Aids to Hearing:
From Julius Caesar to Julius Lempert

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Winning entry, British Association of Otorhinolaryngologists, Head and Neck Surgeons 1998 Undergraduate Essay Prize.

Introduction ▲

> Caesar: "...Speak. Caesar is turn'd to hear."
> Soothsayer: "Beware the ides of March."
>
> Caesar: "What say'st thou to me now? Speak once again."
> Soothsayer: "Beware the ides of March."
> Caesar: "He is a dreamer; let us leave him."
>
> Caesar: "Come on my right hand, for this ear is deaf,
> And tell me truly what thou think'st of him."
>
> from Julius Caesar by William Shakespeare.

> *"The end-aural one-stage fenestration technique which I employ and advocate for the surgical treatment of otosclerosis results in a permanent restoration of practical hearing by air conduction"*
>
> from *The Laryngoscope* April 1941 by Julius Lempert

Between the simple cupped hand and the remarkable results of Lempert's fenestration operation lie a wealth of aids to hearing, from natural sea shells through ornate ear trumpets to electrical devices. In this brief summary, I have divided historical aids to hearing into broad categories, and charted the progress of each roughly chronologically. I begin with 'natural' aids to hearing - ways in which one can enhance hearing without devices. I then discuss external aids to hearing, beginning with devices that channel sound toward the ear before moving on to those that make use of bone conduction to enhance hearing. Electrical devices for amplifying sound are considered next, followed by aids that use electricity to stimulate the cochlea directly. Finally, I consider surgical approaches to assist hearing, and in particular the achievements of Julius Lempert.

'Natural' aids to hearing ▲

Whilst Julius Caesar's hearing impairment may be attributed to Shakespeare's artistic licence, contemporary court descriptions tell of the Emperor Hadrian (117-138 AD) cupping his hand behind his ear in order to head better (Berger, 1984). Not only would the cupped hand reduce sounds from behind the head of the listener, but it 'funnels' sound toward the external auditory meatus. Pollack (1988) claims that at a frequency of 1 kHz the cupped ear can provide an extra 12 dB of volume alone (although somewhat less at the 2-3 kHz required for hearing speech). Moreover, as Berger suggests, the action of hand behind ear alerts the speaker to the listener's impairment - the speaker can then speak up. Other natural, and simple, aids to hearing may assist those with mild hearing impairments. Turning one's head toward a sound can help hearing. Opening one's mouth provides some assistance - the action opens the Eustachian tube, thus minimising the pressure difference across the tympanic membrane, maximising its vibration in response to sound.

External aids to Hearing ▲

It has been proposed that shells belonging to the ancient Greeks were used as ear trumpets. This function has also been attributed to bronze objects found hear Pompeii. The Emperor Hadrian, in addition to the cupped hand mentioned above, may have used an artificial hearing aid. Hunt (1978), quoting a contemporary source, says that Hadrian "made hollow catches to hear better by: and these he fastened to his ears, looking forward" - a device to leave his hands free whilst listening.

Architecture may aid hearing - standing in front of a concave wall provides some assistance to hearing, as reflections of the sound waves converge upon the listener. Roman council halls made use of such a principle by using domes, and even placing the council leader within a concave 'throne'. The Dome of Dionysius, Goldstein (1933) notes, was a prison constructed to enhance the guard's ability to hear his prisoners. The cell itself was subterranean, with large channels rising vertically from it to the floor of a dome-shaped building at ground level. The guard would sit in the centre of this building, where he could clearly hear the activities of his charge.

A detailed account of an external hearing aid comes from Francis Bacon (1521-1626), published posthumously in 1627:

> '*Let if be tried, for the help of hearing... to make an instrument like a tunnel; the narrow part whereof may be the bigness of the hole of the ear; and the broader end much larger, like a bell at the skirts... And let the narrow end of it be set against the ear; and mark whether any sound... will not be heard distinctly from further distance than without that instrument; being (as it were) an ear-spectacle*.'

Moreover, Bacon makes mention of such an instrument in use in Spain, '*that helpeth somewhat those that are thick of hearing*'.

Trumpets and cones such as those in Bacon's account collect sound waves over a wide area, channelling them to the ear of the listener. In the process, some frequencies are amplified and others dulled by the waves bouncing off the wall of the trumpet. In 1650, Athanasius Kircher created a vast trumpet, 16 feet in length, with a bell two feet in diameter installed in an outside wall of his home (Koelkebeck et al, 1984). The trumpet tapered to an opening of two inches' diameter in his workroom, enabling him to both listen and speak to those outside. Kircher also designed smaller, metal hearing trumpets, as did Frederik Dekkers (1648-1720), in the seventeenth century. Dekker's devices included a cone-shaped ear-trumpet tied onto the head with a ribbon (figure 1), described in his Exercitationes Medicae Practica, also published in 1673.

