musicians on stage. The most well-known stage acoustic parameters are the reverberation time parameters,  $T_{30}$  and EDT, and the early and late support parameters,  $ST_{early}$  and  $ST_{late}$ .

It can be assumed that in the ancient theatres, acoustic support must have been beneficial for performers as well. In this study, we used common methods to investigate the stage acoustics of two stages of ancient theatres. As part of the Ancient Acoustics project [7, 8, 9], stage acoustic measurements have been carried out in the Odeon of Herodes Atticus and the theatre of Argos (figure 2). Acoustic measurements have also been performed in the theatre of Epidaurus, but due to time constraints and large crowds no stage acoustic measurements could be performed there.

The goal of this explorative study is to investigate the behavior of the early and late reflected sound level at the 'orchestra' (circle) and on stage in their current state. Comparing the two 'stages' is particularly interesting, because in Argos the back wall is missing while in Odeon Herodes Atticus the back wall still exists. Argos theatre has a severely damaged seating area while at Odeon Herodes Atticus the seats have been renovated. During our measurements at Odeon Herodes Atticus, no the stage floor was present.

The absolute value of the parameters might have limited value because both the audience area and stage were unoccupied during the measurements. Besides, it is not our goal to compare the acoustic conditions found in ancient theatres with those as preferred in modern concert halls.



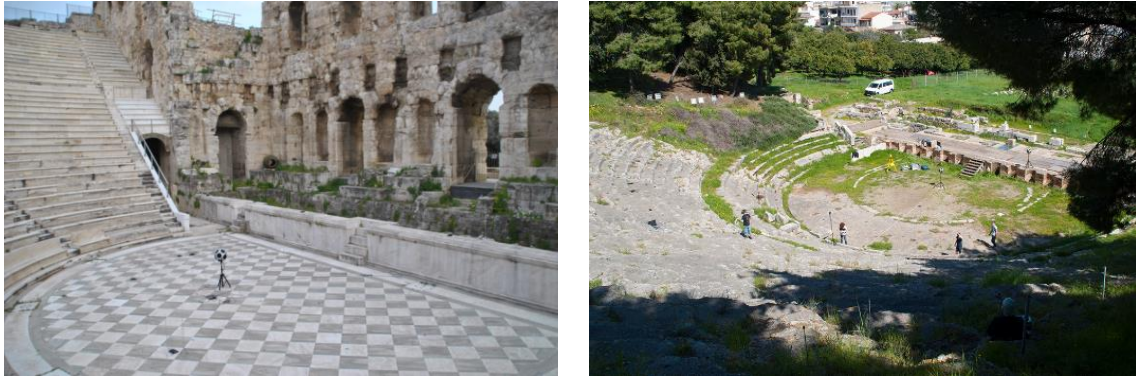


Figure 2: Odeon of Herodes Atticus (left) and the theatre of Argos (right).

It is well known that the typical concentric shape of the audience area gives a focused reflected sound to the stage. In most theatres, the center of the round shape of the seating area lies in the middle of the ‘orchestra’. When source and receiver are both at this center, for instance when clapping ones hands, a typical ‘intimate chirp’ sound, caused by focusing and a time-step increasing sequence of ‘staircase reflections’ can be observed [10]. Focusing also occurs when source and receiver are positioned point-symmetrically along the center of a circle. Figure 3 shows a reflection path analyses of a reconstructed Roman theatre in Aspendos [11]. A position on stage and a position in the ‘orchestra’ lie on the opposite side of the same circle with the ‘orchestra’s’ center in the middle. Sound ‘rays’ are reflected from both lower parts of the audience staircase and from the ‘Diazoma’ (horizontal passage between several rows of seats) via the canopy above the stage. The 3D model is constructed using flat partial surfaces, only showing one ‘ray’ hit per surface. In reality, a sound wave hitting a perfect circular shape will likely result in strong focusing of sound. As we will show in this paper for the first time, stage acoustics measurements of early and late support indeed confirm such focusing effects on stage and in the ‘orchestra’ of two ancient theatres.

