The sound effect of ancient Greek theatrical masks

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ABSTRACT

All theatrical forms developed in ancient Greece were forms of masked drama. Apart from the obvious change of the visual appearance of the actors, the masks also altered the acoustic characteristics of their voices. Therefore, both from the listener's and the actor's points of view these masks significantly modified the acoustic events and inevitably transformed the overall theatrical experience. In this work, we employ recreations of such masks and through controlled experiments, via measurements and simulations, we evaluate their impact on the acoustics of the most typical and famous of the ancient theatres, this one of Epidaurus. Emphasis is given on unraveling the character of the combined acoustics of the voice of masked actor and the response of such a theatre which is famous for its perfect acoustics for speech and drama plays.

1. INTRODUCTION

The acoustics of ancient Greek theatres impress experts and the general public alike. Although the significance of acoustics in the public buildings in ancient Greek culture has been investigated using a wide range of contemporary approaches and methodologies [1-3], there are aspects related to the ancient theatrical drama, especially with respect to the function of theatrical masks that are still not properly clarified. It is accepted that the ancient Greek theatres represent the earliest example of building acoustic design to support and enhance speech and music communication, over large public audiences. Therefore these ancient theatres have universal and timeless significance and if well-preserved, they still attract numerous audiences fulfilling functions similar to those for which they were constructed more than two thousand years ago. The perfect acoustic reproduction of speech and music for audiences of more than 12,000 people, enabled these theatres to become the birthplace of the theatrical act so that age-old ritual ceremonies in honor of gods were transformed into great works of dramatic art performed by actors for their fellow citizens and the world. Hence, these buildings have a special significance for the heritage of the acoustic science and of the theatrical arts.

Theatre masks were a fundamental element of the ancient Greek theatre tradition [4]. All theatrical forms that originally developed in Athens during the 6th and 5th centuries BC (tragedy, comedy or satyr plays) and eventually spread over the ancient world were forms of masked drama, i.e. the actors always were performing wearing such masks. A typical theatre mask allowed a transformation of the actor into a new dramatic identity. Hence the function of such mask was crucial to the dramatic work and was more than just a typical theatrical gadget.

In the early period of this art form, the vase paintings of the 5th century BC never represented an actor wearing the mask since the mask was considered indistinguishable from his face. However, there are paintings illustrating masks before or after the performance. In Figure 1, a painting found in the Pronomos crater, circa 400BC, illustrates some actors who have just finished performing a play and on the right side of the illustration, the chorus leader Papposelinus is holding his white long-bearded theatre mask [4, 5]. Moreover, during the Classical period, ancient Greeks used the same word for the mask and the human face: "*prosopon*". This approach didn't change until the second half of the 4th century BC when Theofrastos used for the first time the word *prosopeion* to describe a mask [4].

Figure 1. The chorus leader of the satyrs is holding his mask (from the Pronomos crater 400BC)

All documentation shows that up to the end of the 5th century ancient Greek theatre masks were closely fitted to the head. On the masks depicted on ceramics, both the whites and the pupils of the eyes are painted, suggesting that the eye holes of the original masks were as small in size as the pupils of a living person. The minimization of the sight leads to the maximization of the listening to the other actors, hence to a different state of awareness of their presence based not so much on seeing but on hearing. It leads the actor to the act of *akroasis*, the act of conscious and active listening.

Ancient drama was largely based on theatrical speech. According to Aristotle, acting was a matter of voice having three important qualities: volume, harmony and rhythm. All these qualities are especially important for communication in the outdoor theatres. Since the actor's voice was the most important theatrical element, the mask is considered as an instrument to enhance the voice presence over the entire theatre space and endow the voice with a decided directional delivery. However, up to now such assumption has not been verified. Also, such elevated importance on acoustic presentation must be also seen in conjunction to the reduced dramatic impact of the visual element in the actor's performance. The mask was displaying a static facial expression, largely functioning as a screen for the audience to project their own emotional state [6].

It is now accepted through the archeological evidence that classical masks had a head-enclosing (helmet) form and the mouth and eyes openings were rather small [4]. However, the method for their construction has not been identified, indicating that these masks were made of perishable materials. Note that such head-enclosing masks apart from transforming the actor's face, were also altering his voice and changed his self voice perception, especially if the ears were also fully enclosed [7].

Figure 2. Keramikos' museum face mask marble template

The mask also influences the actor spatial awareness and mobility leading to the rationalization of the movements and gestures. The modification of the actor's point of view and mobility promotes an increased awareness of his own body axis, the spine, the pelvis and the physical actions. In an outdoor theatre, the actor has not only to express the role but also, simultaneously, project it to the audience through his presence and movements. In this way, the actor must develop presence, relate to the performing space, and must reject all the personal, parasitical movements of everyday life [4].

