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Acoustic measurements of Ancient Greek Theatre Masks

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ABSTRACT

Theatrical masks were always used by the actors during ancient drama and comedy performances. However the acoustic function of the ancient Greek theatrical masks is a challenging topic for acousticians and theatrologists. From previous study by the authors, it is evident that such masks not only modify the natural sound of the actor's voice and the directivity of the human head, but also increase dramatically the level of the actor's self-perceived voice. It was found that the level of the actors voice received to his own ears via the enclosing mask could exceed 100 dB, which over the many hours of the ancient performances, would introduce significant hearing discomfort or even damage the actor's hearing.To verify such effects, this work provides a comprehensive set of acoustic measurements for the voice generated by a masked actor (transmit path, Tx) as well as the self-induced voice reaching his own ears (receive path, Rx). A set of mask templates was constructed using archeological data and the masks were set over a HATS dummy head system. The measurements were based on platforms and equipment used by the industry for speech and audio quality evaluation of current headsets, headphones and other telecommunication devices.

Keywords: theatre masks, acoustics, Greek theatre plays.

1. INTRODUCTION

Theatre masks were a fundamental element of the ancient Greek theatre tradition [1]. 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 visual and acoustic identity. Hence the function of such mask was crucial to the dramatic work and was more than just a typical theatrical gadget. 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. Ancient period vase paintings are illustrating masks before or after the performance and 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 [1]. 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 [2]. However, prior to the earlier work by the authors [2], 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 [2], 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. Such combined effects of measured mask directivity and response properties, combined with ancient theater simulations were examined by the authors in [3]. Nevertheless, these early measurements of masks were limited due the requirement of specialist equipment and controlled environment. Such measurements are now presented here.

2. MEASUREMENT METHOD

2.1 Procedure and standards

The measurements were conducted inside an audio measurement chamber (acoustically treated room with a background noise floor of 20dB(A)) following standards used by the industry for speech and audio quality evaluation as applied to modern head-related and wearable audio devices, such as headsets, headphones and smart speakers, especially during rather complex communication scenarios (e.g. multiple speakers to the near/far-end, background noise). The measurements were performed via multichannel microphones and dummy heads. Multiple measurements on the Rx and Tx paths assessed the on and off-axis / frequency response and Directivity for the masked actor. Thus, the measurements provide a set of Mask Impulse Response (MIR) filters, for different azimuth (θ) and median (elevation) angles (φ), i.e. $h_{\mathrm{MIR}\theta,\varphi}\,(n)$, n being the discrete time index.

The measurements were conducted using the HEAD Acoustics HMS head and torso simulator (HATS) [4] in the

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role of the "actor" and also the G.R.A.S. 45BM KEMAR HATS [5,6]. HATS were placed on a stand and at a height of 1.5 m from the ground, in the middle of the room (Fig. 1(a)). The sound source was calibrated at a level of 94dB at the mouth reference point (MRP). The masks were carefully fitted in the dummy head, in order to reassure that the dummy head mouth simulator coincides with the mask mouth (see Fig. 1(b))

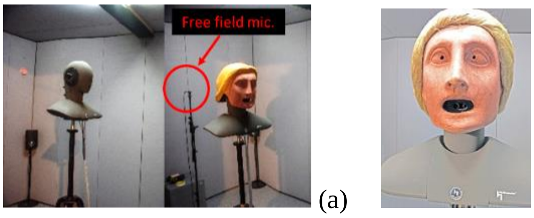


Figure 1 – Measurement of mask response: (a) HATS and HATS fitted with mask, (b) alignment of the artificial mouth to the mask mouth.

2.2 Time, frequency and polar response

For excitation, sweep signals (30 Hz to 16000 Hz range and 2.7 second duration) were transmitted through the built-in Mouth Simulator and recorded through a free field measurement microphone, placed at a distance of 1 m and at the same height as the manikin-mask mouth opening. A complete set of measurements without any mask on the HATS was also preformed and used as reference to all subsequent measured responses. Responses were measured on the horizontal plane for angles from 0^0 (on axis) to 180^0 with a step of 30^0 covering the half plane, assuming symmetrical response (Fig.2). Two additional measurements were made on axis in the vertical plane for +/- 45^0 using the measurement microphone. A total of 6 masks were measured, as shown in Table 1. The recordings were made at 48 kHz with a 24-bit precision using the APx555 and APx 4.6 software (available after registration with AP) [7].