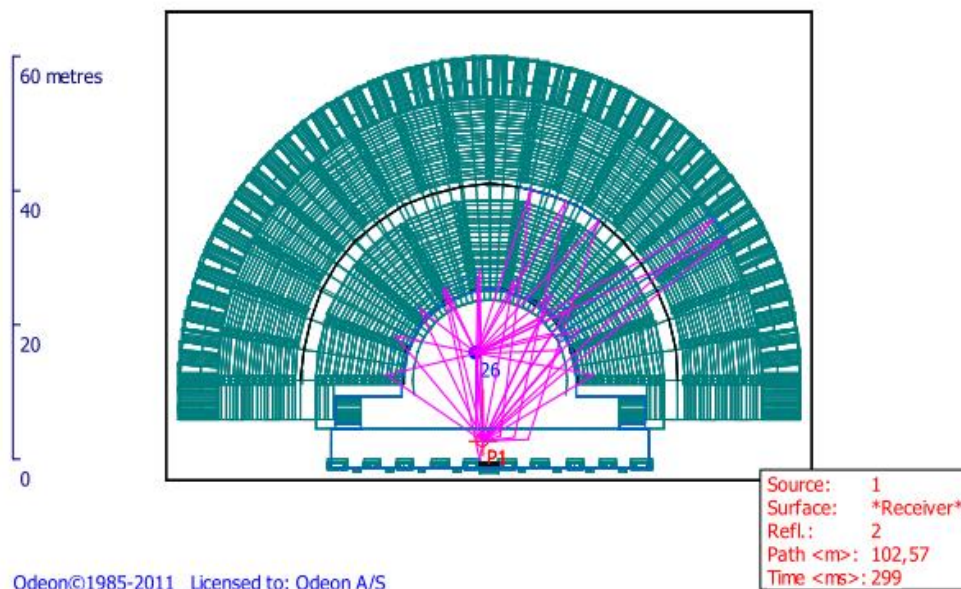


Figure 3: Early reflections from the stage position to a receiver in the orchestra. [11].

## 2. Method

### 2.1 Stage acoustic parameters

Stage acoustic parameters can be derived from impulse responses. Impulse response measurements have been performed in the two theatres, see our paper Project Ancient Acoustics part 1 of 4 [7] for a description of the measurement method and setup. The only difference in current setup is the use of a 5.46 seconds long e-sweep and a transducer height of 1 meter. To evaluate the amount of early reflected sound energy on stage, the Early and Late Support parameters are used as introduced by Gade [5] and extended and modified by Wenmaekers et al. [12], see figure 4.

