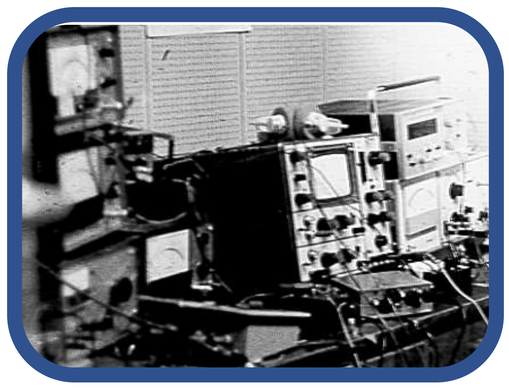
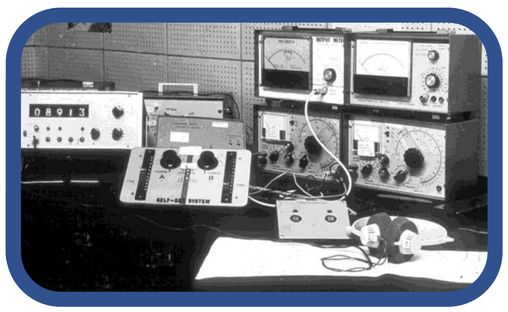
OAE Discovery — How and why did it happen?

Where did it all happen?

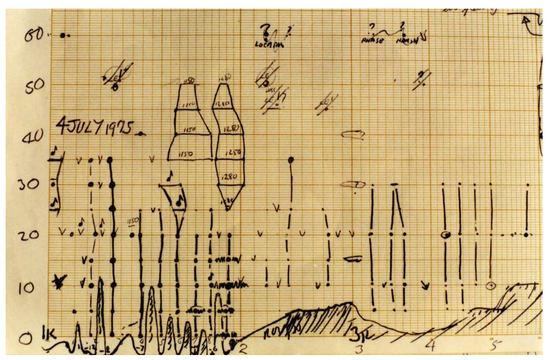


OAEs were first recorded in this basement audiology booth at the RNTNE hospital London. It followed a two year study of the 'auditory microstructure' , a psychoacoustic phenomenon revealed by examining the loudness, pitch and subjective quality of near-threshold tones.

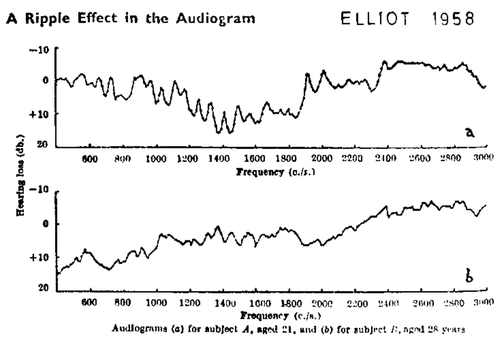


Psychoacoustics- the vital clue.

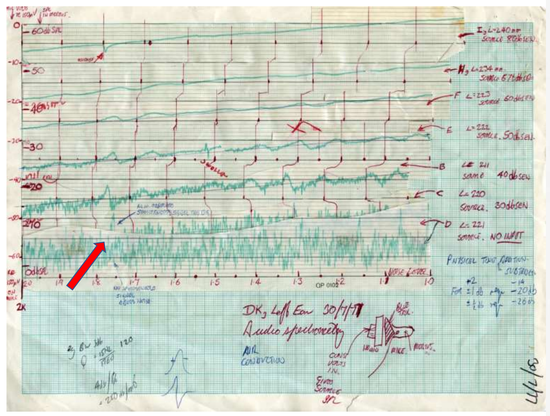
The equipment above was used to study the auditory microstructure from **1975** and gave a vital clue to OAEs' existence. Detailed mapping of pure tone quality revealed rapid variations in loudness with frequency and regions of systematic distortion- seen in the original data below.

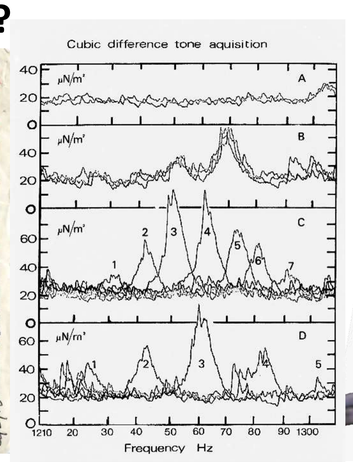


Similar periodic patterns had already been seen in the hearing threshold by Elliot in **1958** (below) but they were considered unimportant for audiology.