Figure 2 – measurements for different orientation of the HATS plus mask.

Table 1 – List of measured masks.

mask code	ears	details
A1	Enclosed	-
A2	Enclosed	horn mouth
A3	Not enclosed	hairdo
B1	Not enclosed	-
B2	Not enclosed	-
B3	enclosed	hairdo

2.3 Binaural self-voice perception and isolation

For measuring the self-perception of the actor's voice when he was wearing the mask, responses of the HATS were made both as a sound source and as a receiver. Additional measurements were also obtained using dumping inside the mask as shown in Fig 3. For the dumping regular wavy acoustic foam of 30mm thickness was used.

Figure 3 – A mask filled with dumping material.

3. RESULTS

3.1 Frequency response measurements

The spectral response of the masks exhibits response peaks at approx. 150Hz, 250Hz and 700Hz. Comparing the measured spectrum of the head (HATS) without the mask, it is evident that the on-axis amplification gain is approximately 5dB and is mostly for the ranges around 250 and 700Hz. For off-axis angles, the radiation above 500Hz is reduced by about 5 to 10dB (see typical example for mask A1 in Fig.5), as will be shown more clearly by the polar plots in the next paragraph.

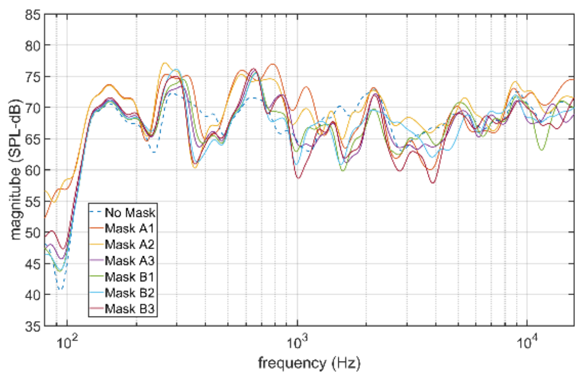


Figure 4 – On axis frequency responses for all masks compared to the HATS response (No Mask, dashed line).

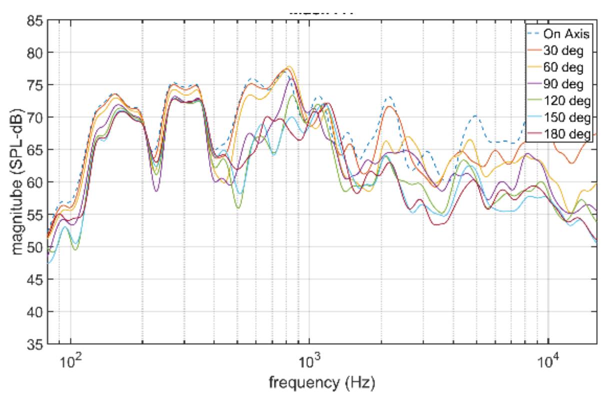
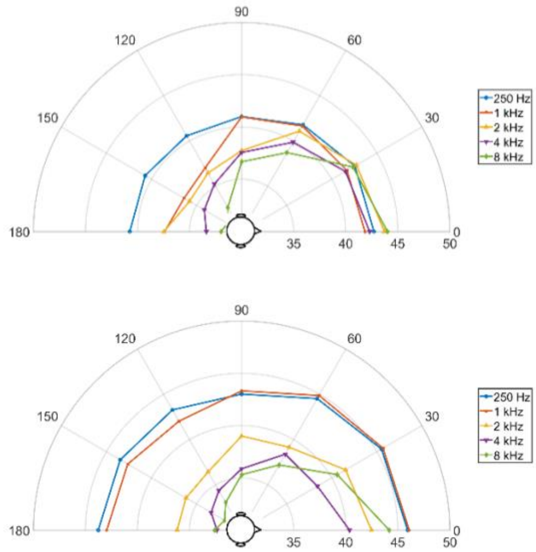


Figure 5 – Frequency response for different azimuth. Angles for mask A1.