Theatrologists, actors and directors have discussed the acoustic effect of the theatrical mask by conducting informal experiments or by reporting their personal experiences from the use of the masks in contemporary artistic performances [4-11]. However, prior to the earlier work by the authors [7], there was no study available in the literature providing acoustic measurements of reconstructed theatre masks. Although this early study provided acoustic measurements for such masks [7], it is still not fully understood how such acoustic properties of the masks were combined with the acoustic response of the theatre and how they affected the overall aural experience of the ancient drama. Hence, here it will be examined and confirmed whether the mask amplified the actor's voice, creating resonances and allowing some control of the direction and the intensity of the voice inside the theatre. The broader functionality of the masks will be also evaluated since it has been also suggested that the mask formed the actor's personal resonance chamber, connecting him to the resonances of the ancient theatre. Note that the word *theatron* means a place to watch, examine and contemplate. It also implies a view, *theoria* and is also etymologically connected to the word divinity, *theos*, and to therapy, *therapia* [6]. Such a therapeutic function of sound becomes even more relevant to the case of theatrical performances in the ancient theatre of Epidaurus which appears to have been constructed especially for healing purposes (see Section 2.2).

This paper is organized as following: Section 2 describes the method used and the results obtained for the acoustics of the reconstructed theatrical masks. Also, the acoustic properties of the ancient theatre of Epidaurus are presented. Section 3 introduces the method for combining mask and theatre responses and for generating speech at the desired listener position. The objective results of angle and frequency dependent gain for the masks in typical audience positions inside the theatre are also established, along with the effects on speech intelligibility. Finally, Section 4 presents the conclusions of this work.


(a)

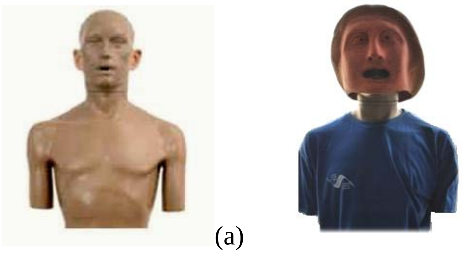

(b)

Figure 3. The mask templates studied.
(a) closed ears (A1), (b) open ears (B1)

2. THE SOUND OF ANCIENT DRAMA

2.1 The acoustics of the masks

The work reported here extends on the measurements and the methodology of the previous work by the authors [7]. For this earlier work, generic theatre mask samples were constructed trying to replicate the essential elements of the ancient Greek mask and not necessarily being exact to any specific mask type. The construction relied on archaeological findings (Figure 2) but also on practical considerations motivated from masked theatre performances experience [4, 9]. These masks were constructed from hardened liquid stone plaster and were based on alternative designs (closed, A1 and open ears, B1). Two of the generic masks reconstructed can be seen in Figure 3. These masks were measured under semi-anechoic conditions using the Head and Torso Simulator (KEMAR) manikin [7]. For excitation, sweep signals were transmitted through the built-in Mouth Simulator and recorded through either a measurement condenser microphone placed at a distance of 1 m and at the same height as the manikin-mask mouth opening or the manikin's in-ear microphones for binaural measurements assessing the self voice perception of the actor.



(a) (b)

Figure 4. (a) the Hats manikin with the Mouth Simulator and (b) with the mask fitted

The measurements produced a set $h_{\theta i}(n)$ of the discrete-time impulse responses measured for the azimuth angles θ (at 30^0 intervals from 0^0 to 180^0) with the mask placed on the manikin. From these impulse responses the corresponding magnitude frequency responses were obtained via DFT. By comparing these responses to the corresponding responses measured when the mask was not placed on the manikin, the angle dependent "mask filter" was evaluated. The results from this work indicate that:

(i) the mask has the properties of an angle-dependent acoustic filter,

(ii) the acoustic radiation of the actor's voice is significantly enhanced for the off axis scenarios.

The typical polar plot of the "mask filter" is shown in Figure 5, utilizing the mean data from the different mask template types and azimuth angles extrapolating the mean mask polar pattern, for octave bands centered in 0.25, 1, 2, 4 and 8 kHz [7]. For the low frequency 250 Hz band the measured masks have omnidirectional characteristics. For the mid-low frequencies below 1000 Hz there is a relative amplification up to 5 dB for mask radiation for the back and side angles.