What was the first OAE recording?





The first OAEs recorded were stimulus frequency, spontaneous and distortion OAEs. Above, the original data from July 1977. The ripples in the sealed ear canal sound pressure, shown on the left, were in response to a constant level, swept tone. These ripples indicated the presence of an interfering tone from the ear- a 'stimulus frequency emission' or SFOAE. The sketch shows how it was done. No probe – just a hearing aid microphone sealed into the ear canal with putty and a headphone to deliver the stimulus. Surprisingly with no stimulus presented there was still a sound in the ear canal at 1750Hz (red arrow). This was the first spontaneous emission recording (SFOAE). Right panel shows the first ever distortion product (DPOAE) recorded . It was generated by presenting a tone close to a spontaneous emission at 1260Hz.

Why were these experiments performed?

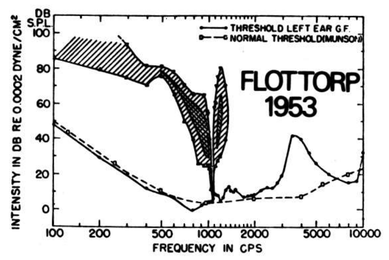
The investigation of sounds in the sealed ear canal leading to the discovery of OAEs- was undertaken to test a possible explanation of the auditory microstructure (see left and below). The reasoning was that if the regular irregularities in loudness were physically present- like in a reverberant room -then those same irregularities should be acoustically detectable outside the 'room', in the ear canal. They were!

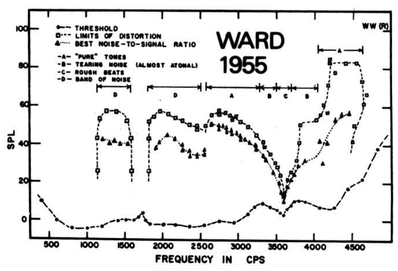
Clues to OAEs had been missed - for decades.

In **1953** Flottorp reported hearing ringing sound (idiotones) after he applied a tone to his ear (right). We now know he was interrupting his spontaneous emission and then hearing its recovery.

In **1955** Ward plotted the levels and frequencies of pure tones which sounded distorted to him. (right). The cause was distortion products generated with his (unsuspected) spontaneous emission acting as f2.

In **1971** Glanville, Coles and Sullivan reported a family that actually emitted multiple high frequency sounds from their ears! They measured their frequencies between 5.6-14.1kHz, but never considered they were from the cochlea. They proposed it was created by blood flow turbulence in the stapedial artery. Others had reported domestic pets with whistling ears but no one had suspected a cochlear origin!

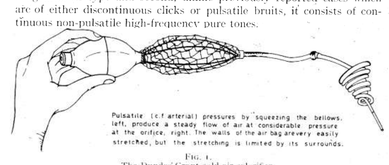




A family with high-tonal objective tinnitus[1]

By J. D. Glanville*, R. R. A. Coles† and Brenda M. Sullivan† (Southampton)

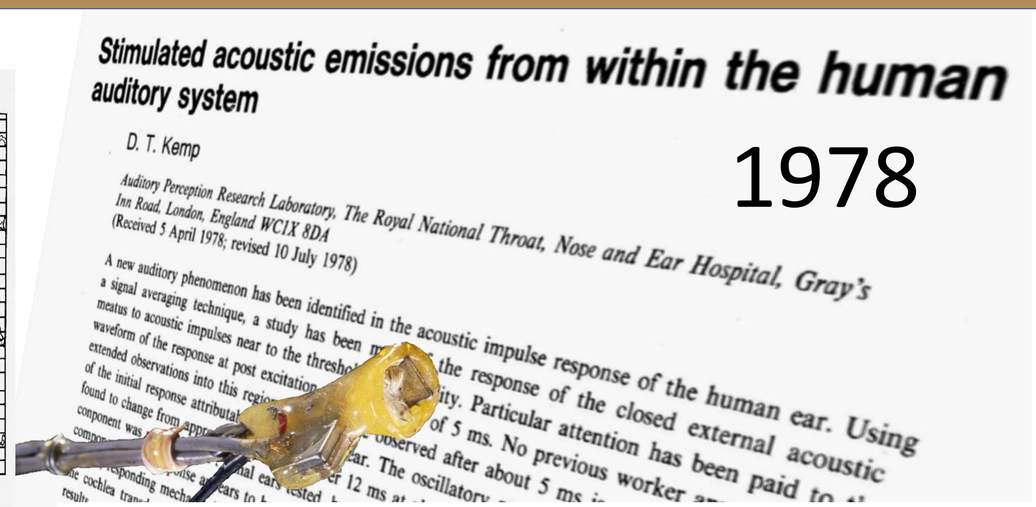
Although 'objective tinnitus' has been described to this Society quite recently and there are over fifty other reports in the literature, the present cases present two quite unique features. First, the tinnitus appears to be congenital in type and second, unlike previously reported cases which are of either discontinuous clicks or pulsatile bruits, it consists of continuous non-pulsatile high-frequency pure tones.



