Editorial

WestFailures (2): Hardly hearing

In any planned activity, including research, there must be an aim towards a goal. If this is attained, one calls it a success; if not, there is failure. But the situation is not quite so simple, for there may be surprising unplanned successes. So, on this criterion failure by aims not achieved may, with a different view, be seen as success perhaps beyond the wildest dreams.

This is not uncommon for inventions, which are often side effects of basic research, or intelligent play; though inventions may be new combinations of things or concepts already known but seen in new ways. Thus, as described by Charles Panati (1987), that useful jelly Vaseline was invented in 1859 by a Brooklyn chemist, Robert Augustus Chesebrough, who was looking at oil wells in Pennsylvania to try to get rid of an annoying sticky substance which gummed up the drilling rods and blocked the pumps. It was believed by the oil men to heal cuts. Chesebrough took a sample back to Brooklyn, purified it, obtained a clear jelly, and tested its curative powers with self-inflicted wounds. At first it was called petroleum jelly, and it found an astonishing range of uses. It was used as a bait for catching trout, and by actresses to catch sympathy by simulated tears. It was taken to the North Pole by Robert Peary to prevent frostbite and to prevent his machines from rusting; and it was used for softening leather, and for coating long distance swimmers, as well as for preventing the green corrosion of car battery terminals. Amazonian natives cooked with it, as it did not go rancid, and they exchanged jars as money. Having found so many uses for his omnipotent jelly Robert Chesebrough became extremely rich, and, religiously taking a mouthful of Vaseline daily, he lived with the happiness of serendipitous success to extreme old age. Presumably great inventions of antiquity such as cheese were of this kind, and no wonder they were attributed to benign moods of the Gods.

A very different invention is radio. It started from the fundamental theoretical work, around 1865, of the mathematical physicist, and the first head of the Cavendish Laboratory at Cambridge, James Clerk-Maxwell. He also studied colour vision, and much of his apparatus survives. His theory of light as electromagnetic waves predicted that there should be similar waves through a great range of frequencies, all travelling at the speed of light. But different kinds of detectors were needed for different frequency bands, as, although the waves were essentially the same for all frequencies, they interact with matter differently. Hence the narrow frequency response of eyes. What are now called radio waves were generated and detected in 1887 by Heinrich Hertz, who was a student of Helmholtz. Practical developments of this—physics’ answer to lack of biological telepathy—were incredibly fast and were in part predicted. In 1892 William Crookes said in a lecture [published in The Fortnightly Review, February 1892; quoted by Constable (1980) page 10]:

"Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more of wavelength, of which I have spoken, will easily pierce such mediums, and which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment."
Crookes even predicted what a radio set would be like:

"I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering a length of a wire, so as to become receptive of wavelengths of any preconcerted length. Thus, when adjusted to fifty yards, the transmitter might emit, and the receiver respond to, rays varying between forty-five and fifty yards, and be silent to all others."

Crookes patented the principle of electrical resonance in 1897, with his 'syntonized telegraphy', which later allowed radio stations to be separated. Marconi patented his version (which originally served a somewhat different purpose) in 1900. Marconi put the practical package of radio communication together from many inventions, such as the Russian physicist Alexander Popov's aerial (first used for detecting lightning), Hertz's spark gap oscillator, and Edouard Branley's coherer of 1890, which consisted of a glass tube containing powdered metal that 'cohered' by the action of radio frequencies to give a lower resistance. This was the first radio-frequency detector, and it was used by many experimenters before Marconi.

The ingenious inventor David Hughes, a professor of music, claimed to have transmitted signals over several hundred yards up Gt Portland Street in London several years before Hertz's demonstration; but was discouraged by lack of appreciation from the Royal Society, as he did not conduct systematic experiments or have a proper basis of theory. Hughes thought he was extrapolating Faraday's magnetic induction, so he got there through a wrong analogy. More dramatic, in this kind of way, was the much earlier invention of the Leyden jar for storing electricity: fluids can be stored in glass bottles, electricity is a fluid, therefore electricity can be stored in a glass bottle—and it worked!

The respected physicist Oliver Lodge demonstrated wireless telegraphy over a short distance at the Royal Institution in 1894. Most sadly, he tried for years to hear the voice of his dead son by radio, through the sighs and crackles of the aether, and sometimes he thought he succeeded.

Among Marconi's great achievements was transmitting across the Atlantic in 1901. This planned experiment flouted the science of his day, and should have failed—as Maxwell's or Hertz's waves should not have bent round the Earth anything like as much as Marconi found that they did, when he heard the letter 's' in Morse across over two thousand miles of sea.

The history of almost any invention is such a rich mixture of fact and fiction, and success and failure that it is hard to keep track of what, as understood at the time, is fact and what is creative fiction, and harder still to assign successes and failures. This is especially difficult because our judgement is generally in terms of what followed years later—and each major invention changes aims and how history is seen, as the past (surely wrongly) always seems to be aimed at our present. But, no doubt, there is a lot of luck and serendipity in future-creation.

Yet now research is nearly always goal-directed, set up by grant funding or industrial need, to some promised discovery or improvement. If this is achieved there is a kind of success. But this is limited if it does not lead to further questions and new possibilities, for it is future promise that seems to give significance to the present.

Some years ago, following experiments which seemed unrelated to hearing problems, we set out to produce a better kind of hearing aid. Far more distinguished, a hundred years earlier, Alexander Graham Bell had set out to do the same, but after many years of work by this inventive genius his hearing aids came to nothing. Instead, almost by accident, he invented the telephone. Bell's telephone patent was the most valuable in the entire history of inventions and it transformed the world; but, from the point of view of the hearing aid he set out to invent, it was a failure.
Was our hearing aid (based on technologies unavailable to Bell, though largely set up by him) a failure? It worked, much as we hoped it would, yet it is not available, so it cannot be called successful.