As is found in Section 3.2.2 this property is advantageous for speech intelligibility for off-axis radiation angles inside the semi-circular shape of the ancient Greek theatres. As will be shown in Section 3.2.1, an increase of relative levels at the off-axis positions of the cavea was confirmed particularly for the low-mid frequency region. Note that the majority of the formants of the common modern Greek vowels falls within this same frequency range and that these vowels typically correspond to the "cries" highlighting important and dramatic moments in ancient Greek tragedies [12].

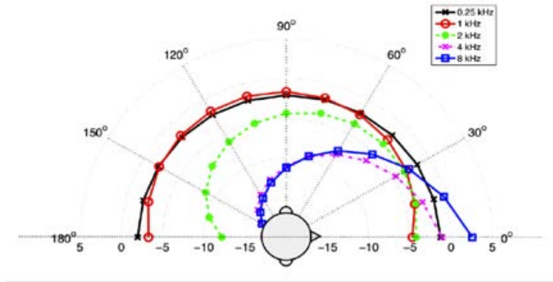


Figure 5. Polar patterns for the mask filter showing the mask radiation for octave bands centered at 0.25, 1,2,4 and 8 kHz (from [12]).

Given that in the earlier work no significant differences were found between the various alternative mask template designs, in this work two different mask templates A1 and B1 were studied (Figure 3). Mask template A1 is full-head enclosing (also enclosing the ears), while mask template B1 covers the head but not the ears.

An important finding of the earlier work [7] was that the mask significantly amplified the speech signal levels reaching the manikin's ears even for mask templates leaving the ears open. This level boost is in average 18 dB and the effect is greater for high frequencies, clearly drastically increasing the sound pressure level of the actor's own voice. Assuming that levels of at least 90 dBA would be produced by the actors during ancient drama performances, this finding indicates that with masks, the potential in-ear levels could be up to 110 dBA. This leaves open the possibility that the actors wore some kind of earplugs for protecting their hearing from damage and ensuring comfortable listening during the performance. It should be noted here that according to the authors' experience, earplugs are often employed during many modern theatre performances with masked actors.

It also possible that the ancient masks were constructed by different materials than the templates tested here. For example, it may be possible that the masks were only of solid construction material for their front "face" and were made of soft cloth for the rest of the head enclosure (often covered by synthetic hairdo in ancient times), hence reducing sound levels at the actor's ears.

2.2 The acoustics of ancient theatre of Epidaurus

The Epidaurus ancient theatre presents the finest early example of building with acoustics appropriate for speech communication over large public audiences. Such an achievement was possibly crucial for the wide acceptance of the theatrical, music and other performance-based arts by the ancient Greek society. Via the geographical spread of these theatres and their continuous evolution through the Roman era until the modern times, these art forms have been established as an indispensable part of the Western cultural heritage and became a timeless and universal constituent of our civilisation.

There are some obvious factors that are responsible for these “good acoustics”. At first, the theatre is well-isolated from the pollution created by the noisy modern activities and hence the level of background noise is low. Secondly, unlike most other ancient theatres, the theatre of Epidaurus has been preserved in an extremely good condition, practically having intact all the tiers and structure of the cavea (*koilon*) and with only the stage building structure missing (see Figure 6).

These factors allow the acoustic functionality of the building to remain close to its original conception, thousands of years ago. It also has allowed detailed acoustic measurements to be undertaken clarifying the reasons for the exemplary acoustic performance of the theatre [13].

Figure 6. The ancient theatre of Epidaurus as it is today

The acoustics of the theatre of Epidaurus were perfectly tuned for the performance of ancient drama and were the result of an evolutionary design process. The measured impulse responses of the theatre indicate excellent acoustic parameters especially for speech intelligibility which remain around 0.9 (for STI / RASTI) at all audience positions, even at distances of 60m from the source, as can be seen in Figure 7. Note that even today the theatre supports theatrical performances for audiences numbering more than 14000.

The reasons for such properties are well understood by using modern methods. From measurements and recent studies [3, 13] it is now clear, that from any sound produced in the orchestra, the geometric shape of the theatre generates reflected and scattered sound energy which comes initially from the orchestra floor and then periodically, from the hard reflecting limestone surfaces at the top and back of a number of seat rows around the listener position. The main bulk of this reflected sound energy is acoustically beneficial since it arrives at the listener’s ears with very short delay (within 40 milliseconds) after the direct signal and as far as the listeners’ brain is concerned, the early reflection sound is also perceived coming from the direction of the source at the stage. In this way, the strong reflections fuse with the voice which is perceived to be significantly amplified. Such increase in voice level by reflections and backscattering is sufficient to ensure good speech intelligibility even at the distant positions. Some additional, beneficial diffuse reflections are produced from sound diffraction along the tier edges [13].