3.2 Polar response measurements

Figure 7 shows the measured horizontal plane (azimuth) polar plots for the HATS with no mask (Fig. 7(a)) and with mask 1 (Fig. 7(b)), noting that similar results were obtained for the other masks. It is clear that the mask amplification gain is nearly 5dB for most angles up to 1KHz whilst above 2KHz it is mostly reduced mostly for angles close to the head axis. However, as was previously shown, the amplification gain at low and mid frequencies was for discrete bands of resonance.

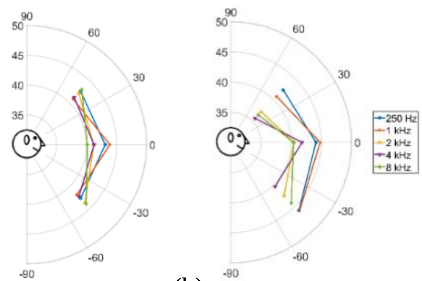


(a)

(b)

Figure 6 – Horizontal polar radiation of the HATS: (a) no mask and (b) fitted with mask A1.

Figure 8 shows the corresponding radiation plots for the median (elevation) plane and for on-axis azimuth measurements (for 3 angles). The comparison between the head (HATS) radiation without and with the mask, shows some small amplification gain for the -45^0 angle when the mask is used, especially for the mid-low frequency range can reach 5dB. The higher-frequency bands show a clear gain reduction of up to 10dB for the mask, for the off-axis angles.



(a) (b)

Figure 7 – On axis vertical polar radiation of the HATS: (a) no mask and (b) fitted with mask A1.

It is evident that the masks provide significant radiation gain for the actor's voice, at least below 2kHz, for broad azimuth angles and for the vertical angle that radiates the sound towards the floor (orchestra) for generating a reflection that is critical for speech perception especially at distant positions. Direct speech radiation via the mask (for the same frequency range) is also enhanced increasing the level at similar distant and elevated listener positions.

3.3 Self-voice perception

Previous work [2] has highlighted the potential extreme levels of the actor's voice reaching his ears due to the amplification by the mask. As can be observed by Fig.9 this finding is also verified here, noting that the results refer to on-axis sound pressure level of 80 dB/ 1m.

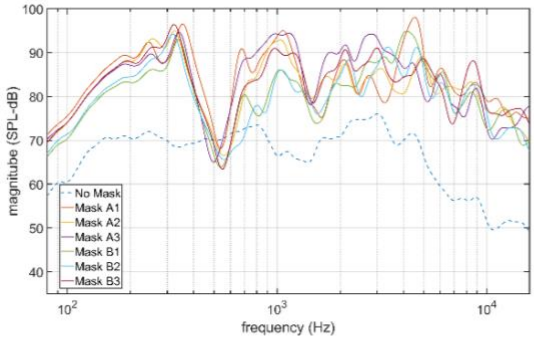


Figure 8 – Self-perception for HATS generated signal without a mask (dashed line) and when fitted with the tested masks (solid lines).

Figure 9 shows that for all masks, there is an approx. 15dB increase in the self-perceived voice level, thus for a normal voice level of 80dB /1m, the actors would receive up to 95dB, (level varying with the frequency). Therefore, for extremely loud voice delivery by the actor in period and for lengthy performances (the plays could last for many hours), the level of the self-perceived voice would be potentially deafening. There is no historic evidence for any solution for this problem. Perhaps the actors were wearing some form of ear protectors, which of course would eliminate reception of outside sounds, e.g. the voices from other actors. There is also a possibility that perishable absorptive materials could be used in period to reduce the internal sound level. To examine this possibility, as mentioned previously, absorptive damping was also used which as can be observed in Fig. 10, resulted to a sound level reduction between 5 and 10dB, thus still a significant loud voice level.