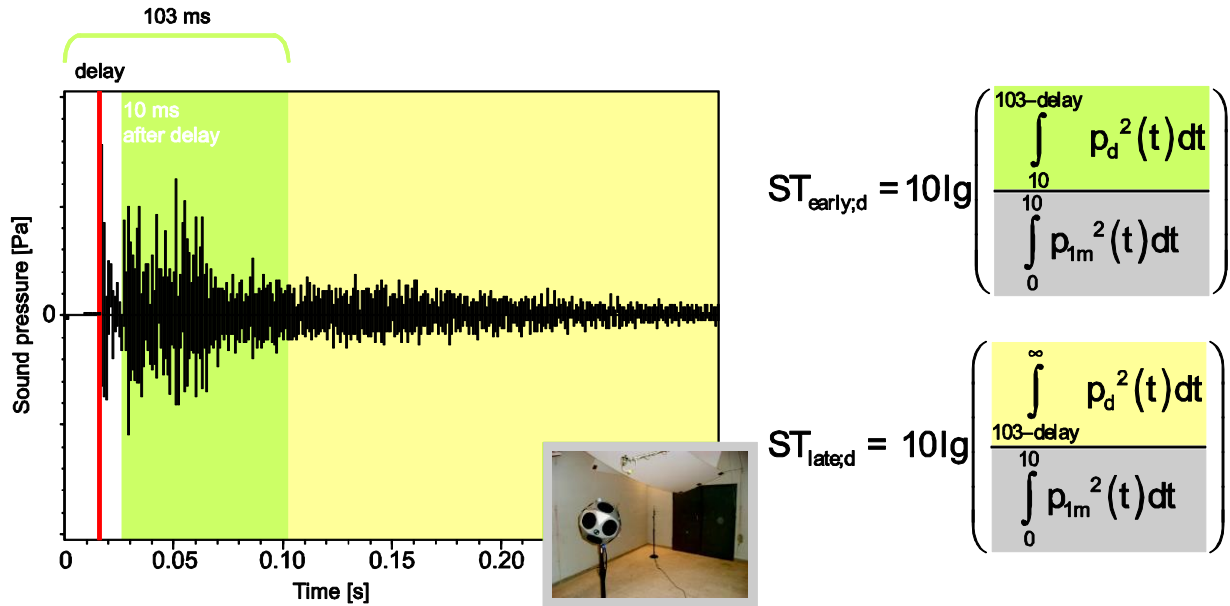


Figure 4: Measured impulse response (left) with direct sound delay in red, early reflected sound in blue and late reflected sound in orange.  $ST_{early;d}$  and  $ST_{late;d}$  (right) are the Early and Late Support at distance  $d$ ,  $p$  is the sound pressure measured at distance  $d$ ,  $p_{1m}$  is the free field sound pressure measured at 1 m distance derived from sound power measurements in a laboratory (green colored) and delay is  $r$  times 1000 divided by the speed of sound. Unless mentioned otherwise, the average  $ST$  over the 250 to 2000 Hz octave bands is used in this paper as a single number rating. See Wenmaekers et al. [12] for more background information on these parameters.

The stage acoustic parameters  $ST_{early;d}$  and  $ST_{late;d}$  are not limited to 1 meter source-receiver distance and can be measured at various distances. The limit of the integration interval for useful reflections is reduced according to the time it takes for the direct sound to reach the receiver at a certain distance. This means that the interval is defined relative to the time of emission, similar to the concept of the *EEL* (Early Ensemble Level) as introduced by Gade [5]. The main difference between  $ST_{early;d}$  and *EEL* is that the direct sound is not included in  $ST_{early;d}$ . From both a physical and architectural point of view it is interesting to evaluate reflected sound separately from the direct sound. The reference values  $p_{1m,free-field}$  is derived from a diffuse field sound power measurement in a reverberation room.

In our earlier paper [12], we have shown that  $ST_{early;d}$  measured on unoccupied concert hall stages decays as a function of source-receiver distance following a logarithmic trend line. The late reflected sound level, measured with  $ST_{late;d}$ , has shown to be independent from distance as can theoretically be expected from a diffuse sound field.

## 2.2 Measurement positions

A schematic plan with the numbering of the measurement positions is shown in figure 5a. In the Odeon of Herodes Atticus, see figure 5b, positions were selected on two half circles at 3 and 6 meters from the centre of the ‘orchestra’, with 10 positions per half a circle. Source positions were selected in the middle of the ‘orchestra’ (S1) and on the half circles in forward direction (S2 and S3) and sideward direction (S4 and S5). Besides, 12 positions were selected on the edge of what remains of the original stage with a mutual distance of 2.5 meters. Source positions S6 and S7 were on the stage edge, parallel to source positions S1 and S5. In the theatre of Argos, see figure 5c, the stage back wall is missing. Therefore, no source and receiver positions were selected on the stage edge. The positions in the ‘orchestra’ are equal to the positions used in the Odeon of Herodes Atticus.