The width of the seating rows (0,746 m) and the height of the seat backs (0,367m), as well as the cavea slope ($26,2^0$ for the lower rows and $26,5^0$ for the upper rows), result to fine tuning of the frequencies of in-phase and out-of-phase combinations of these direct and periodic reflected sounds. So, at all positions, frequencies significant for male speech (e.g. male speech pitch fundamental from 125-140 Hz, first voice harmonics from 250-420 Hz and formants from 300 Hz to 3 KHz) are amplified whereas relatively insignificant voice spectral regions (around 200 Hz) are filtered-out. This property ensures the preservation of the “voice quality” and speech intelligibility at all listening positions being complementary to the previously discussed perceived voice level amplification. The resulting tonal character can be observed in an exaggerated way when the visitors clap their hands at the orchestra and hear the response from periodic in-phase and out-phase reflections which create a distinct metallic-sounding effect. This sound is pitched close to the A note (at 220 Hz) with emphasis at the note’s harmonics at 440, 660, 880 Hz, etc. Such tonal response is helping speech sounds to reach clearly the audience although its sound colour is stronger and most evident to the listeners at the orchestra i.e. the performing actors. From contemporary actors’ comments, it is deduced that this acoustic signature is less distinct when the theatre is filled with audience. However, recent measurements with audience in the theatre show that speech intelligibility at the audience is not affected and remains very high [13], provided of course that the noise is kept low.

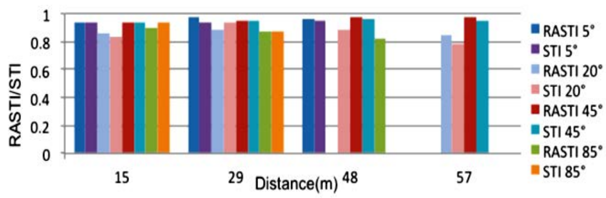


Figure 7. Measured speech intelligibility results for Epidaurus, for different distances and angles from an omni source at the middle of the orchestra (position S1, [13])

Note also that the theatre is part of a complex of buildings situated in the nearby valley, constituting the ancient sanctuary of Asclepius, the god of health, medicine and healing. The acoustic clarity of voices and sounds during the theatrical acts was also considered as an important element of this healing process; hence it appears that the location of the theatre and the valley were carefully chosen in order to protect the theatre space from extraneous noise and provide ideal conditions for voice transmission. Even today, the area remains largely free of such interferences from modern day activities and provides a perfect test bed for studying the acoustic ethos of the ancient Greek society.

3. METHOD AND RESULTS

3.1 Method for combining mask and theatre acoustics

The combined acoustic effect of mask wearing actor and the acoustics of the theatre is examined here via simulations, utilizing however the measured impulse response functions. Let denote by $h_{MIR\theta i}(n)$ the discrete-time impulse responses of the "mask-filter" measured for the azimuth angles θ_i (at 30^0 intervals from 0^0 to 180^0) with the mask placed on the manikin, as was described in the previous section. We shall term this as "Mask Impulse Response" set, or MIR.

For the theatre, we shall employ a set of early measurements by the authors [14], which correspond to monaurally recorded impulse responses at positions where computer simulations of the theatre were generated [3], and also, a later set of response measurements was recorded [13]. These impulse responses were post-processed so that the loudspeaker impulse response used for excitation, was removed by deconvolution.

As can be seen in Figure 9, 14 such Theatre Impulse Responses (TIR) were employed, for receiver positions (R1-R14) at various angles (θ_j) and distances (r_j) from a source located at the centre of the orchestra (S1). An alternative source position (S2) at the front of the stage building (*proskenion*) was also employed, but only for simulated TIRs, given that the stage building is not present today and has to be reconstructed via a computer acoustic model. Such a reconstructed acoustic model can be seen in Figure 8.

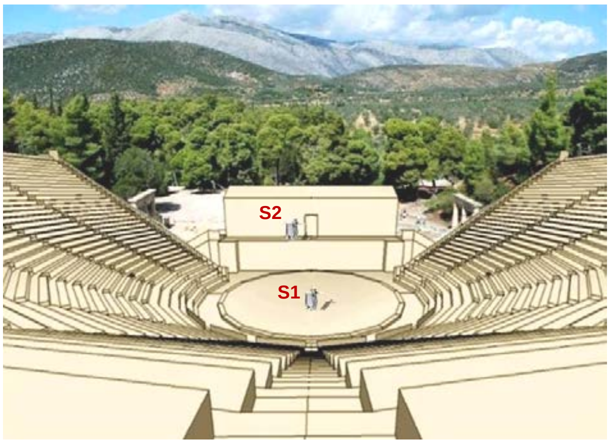


Figure 8. Visualisation of the combined acoustic effect of mask wearing actor at the Epidaurus theatre. Actor position S1 is at the centre of the orchestra (available for both measured and simulated responses); actor position S2 is at the stage building (available only for simulated responses)