In our total population of about 60,000,000 people in Britain approximately 1,000,000 have clinically impaired hearing. Most are middle-aged, or older; but this handicap can destroy the careers in midstream of such people as lawyers and judges and doctors. Deafness creates loneliness and can cloud sunny characters into miseries of suspicion. Among those who help the deaf and the blind, it is generally thought that deafness is the worse affliction. Isn’t it odd that there is so little research devoted to hearing and deafness? Where research is concerned, the eyes have it.

Our approach started with attempts to measure, with psychophysical methods, the ‘neural noise’ (residual randomness of afferent action potentials) in human sensory systems, with the mathematical statistician Violet Cane (Gregory and Cane 1955), and then to relate this to ageing (Gregory et al 1956). The idea was that the usual slowing down in skilled behaviour, memory losses, and raised sensory discrimination thresholds might be due to neural signals being masked by this increased randomness of neural action potentials, much as signals are degenerated in ageing electronic circuits. Starting with vision, we adapted the method for hearing (Gregory and Wallace 1958). A key phenomenon was the ‘recruitment’ associated with (as it was then called) nerve deafness. This is inability to hear faint sounds, but with rapidly increasing apparent loudness and then discomfort for loud sounds. There is a narrow range of loudness in which hearing may be almost normal in this kind of impairment. The suggestion was that recruitment is due to an effective, more or less constant, added noise (neural noise), masking all signals, but principally affecting low signal levels; as the masking ‘noise’ is insignificant when it is small compared to the wanted signal, loud sounds are much less affected. For comparison, the other well-known kind of deafness, conduction deafness, is entirely different, for this affects all loudness levels equally, and may be effectively cured with a simple linear amplifier. Such an amplifier is far less effective for nerve deafness, for though it can make weak sound audible it overloads the ear for loud sounds, as the ear’s basic sensitivity is normal. The situation is much like a party where everyone speaks louder and finally shouts to be heard, so the noise is deafening.

How could a hearing aid be made that would increase intelligibility without overloading, and so perhaps further damaging, nerve-deaf ears? A key was provided by a discovery of J C R Licklider. Licklider (1946) showed that if the peak energies (or amplitudes) of the speech wave are clipped off, speech is still intelligible. His most dramatic demonstration was to have a mechanical relay follow the change of direction of the wave around its zero amplitude—and intelligible speech came from the relay! The device sounded awful, but words could be heard, though there was no amplitude information. This suggested that less drastic electronic amplitude clipping, with amplification, might allow the information-bearing cross-overs to convey speech, while cutting off the amplified peaks, which would overload the ear. We tried this, and it might have been a slight help; but it sounded unpleasant, as the clipping produced harmonic distortion. It is impossible to clip waves without producing harmonics of their frequencies. As these were in the speech band, they masked the speech signal, so any improvement in intelligibility was small.

We also tried shifting the frequencies of the speech, to move it to a better frequency band (in practice, lower frequencies) for the impaired ear, but this is another story.

As Fourier analysis tells us that it is strictly impossible to clip a wave without producing harmonic distortion components, the idea was dropped. But twenty years later, on a train journey, I was reading an article in *Wireless World* (Tong 1975) on methods for combatting noise for short-wave radio systems. It turned out that, although clipping must produce the harmonic distortion, there is a way of putting the harmonics
outside the speech band, where they can do no harm. The method is to impose the speech on a high-frequency carrier (as in a radio transmitter) and clip the peaks of this high- (radio-) frequency modulated carrier. If this is done appropriately, the harmonics generated will be multiples of the carrier and not of the speech. It is easy to demodulate the carrier and filter out the unwanted components—to give clipped speech without the harmonic distortion. So the seemingly impossible is achieved. Alan Drysdale and I tried this on deaf patients, and on normal subjects given added masking noise to make them artificially nerve deaf (Gregory and Drysdale 1977; Drysdale and Gregory 1978) with promising results. As this point Alan Drysdale—an excellent physicist and experimenter—emigrated to America to work on experiments for the Space Shuttle. Tom Troscianko then joined the laboratory and took over this work. He produced a series of papers which indicated advantages in most conditions (Troscianko and Gregory 1984). Ian Low built a hundred reasonably portable Carrier Clipping Aids, and we carried out field studies and tested patients at the Bristol Royal Infirmary. All this was a lot of work. It was supported by the Medical Research Council, which at about this time set up the National Institute for Hearing in Nottingham, directed by Mark Haggard, who had been a student of mine at Cambridge. All credit to the MRC for major investment in hearing research, and also at the University of Keele, in London, and in Cambridge.

What happened to us then? The hearing-aid industry, frankly, is nothing like as innovative or as research-minded as the ophthalmic people. In fact, they seem mainly concerned to make their aids invisibly small with corresponding loss of effectiveness. But the most effective aid is probably a large trumpet; or, still better, a string hanging out of the ear—so people noticing it speak louder and clearly. But, finally, I found an excellent firm which, though not into hearing aids, wanted to move into a new area and was keen to take on our Carrier Clipping Aid. But naturally it wanted some support. So I applied for a government grant, on the scheme that the firm provided 90%, and the government the remaining 10% of the cost. I also found a well-qualified man to take the project on at this stage. But we did not get the essential (not MRC) grant. The entire scheme folded, and nothing further has been done.

It is possible that new techniques of miniaturization might make this a more attractive proposition, perhaps with now available high-speed digital circuits, which might respond intelligently to optimize the processing for prevailing conditions. Certainly there are now people with far more knowledge working on these difficult and important problems. I hope that industry is not deaf to their ideas.

Richard L Gregory

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