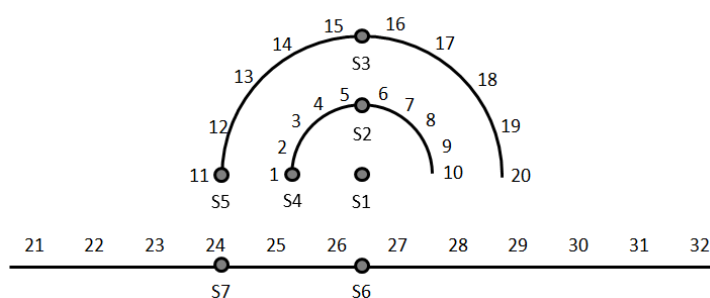


Figure 5a: source – receiver numbering



Figure 5b: schematic positions in the Odeon of Herodes Atticus



Figure 5c: schematic positions in the theatre of Argos

### 3. Results

Figures 6a-c show the results for  $ST_{early,d}$  and  $ST_{late,d}$  as a function of source-receiver distance. For the Odeon of Herodes Atticus, figure 6a only shows results for both source and receiver position at the ‘orchestra’ in front of the stage, while figure 6b only shows results for positions with either source in the ‘orchestra’ and receiver on the stage edge or vice versa. For the theatre of Argos, only positions were measured at the ‘orchestra’, shown in figure 6c. As explained in section 2.1,  $ST_{early,d}$  measured in concert halls decays over distance and  $ST_{late,d}$  is not dependent on distance. A similar trend can be observed in the current data, expressed by clouds of data points. However, in the ancient theatres, clear outliers from these clouds are found with a higher reflected early or late sound level compared to the ‘cloud’. These are indicated in the graphs by circles or lines.

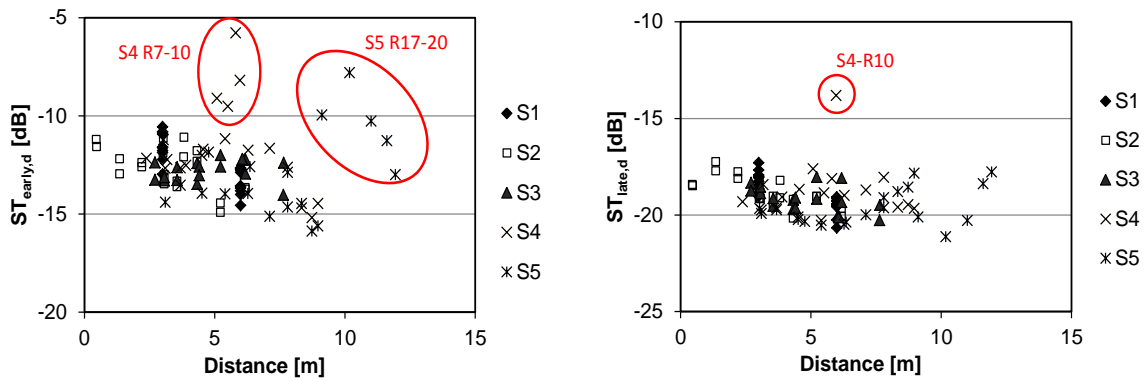


Figure 6a:  $ST_{early,d}$  and  $ST_{late,d}$  in Odeon of Herodes Atticus, positions in the ‘orchestra’