Let denote by $h_{TIR\theta jrj}(n)$ the discrete-time impulse responses of the "theatre-filter" TIR measured for azimuth angles θ_j and distances r_j. Then, the combined mask and theatre impulse response (CIR) $h_{CIR\theta ijrj}(n)$ at any audience position, may be expressed as a discrete convolution of the corresponding responses, i.e.:

$$h_{CIR\theta_{ij} r_j}(n) = \sum_{m=1}^{M} h_{MIR\theta_i}(n-m) h_{TIR\theta_j r_j}(m) \tag{1}$$

Note that the coordinate system in the horizontal plane may be different for the mask direction and the relative angle of the listener position, so that the actor may be facing at any angle of the measured audience positions. Here, for simplicity we shall ignore any potential medial plane variations in the mask-filter due to varying elevation of the listener positions. Figure 9 shows the coordinate audience positions that can be evaluated via this approach, noting that for simplicity and given the theatre's symmetrical shape, only half of the semi-circle is considered for further analysis.

Assuming that anechoic speech $s(n)$ is used to drive this simulated system, then at any receiver position, the speech signal will be $u_{CIR\theta ijrj}(n)$ given via the convolution:

$$u_{CIR\theta_{ij} r_j}(n) = \sum_{m=1}^{M} h_{CIR\theta_{ij} r_j}(n-m) s(m) \tag{2}$$

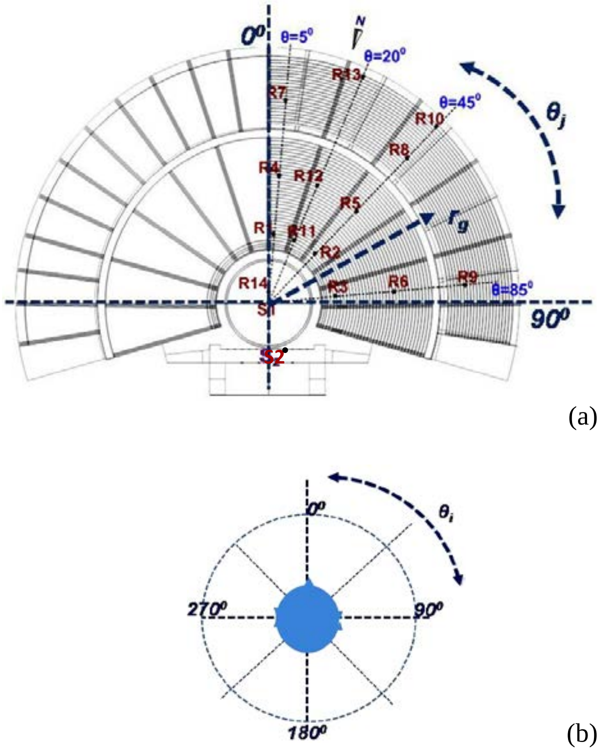


Figure 9. Horizontal plane measurement and simulation coordinates for: (a) theatre source and receiver positions, (b) masks

The schematic diagram of the method used for acoustic reconstruction is shown in Figure 10.

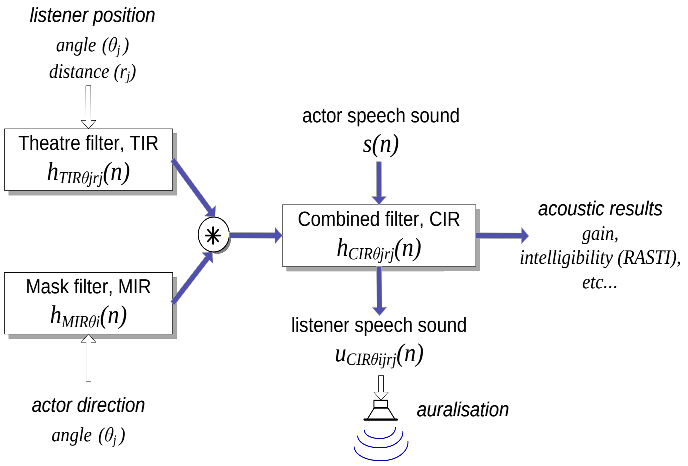


Figure 10. Schematic diagram for acoustic reconstruction of actor performances in the ancient theatre of Epidaurus based on measured responses