Antonias Nuck (1650-1692) first described his coiled metal hearing aid in 1692 (figure 2), although it was pictured in Dekkers' 1673 book.

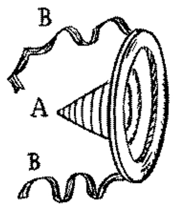

Figure 1: Dekker's Ear Trumpet

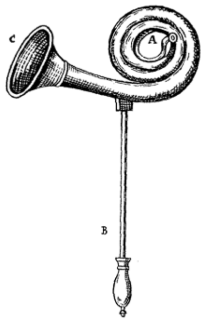

Figure 2: Nuck's Ear Trumpet

The oldest commercial manufacturer of hearing aids was Frederick C Rein. His firm was established by 1800, and ceased trading in 1963. His most famous device was probably the 'acoustic throne' of King Goa VI of Portugal. Manufactured in 1819, the sound collectors were the mouths of sculpted lions within the arms of the throne. Tubes channelled the sound from a resonant box in the seat of the throne to the King's ears.

T Hawksley's company, established in 1869, invented, produced and sold a wide range of 'otacoustical instruments to aid the deaf' in Victorian Britain. Their devices included conversation tubes, ear trumpets for ladies ('tastefully trimmed in leather, black silk and lace... suitable for use in public'), cornets to be hidden in the hair (figure 3), acoustic fans and acoustic walking sticks.

Figure 3: Auricle (Hawksley & Son, 1909)
'The drawing shows how the auricle is applied before drawing the hair over it to conceal it'

Conversation tubes - flexible rubber tubes which channel the sound to the listener - included tabletop designs for use at dinner (figure 4).

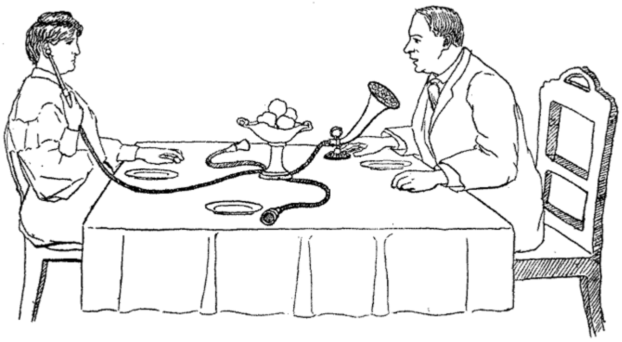

Figure 4: Table instrument (Hawksley & Son, 1909)
'The fruit dish on the table has no acoustical properties but simply holds the tubes steady'

Adam Politzer (1835-1920), whilst head of the Vienna Ear Clinic, designed an in-ear hearing aid. Manufactured from vulcanite, this comprised a tube running from the tympanic membrane to the external auditory meatus, and a bell which emerged from the external meatus, pointing forward.

Bone conduction ▲

Ear trumpets, conversation tubes and resonating domes can only assist the listener if both outer and middle ear are functioning, albeit at a reduced level. A number of historical aids to hearing make use of bone conduction - transmitting sound vibrations to the cochlea through bony structures. Perhaps the simplest way of achieving this is to place ones fingernail on a large piece of furniture.

Giovanni Filippo Ingrassia, a Sicilian anatomist, left a treatise after his death in 1580 which considered the possibility of sound wave conduction through the teeth. In 1757 the German physician Jonissen suggested that the deaf hold one end of a wooden rod between his teeth, with the other end between the teeth of the speaker (evidently a ventriloquist!) to aid his hearing. Within a few years, the German A. E. Buchner reported on '*a man of Copenhagen who was so deaf he could not hear a cannon shot but yet could understand a sermon by holding one end of a long wooden stick between his teeth and resting the other end against the pulpit*' (Niemoeller, 1940). Niemoeller also points out that Beethoven (1770-1827), once deaf, found that he could hear the music of his piano by placing one end of a wooden rod against the piano, and the other between his teeth, or against the side of his head.

In 1876, Giovanni Paledino published details of his bone conducting hearing aid, the 'Fonifero' (figure 5). This consisted of a metal rod - a horseshoe-shape at one end was placed around the speaker's larynx, and a small cup at the other end was held between the listener's teeth, or against his forehead or mastoid process. This provided a direct path of conduction between the speaker's larynx and listener's cranium.

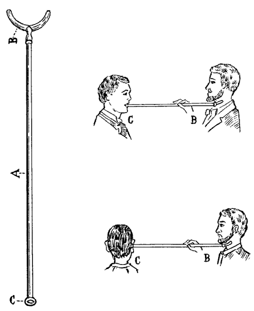

Figure 5: Paledino's Fonifero

Richard Rhodes' Audiphone, designed in 1879, was a strip of wood, held curved and under tension by a piece of string, similar to an archer's bow (figure 6). One end of the bowed wooden strip was applied to the teeth. The strip of wood would vibrate in response to sound of certain frequencies - the frequencies picked up could be adjusted by shortening or lengthening the string, thus relaxing or tensing the wood.