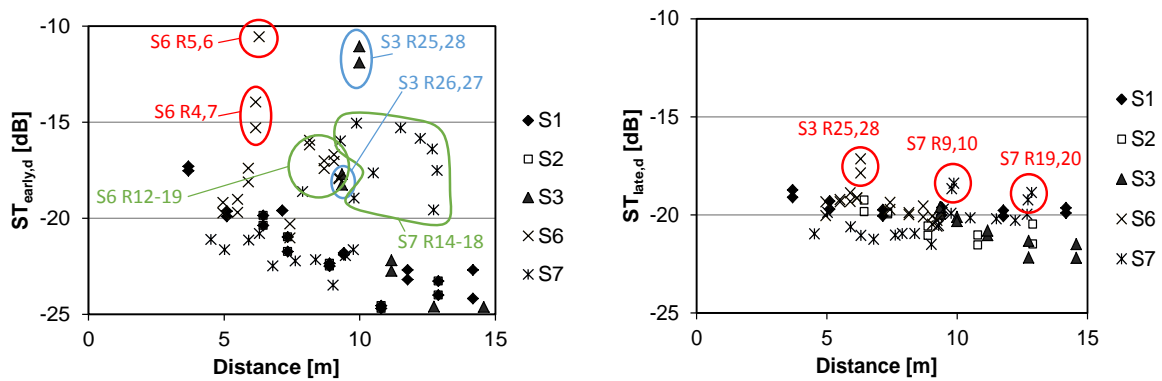


Figure 6b:  $ST_{early,d}$  and  $ST_{late,d}$  in Odeon of Herodes Atticus, positions from ‘orchestra’ to stage

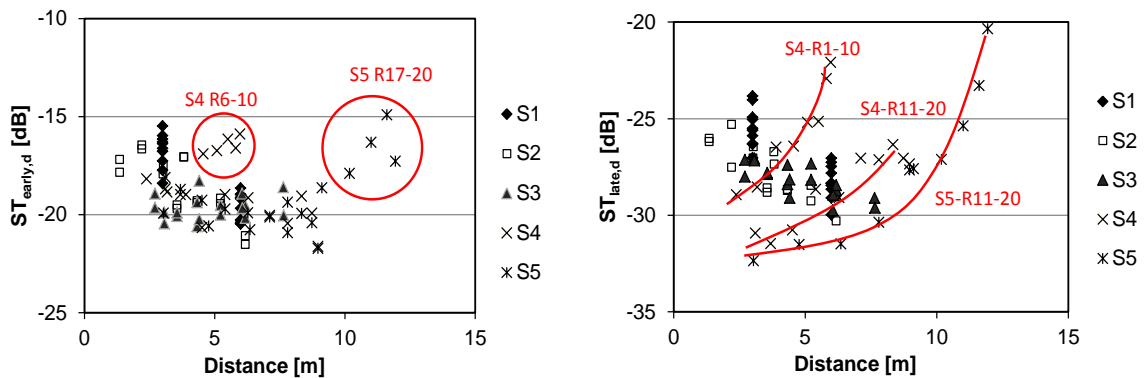


Figure 6c:  $ST_{early,d}$  and  $ST_{late,d}$  in theatre of Argos, positions in the ‘orchestra’



In each theatre, S4R10 is one of the positions that clearly stands out from the ‘cloud’ by a stronger early and late reflected sound level. For further investigation of these positions, the ETC’s (Energy Time Curves) for each theatre are presented in figure 7. For comparison, the ETC of position S1R15 which has the same source-receiver distance as S4R10 (6 meter), but without the focussing effect, can be observed.