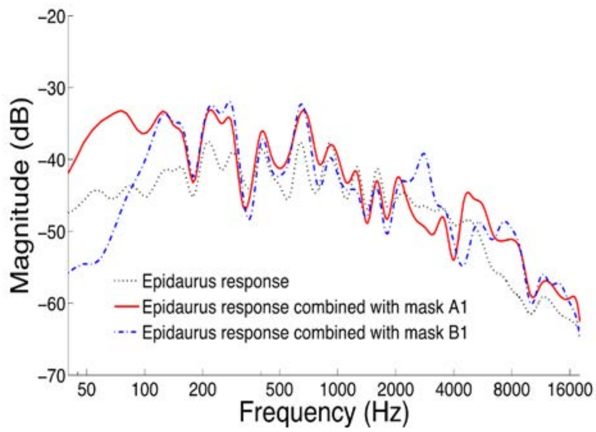


Figure 11. Frequency response at the position R1 (15.6 m) on-axis position of Epidaurus theatre and for the combined theater – mask response for the A1 and B1 masks. All responses were smoothed at 1/3 octave resolution

3.2 Results

3.2.1 Spectral and radiation effects of the masks

From the DFT of the combined response (CIR) of equation (1), the corresponding magnitude frequency response (in dBs) is evaluated as:

$$H^{dB}{}_{CIR\theta_{ij} r_j}(k) = 20\log\left|DFT\left\{h_{CIR\theta_{ij} r_j}(n)\right\}\right| \quad (3)$$

Similarly, for the theatre response (TIR), the corresponding magnitude frequency response is evaluated as:

$$H^{dB}{}_{TIR\theta_{ij} r_j}(k) = 20\log\left|DFT\left\{h_{TIR\theta_{ij} r_j}(n)\right\}\right| \quad (4)$$

Figure 11 presents the comparison between measured magnitude frequency response of the theater of Epidaurus $H^{dB}{}_{TIR\theta_{ij} r_j}(k)$ to the combined frequency response of the theatre and mask filter, $H^{dB}{}_{CIR\theta_{ij} r_j}(k)$ for the on-axis listening position R1 ($\theta_j = 5^0$ and $r_j = 15.63$m) from a source located at the centre of the orchestra (S1). The combined response is shown for both masks A1 (fully enclosed) and B1 (with openings for the ears). The responses were smoothed using a resolution of one-third octave. In this graph it is evident that both masks boost the frequency region up to 1000 Hz and, slightly, the higher frequency band. These results agree with reports indicating a resonance or "muffled" effect of masked actor's voice in contemporary artistic performances [4, 15]. Such bass amplification was maintained for the other test cases and for the off-axis receiver positions. Since the masked actor response does not amplify the pronounced mid-frequency region of the Epidaurus response, the combined response appears now more balanced overall.

From the evaluated TIR and CIR magnitude responses (eq. (3), (4)), the normalized responses were derived for octaves with central frequencies k_o = 60, 125, 250, 500 and 1000 Hz and let $\widetilde{H}^{dB}{}_{TIR\theta_{ij} r_j}(k_o)$ and $\widetilde{H}^{dB}{}_{CIR\theta_{ij} r_j}(k_o)$ be these functions. Then, the low-mid frequency band relative gain for the mask-filter was evaluated as:

$$G(k_o) = \widetilde{H}^{dB}{}_{CIR\theta_{ij} r_j}(k_o) - \widetilde{H}^{dB}{}_{TIR\theta_{ij} r_j}(k_o) \quad (5)$$

This octave-band relative gain is plotted in Figure 12 for on-axis positions ($\theta_j = 5^0$) and for different distances (15.63m < r_j < 47.6m). Figure 13 shows similar results for positions at around $\theta_j = 45^0$ and Figure 14 for side positions in the cavea ($\theta_j = 90^0$).

The results shown in Figures 12 - 14 indicate that in the region of 60 - 1000 Hz the masks enhance the actor's voice resulting in a "deeper" and amplified sound for most listener position angles and distances. Hence, the region around the fundamental of male speech appeared to be amplified by the masks for most listener positions around the cavea. For the on-axis position (Figure 12), the amplification was more prominent for the close listening positions. It is interesting that although mask B1 generally is not boosting this frequency region for the on-axis positions, it does so for the off-axis positions $\theta_j = 45^0$ (Figure 13) and $\theta_j = 90^0$ (Figure 14) where the relative amplification gain reaches 14 dB. It can be also observed that especially for the off-axis listener positions, the low-mid frequency region amplification effect was significant for the more distant positions. The results also indicate that the shape of the mask can vary significantly the speech sound radiated at different sections of the cavea.