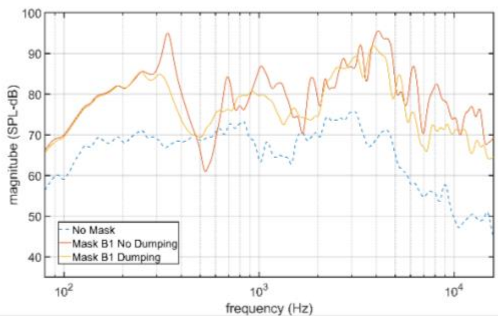


Figure 9 – The effect of the internal dumping for mask B1 at the self-perceived sound level by the actor.

3.4 Mask and amphitheatre acoustics

The effect of the mask acoustic response to the sound of the actor's voice within an amphitheatre (e.g. Epidaurus) has been studied in the past by the authors [3]. This can be described as a linear filtering process that for a specific receiver / listener position at various angles (θ_j) and distances (r_j) from a source located at the centre of the orchestra. For simplicity, we will only consider variation for azimuth, 'though in practice, the elevation angle must be considered.

Denoting by $h_{\mathrm{TIR\theta jrj}}\,(n)$ the discrete-time impulse responses of the "theatre-filter" (TIR) measured or numerically simulated for azimuth angles θj and distances rj. Then, the combined mask and theatre impulse response (CIR) $h_{\mathrm{CIR\theta ijrj}}\,(n)$ at any audience position, may be expressed as a discrete convolution of the corresponding responses, as is shown in Figure 11.

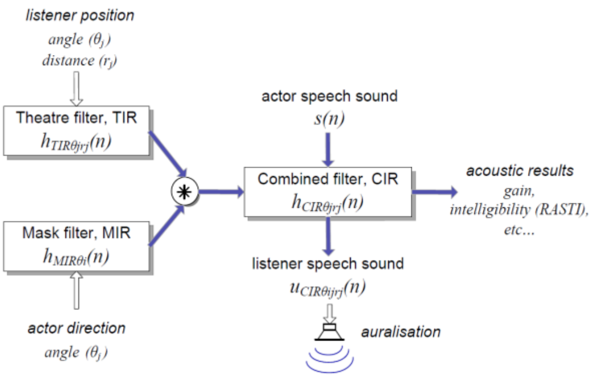


Figure 10 – Schematic diagram for acoustic reconstruction of masked actor performances in an ancient theatre.

4. CONCLUSIONS

This comprehensive acoustic measurement study of the ancient theatrical masks extends and validates previous results in tests previously carried out by the authors. With reference to a typical manikin head radiation, the spectral and spatial radiation gain added by the tested masks was established.

It is evident that the masks provide a nearly 5dB gain for the actor's voice, at least below 1kHz, for broad azimuth angles and for the vertical angle that radiates the sound towards the ground (e.g. the orchestra). This amplification gain is concentrated in distinct spectral regions, with peaks at approx. 150Hz, 250Hz and 700Hz, with progressive attenuation for high frequencies, properties which add percieved colouration to the sound of the voice. Furthermore, such spectral amplification may relate to male fndamental and formant peaks, provided that the actors delivered a rhapsodic style speech with constant or small pitch. However, there is no historic evidence on the way ancient greek language was pronounced and spoken, especially for theatrical speech delivery, so this aspect is open to speculation and may be partially verified by modern theatrical practices.

Another controversial aspect of these tests with respect to the ancient theatrical performances is the finding of extreme levels of self-perceived voice at the actror's ears, irrespective of the shape of the mask. It was verified that this amplification could exceed 15dB at some frequencies, with respect to the level without mask. Even if some internal absorption was used (assumed that the ancients were aware of the acoustic absorption properties of some materials, e.g. wool), then a reduction of approx. 5dB was measured, so still the voice level at the actor's ears would be highly uncomfortable during lengthy performances. If the actors wore hearing protectors, then they would not be able to receive any information from other actors.

Analyzing 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.

Preliminary tests for the combined effect of the masks and the theatre's acoustic indicate that the masks enhance directivity even 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. Overall, the masks were not found to affect the excellent speech intelligibility of the Epidaurus theatre which has remained perfect for all listener positions.

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