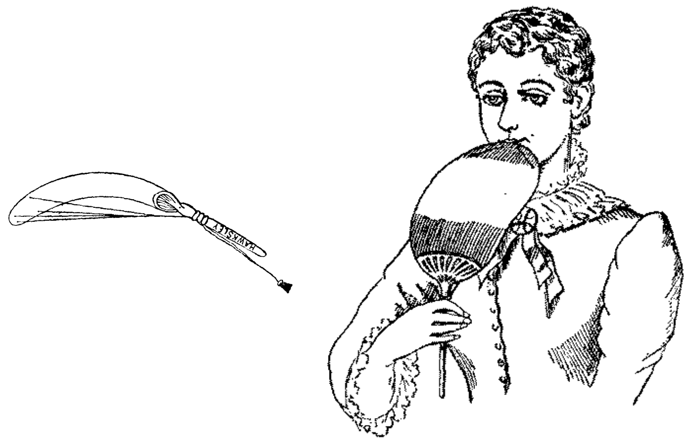

Figure 6: Rhodes' Audiphone

Electrical amplification ▲

Some claim that Alexander Graham Bell's telephone, developed in 1876, was conceived as an electric hearing aid for his mother. Pollack points out, however, that Bell was a speech teacher for the deaf, and states that the original intention of Bell was to create a device to enable deaf children to visualise the sound of their speech. This is supported by a statement by Bell in 1894, '*My original skepticism... of speech reading... led me to devise an apparatus that might help the children... A machine that should render visible to the eyes of the deaf the vibrations of the ear*'.

The first electric hearing aid may have been the Akoulathon, designed in 1898 by Miller Reese Hutchinson of the Akouphone Company in Alabama. This was a tabletop device, using a carbon microphone attached to up to three pairs of earphones. Hutchinson later devised a more portable machine, the 'Acousticon' (figure 7). Dr Ferdinand Alt of the Politzer Clinic in Vienna espoused a similar device in 1900.

Carbon devices consisted of a layer of carbon particles sandwiched between a fixed electrode plate, and a vibrating electrode, acting as the diaphragm. The resistance between the two electrodes depended upon the pressure exerted on the carbon particles by the vibrating electrode. The current flowing between the two electrodes would therefore change with the vibrations of the diaphragm, providing amplification, with the electrodes connected to an electric earphone.

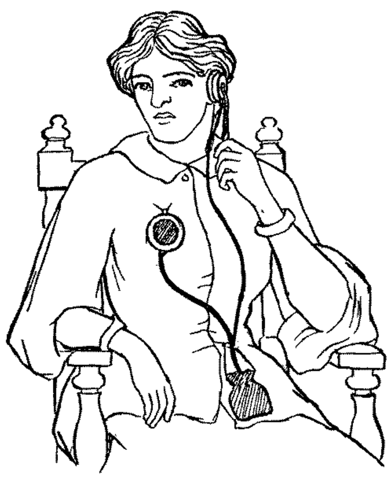

Figure 7: Miller Reese Hutchinson's Acousticon

Carbon devices could achieve 45dB of amplification at 1 kHz (though less at the 2-3 Hz required for speech), and bone vibrators were added to some models in the 1930s. However, carbon hearing aids had a narrow frequency response and were temperamental, their efficiency reduced by high humidity, dust particles or movements of the wearer.

Earl C Hanson patented the first vacuum tube-based hearing aid in 1921. This was large, expensive and unstable, so had little impact on the sales of carbon devices. In 1931 the introduction of a pentode vacuum tube hearing aid provided more powerful and stable amplification, but it failed to catch on. The device was large and heavy, requiring two batteries - one to warm the vacuum tube filament, the other to amplify. In 1937, 95% of hearing aids still used carbon amplifiers. Not until the 1940s did vacuum-tube based devices take over the market, with miniaturised devices from Multitone and Amplivox.

In 1947, Bardeen, Brattain and Shockley produced the first transistor-based hearing aid. Smaller, more powerful and stable, all electric hearing aids used today are based on transistors.

Electrical stimulation of the auditory nerve ▲

Benjamin Franklin speculated that electricity could bring about the sensation of hearing in the deaf in 1751. This principle forms the basis of today's cochlear implant.