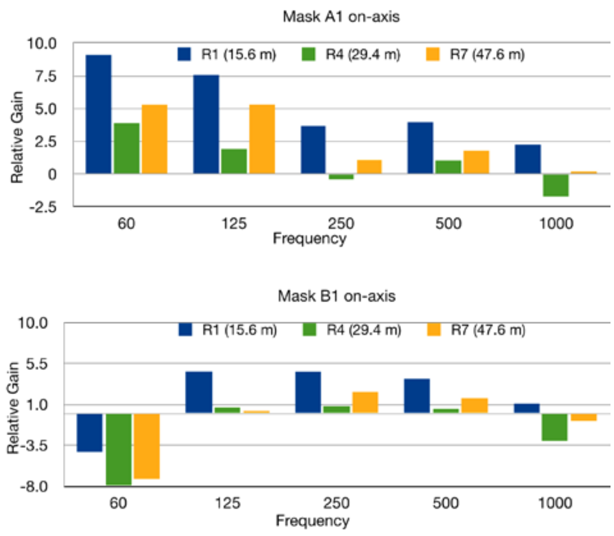


Figure 12. Total relative gain per octave frequency band between a masked and a non-masked speaker for the on-axis listening at positions R1 (r_j = 15.6 m), R4 (r_j = 29.4 m) and R7 (r_j = 47.6 m) in the theatre of Epidaurus

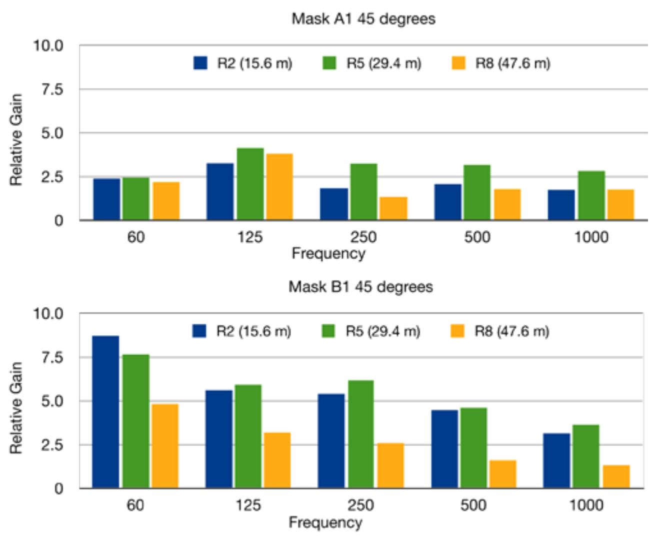


Figure 13. Total relative gain per octave frequency band between a masked and a non-masked speaker for the θ_j = 45^0 listening at positions R2 (r_j = 15.6 m), R5 (r_j = 29.4 m) and R8 (r_j = 47.6 m) in the theatre of Epidaurus.

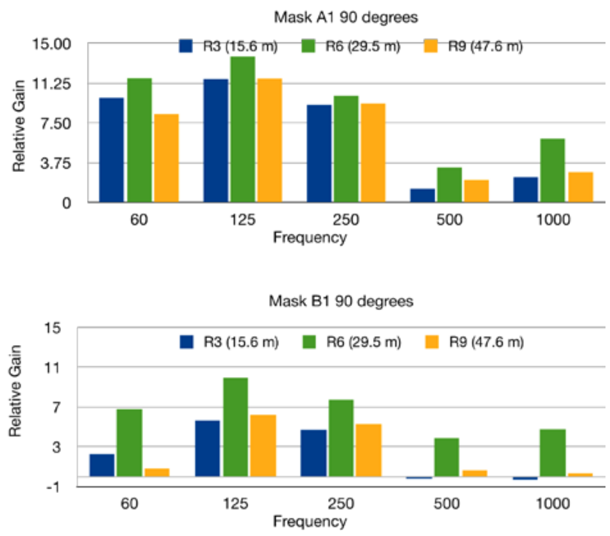
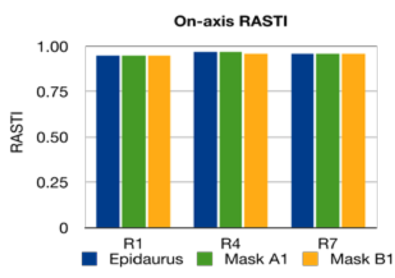


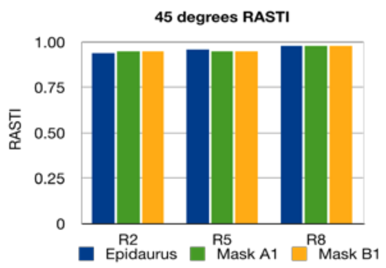
Figure 14. Total relative gain per octave frequency band between a masked and a non-masked speaker for the θ_j = 90^0 listening at positions R3 (r_j = 15.6 m), R6 (r_j = 29.4 m) and R9 (r_j = 47.6 m) in the theatre of Epidaurus.

