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NEWS

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Why the Greeks could hear plays from the back row

An ancient theatre filters out low-frequency background noise.

Philip Ball

The wonderful acoustics for which the ancient Greek theatre of Epidaurus is renowned may come from exploiting complex acoustic physics, new research shows.

Modern actors can be heard clearly 60 metres away on a windless day.

Nico Declercq

The theatre, discovered under a layer of earth on the Peloponnese peninsula in 1881 and excavated, has the classic semicircular shape of a Greek amphitheatre, with 34 rows of stone seats (to which the Romans added a further 21).

Its acoustics are extraordinary: a performer standing on the open-air stage can be heard in the back rows almost 60 metres away. Architects and archaeologists have long speculated about what makes the sound transmit so well.

Now Nico Declercq and Cindy Dekeyser of the Georgia Institute of Technology in Atlanta say that the key is the arrangement of the stepped rows of seats. They calculate that this structure is perfectly shaped to act as an acoustic filter, suppressing low-frequency sound — the major component of background noise — while passing on the high frequencies of performers' voices[1].

It's not clear whether this property comes from chance or design, Declercq says. But either way, he thinks that the Greeks and Romans appreciated that the acoustics at Epidaurus were something special, and copied them elsewhere.

Sound steps

In the first century BC the Roman authority on architecture, Vitruvius, implied that his predecessors knew very well how to

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design a theatre to emphasize the human voice. "By the rules of mathematics and the method of music," he wrote, "they sought to make the voices from the stage rise more clearly and sweetly to the spectators' ears... by the arrangement of theatres in accordance with the science of harmony, the ancients increased the power of the voice."

Later writers have speculated that the excellent acoustics of Epidaurus, built in the fourth century BC, might be due to the prevailing direction of the wind (which blows mainly from the stage to the audience), or might be a general effect of Greek theatre owing to the speech rhythms or the use of masks acting as loudspeakers. But none of this explains why a modern performer at Epidaurus, which is still sometimes used for performances, can be heard so well even on a windless day.

> **"The acoustic cut-off frequency is right where you would want it"**
>
> Nico Declercq, Georgia Institute of Technology, Atlanta

Declercq and Dekeyser suspected that the answer might be connected to the way sound reflects off corrugated surfaces. It has been known for several years now that these can filter sound waves to emphasize certain frequencies, just as microscopic corrugations on a butterfly wing reflect particular wavelengths of light. The sound-suppressing pads of ridged foam that can plastered on the walls of noisy rooms also take advantage of this effect.

Declercq has shown previously that the stepped surface of a Mayan ziggurat in Mexico can make handclaps or footsteps sound like bird chirps or rainfall (see '[Mystery of 'chirping' pyramid decoded](#)'). Now he and Dekeyser have calculated how the rows of stone benches at Epidaurus affect sound bouncing off them, and find that frequencies lower than 500 hertz are more damped than higher ones.

Murmur murmur

"Most of the noise produced in and around the theatre was probably low-frequency noise," the researchers say: rustling trees and murmuring theatre-goers, for instance. So filtering out the low frequencies improves the audibility of the performers' voices, which are rich in higher frequencies, at the expense of the noise. "The cut-off frequency is right where you would want it if you wanted to remove noise coming from sources that were there in ancient times," says Declercq.

Declercq cautions that the presence of a seated audience would alter the effect, however, in ways that are hard to gauge. "For human beings the calculations would be very difficult because the human body is not homogeneous and has a very complicated shape," he says.

Filtering out the low frequencies means that these are less audible in the spoken voice as well as in background noise. But that needn't be a problem, because the human auditory system can 'put back' some of the missing low frequencies in high-frequency sound.

"There is a neurological phenomenon called virtual pitch that enables the human brain to reconstruct a sound source even in the absence of the lower tones,"

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Declercq says. "This effect causes small loudspeakers to produce apparently better sound quality than you'd expect."

Although many modern theatres improve audibility with loudspeakers, Declercq says that the filtering idea might still be relevant: "In certain situations such as sports stadiums or open-air theatres, I believe the right choice of the seat row periodicity or of the steps underneath the chairs may be important."

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References

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