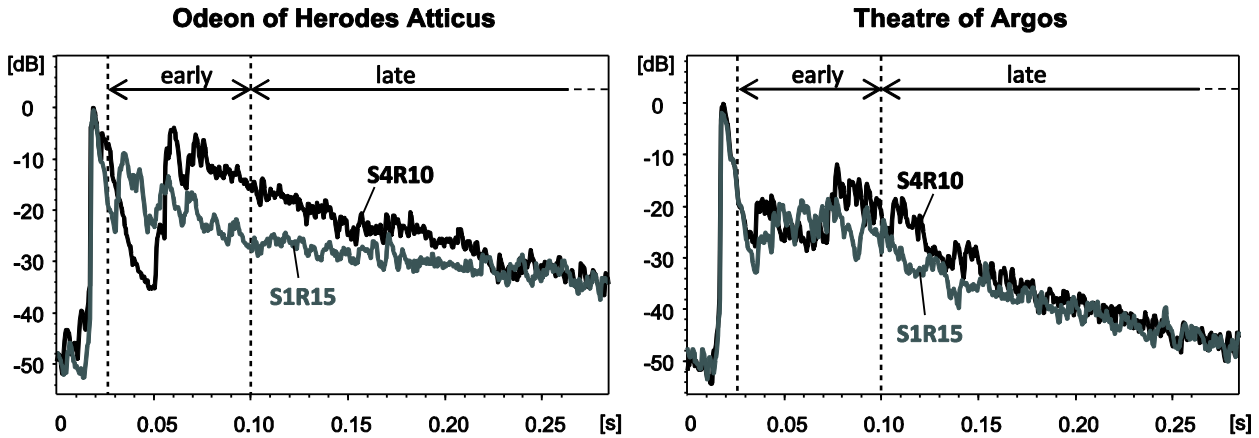


Figure 7: Smoothed broadband Energy Time Curves for positions S4R10 with focussing and S1R15 without focussing for both theatres. The direct sound is equally loud in each graph (equal distance).

#### 4. Discussion

The results for the early and late reflected sound level, measured by the support parameters  $ST_{early,d}$  and  $ST_{late,d}$ , show clear outliers for certain positions, see figure 6. Over 5 dB higher levels are found when the source and receiver are positioned point-symmetrically along the center of the ‘orchestra’. Examples of such positions are S4R10 versus S5R20 within the ‘orchestra’ and positions S6R5 versus S7R17 with one position in the ‘orchestra’ and one position on the stage edge. When listening to the measured impulse responses, the typical ‘chirp sound’ can be heard, which one also hears when clapping ones hands in the centre of the ‘orchestra’. The ETC curves presented in figure 7 illustrate that indeed multiple delayed reflections arrive at the receiver position, both before and after 103 ms after the emission of the sound (103 ms separates early from late in the ST parameters). The reflections are stronger than those in a different measured impulse response not being in the focal point. In the Odeon of Herodus Atticus, these reflections can be observed up to 225 ms. This delay corresponds to a path length of 77 meter, which is approximately twice the distance from the ‘orchestra’ centre to the last row of the seats. This shows that even the last seating row causes focussing effects. In Argos, the increase in sound level is observed in the ETC up until 150 ms, which indicates that reflections from the severely damaged seating beyond 25 meter do no longer cause focussed reflections.

An increased sound level is not limited to the exact focussing point. The results for  $ST_{late,d}$ , measured in Argos at positions S4R1 to S4R10 and S5R11 to S5R20, show that the reflected sound level gradually increases when positions are closer to the focal point. The reflected sound level is also stronger in positions close to the focal point measured in the Odeon of Herodus Attica, for example S7R14 to S7R18 and S6R12 to S6R19. It seems that this is only the case for positions on the same circle with the ‘orchestra’ centre in the middle. This trend is not observed for the positions S3R21 to S3R32 on a straight line: only positions S3R25 to S3R28 which are more or less on the same circle show an increased level caused by focussing.

## 5. Conclusion

We can conclude that a strong focussing effect occurs in an amphitheatre, not only when the source and receiver are positioned in exact center of the ‘orchestra’, but also when positioned point-symmetrically along the center of the circle. At these positions, the typical ‘chirp’ sound can be heard clearly. In a clapping experiment with two persons positioned point-symmetrically along the center of the circle, the effect is only heard by the listener (receiver) and not by the person clapping and listening (both source and receiver). Therefore, it will likely be unnoticed by most visitors of amphitheatres.

Literature suggests that the ‘chorus’, a group of singing and dancing individuals, might have formed circles around the centre of the ‘orchestra’. In this formation, one will hear strong focussed sound coming from other persons in the circle, especially from those standing on the opposite side. The temporal filtering, heard as a ‘chirp’ when clapping ones hand, will cause the voice to sound unnatural. The ‘chirp sound’ is quite audible and is heard by the many tourists visiting the theatres nowadays, and must have been heard by the performers in earlier times. It might even have had an effect on their performance, but whether the extra ‘support’ was beneficial is uncertain, because the ‘chirping’ can also cause unwanted colouration and poor balance among different performers. Besides, the question is whether the effect still exists when the theatres are occupied.

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