3.2.2 Effect of the masks on speech intelligibility

The discrete-time impulse responses $h_{TIR\theta jrj}(n)$ of the "theatre-filter" (TIR) and the combined mask and theatre impulse response (CIR) $h_{CIR\theta ijrj}(n)$ measured for azimuth angles θ_j and distances r_j and for masks A1 and B1 were analysed via a standard commercial software in order to calculate the RApid Speech Transmission Index (RASTI). Such analysis will indicate the expected degree of speech intelligibility that can be achieved for these conditions and positions. From Figure 15 it is observed that the speech intelligibility measured for the theatre by a standard omnidirectional source (i.e. for responses TIR), was not affected to any measurable degree when the source was substituted by an actor wearing either mask A1 or B1. The extremely high, distance and angle independent, speech intelligibility measured via earlier studies in the theatre (see Figure 7 and [13]) is thus fully maintained when masks were employed by actors.



(a)



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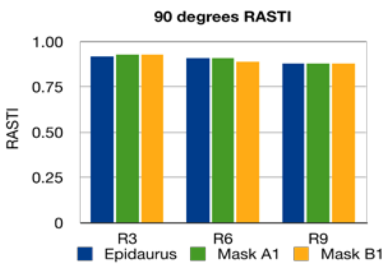

(c)

Figure 15. RASTI comparison between non-masked and masked speaker at the (a) on-axis listening positions R1 (15.6 m), R4 (29.4 m) and R7 (47.6 m), (b) $\theta_j = 45^0$ listening positions R2 (15.6 m), R5 (29.4 m) and R8 (47.6 m) and (c) $\theta_j = 90^0$ listening positions R3 (15.6 m), R6 (29.4 m) and R9 (47.6 m).

3.2.3 Simulations and auralisation

Based on the schematic of Figure 9, auralisations were produced using monaural audio files of typical speech. For these responses obtained from measurements, the source position was assumed to be at S1 (see Figures 8 and 9(a)). Furthermore, using simulations [3] of the theatre of Epidaurus in its original form (i.e. with the stage building), binaural auralisation files were also produced for the source at position S1 and also at S2. The acoustic properties of the masks (frequency response and directivity characteristics) were introduced in the simulation computer model allowing the auralisation at any desired position on the tiers. Audio demonstrations of such simulations will be given during the presentation of this work [16].

4. CONCLUSIONS

The study of the spectral and radiation sound effects of masks employed by actors performing in the typical ancient Greek theatre of Epidaurus, has provided some clear evidence for the acoustic function of such masks that were always used during the ancient drama performances by the (male) actors.

Using template masks constructed from archeological evidence, their measured frequency and angle-dependent response was combined with measured acoustic impulse responses of the theatre for various positions. Thus, these simulated tests generated the combined mask-theatre responses and also the corresponding speech sounds at the desired audience positions.

Analysing these combined mask-theatre responses, it was found that the masks amplified the spectral region up to 1000 Hz. This effect was found to be stronger around the male speech fundamental frequency. Given that the theatre responses present a significant peak around the mid 1000 Hz region, the “mask-filter” effect appears somehow to smooth the overall spectral profile of the “theatre-filter”. Furthermore, the masks would alter the actor’s voice by boosting the low-mid region of speech reaching the audience.

In addition to that, the masks were found to enhance directivity for the side of the actor’s head and hence amplify significantly such low-mid speech frequency region, for listeners located beyond the central positions and especially at the sides of the cavea. This radiation property of the masks would improve reception at these more problematic audience positions, especially under noisy conditions. However, under normal conditions, the masks were not found to affect the excellent speech intelligibility of the Epidaurus theatre which has remained perfect for all listener positions.

Further in-situ impulse response measurements of the masked manikin in the theatre of Epidaurus would be a desirable addition to the present study and are left for future work. Moreover, binaural recordings of a masked actor performing in the theatre may also allow more realistic demonstrations of the acoustic experience of the ancient Greek spectators in such theatres and hence compliment this work.

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