In 1790 Alessandro Volta, Italian physicist and creator of the 'voltaic pile' electric battery, resolved to test such a theory. He placed metal rods in his ears, and applied a direct current through them. Whether the bubbling sound he heard was an induced nerve impulse, or the effect of electrical current on flesh is questionable. Volta passed out shortly after the experiment began. The idea was taken up by Politzer, Pitter, Gradenigo et al at the end of the nineteenth century. They applied an alternating current to electrodes placed around the ear. The 'electrophonic effects' they documented may not have been a consequence of electrical stimulation of the auditory nerve. The impedance of the electrode-skin interface would create a capacitance - in the face of the alternating current, this would cause the skin to vibrate. It is suggested that these vibrations, transmitted to the cochlea, are what were heard. A more convincing example of direct electrical stimulation of the auditory nerve came from the Russians Andreof, Gersuni and Volokhov in 1934, who published a paper called 'Electrical stimulation of the hearing organ' - a buzzing noise was generated when an electrode was applied directly to the round window. Jones, Stevens and Lurie published similar findings in 1940. Djurno and Eyries created the first cochlear implants in 1957.

Surgical intervention to aid hearing ▲

Surgery for chronic ear disease has historically been limited by a paucity of instrumentation, lack of anaesthetics, and the frequency of post-operative sepsis.

The first published account of surgery was in 1640, with Marcus Banzer's attempt to repair the tympanic membrane with a pig's bladder stretched across an ivory tube (Rizer, 1997). In 1853, Toynbee improved hearing by patching a tympanic membrane perforation with a rubber disk. Blake covered perforations with paper patches in 1877 - this procedure is used today to demonstrate the improvement in hearing likely to be achieved by tympanoplasty.

Mastoid operations to relieve chronic ear infection, and restore hearing, date back to 1774, when Jean Petit published an account of a successful drainage. In 1853 Sir William Wilde published his procedure for removal of the mastoid cortex using a postauricular incision. Mastoidectomy was a life-saving operation for many children suffering from acute mastoiditis until the introduction of sulphonamide antibiotics in the 1930s.

Fixation of the ossicles leads to a conductive hearing loss - it may be congenital, or caused by otosclerosis or tympanosclerosis. Stapedectomy, first performed in 1877 by Ketzel went some way toward relieving this. In 1888, Boucheron reported on 60 cases of stapes mobilisation, while Miot in 1890 and Faraci reported a further 200 and 30 cases respectively. This procedure was largely forgotten until 1952 when Rosen rediscovered its effectiveness.

Julius Lempert's fenestration procedure ▲

Fenestration operations attempt to attach the tympanic membrane directly to the labyrinth. The ossicles are thus bypassed with the intention of restoring air conduction, albeit without the benefit of the ossicles. Fenestration operations were not new when Julius Lempert published his technique. His remarkable achievement lay in developing a new, single-stage procedure, and in the excellent results he achieved.

Previous attempts at fenestration, such as those of Jenkins in 1914, Barany in 1924, and Holmgren in 1937, were initially successful, but failed in the longer term. The new window, or fenestra, created in the bony labyrinth soon ossified, leading to a deterioration in hearing. Staged operations, such as that of Sourdille in 1937, gave a more lasting result, but only after repeated removal of the bony layer that developed over the new fenestra.

Lempert published a detailed account of his surgical fenestration technique in 1938 (Lempert, 1938). Under local anaesthesia an endaural approach, passing through the mastoid bone, was used to expose the lateral semicircular canal and middle ear. The tympanic membrane was meticulously freed from its attachments with the exception of its inferoanterior portion. A trough-shaped window was excavated in the bony capsule of the lateral semicircular canal, exposing the perilymph space (and giving the patient severe vertigo). The endosteum of the semicircular canal had to be carefully removed to prevent re-ossification. The tympanomeatal membrane was then placed over the fenestra, moulded into place and the wound dressed.

In 1941 Lempert reported that 80% of 150 cases operated had '*a permanent restoration of practical physiological hearing... these 93 patients are now socially and economically rehabilitated*' (Bailey, 1997). His success can be attributed to a sound anatomical knowledge of the temporal bone and middle ear, appreciation and study of the problems that dogged other fenestration procedures, remarkable technical skill and strict asepsis.

Conclusion ▲

Between Roman times and Julius Lempert's fenestration operation, aids to hearing have developed along many different lines. From simple shells to elaborate and vast ear-trumpets, from wooden sticks to bone-conduction electric aids, from tabletop carbon amplifiers to cochlear implants and from tympanic membrane patches to Lempert's fenestration operation, advances in aids to hearing have mirrored advances in science. Physics, physiology, anatomy, engineering and electronics have all made their mark, but not without important contributions from the individuals mentioned. The aim of all these aids has been to provide as normal a life as possible to the hard of hearing.

The impact on the lives of the deaf of other advances and aids, though not strictly aids to hearing, should not be forgotten: sign language, lip-reading, speech teachers, subtitling, textphones and computers have all helped. Moreover, the advent in the twentieth century of sulphonamide antibiotics, and then penicillin, has vastly reduced the incidence of hearing impairments.

Finally, I doubt that the stubborn failure of one Julius to listen to his soothsayers would have been amenable to the other's fenestration.

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