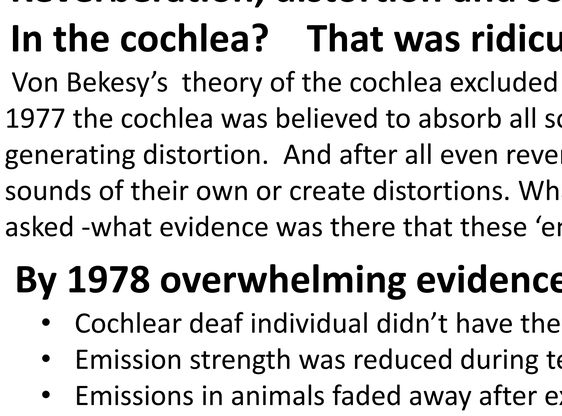
Pulsatile (c.f. arterial) pressures by squeezing the bellows, left, produce a steady flow of air at considerable pressure at the orifice, right. The walls of the air bag are very easily stretched, but the stretching is limited by its surrounds.

Fig. 4
The Dundas-Grant cold-air calorifier.

It is thought that the observations at e.u.a. could best be explained by an abnormality of the venous system, e.g. at the jugular bulb. This could have sufficient pressure but be non-pulsatile, if formed in something akin to the system of bellows and valves used to produce a steady stream of air through the Dundas-Grant cold-air calorifier (Fig. 1). The fibres could be stretched across the steady-flow part of the system and thus cause a non-pulsatile tonal sound.



How do transient evoked otoacoustic emissions (TEOAE) fit into the OAE discovery story?



The first recording of TEOAEs. Right, no stim, Left.

Once it was clear that the cochlea was behaving like a reverberant room -there was the possibility of using the acoustician's favorite method for testing reverberation. Clap your hands and listen to the lingering sounds!

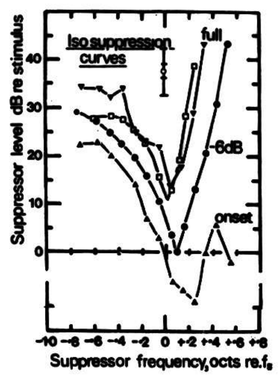
Using a signal averager (otherwise employed in the hospital to record cortical responses) the waveform of the ear canal's acoustic response to clicks was captured This revealed that stimulus frequency emissions were like a complex 'echo' . This methodology of recording OAEs was chosen for first publication in 1978 because it could be readily understood by both audiologists and physicists.

Reverberation, distortion and sound generation… In the cochlea? That was ridiculous!

Von Bekesy's theory of the cochlea excluded the possibility of reverberation. In 1977 the cochlea was believed to absorb all sound energy and to be incapable of generating distortion. And after all even reverberant rooms didn't MAKE sounds of their own or create distortions. What was going in? Physiologists asked -what evidence was there that these 'emissions' were from the cochlea?

By 1978 overwhelming evidence pointed to the cochlea.

- Cochlear deaf individual didn't have these emissions
- Emission strength was reduced during temporary threshold shift
- Emissions in animals faded away after exposure to noise, ototoxic drugs, or anoxia.
- The application of an interfering tone supressed the emission and revealed tuning. curves as sharp as auditory nerve tuning(right)
- The emissions 'saturated' (nonlinearly) with increased stimulation – a typically physiological characteristic
- Emissions were delayed with respect to the stimulus by an amount inversely proportional to the frequency, exactly as in the cochlear travelling wave.



These emissions clearly involved the cochlea- but a cochlea which didn't behave in the way physiologists believed it should!

What's in a name? The term 'acoustic emissions' comes from materials science. Welded metals make sounds as stresses are released. The fact that you could stimulate acoustic emissions from within the human ear surprized physiologists and biophysicists alike. Auditory acoustic emissions were given a variety of names at first including the 'Evoked Cochlear Mechanical Response' (ECMR) and 'Kemp Echoes'. The name 'otoacoustic emissions' was first used in 1983 probably by Pat Zurek.

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