<u>Device Effectiveness And Techniques In Hearing Processors</u>

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<u>Overview:</u>

Three of the powerful contributors to hearing loss are age, noise exposure and drugs, both pharmaceutical and "recreational".

With an ageing population, and where exposure to noise is met more commonly in recreational rather than industrial settings, at least two of these factors, age and noise, will contribute to a greater incidence of hearing loss in the population in the future.

However, through personal anecdotes at least, we are very aware of the lack of uptake of hearing aid provision, and the resulting social distress that this causes both to the hearing-impaired person and to close family. There is a lack of satisfaction from hearing aids, partly due to a lack of perceived benefit. The device, once fitted in the clinic, often moves to the drawer at home, rarely touching the ear of the user. Indeed, until about 20 years ago, even the better commercial devices resulted in additional hearing <u>impairment</u> to all except a minority. This minority typically had a hearing loss that was so great that they could not cope even in the simplest of listening environments, a quiet room.

(*SLIDE: picture*) Today, that situation is changing, but we are not out of the woods yet. We have moved on from the ear trumpet that captured more sound, but fails on several scores for acceptability such as aesthetics and the lack of controls to adjust to the user's hearing loss. Let's look first at the components of a modern hearing prosthesis, which will help to frame my talk. (*SLIDE: components*) Primarily it comes in 3 parts: (*Animate:*1) sound capture such as by a microphone (*Animate:*2) processing to overcome hearing loss (*Animate:*3) a delivery method which may be physical such as via a loudspeaker or vibrator, or electrical such as the direct neural stimulation provided by a cochlear implant. Without belittling sound capture or delivery, to which I will return later, I want to focus first on this black box : "processing". We start with a basic need for the processing to compensate for the hearing loss, to make the impaired hearing system behave "more like normal". That last phrase has the potential to open a whole can of worms, but let's use that as a working definition for the moment. The primary aim of the processing can be seen to map the range of levels and frequencies encountered in everyday life into the residual audible range of the hearing impaired person. For a long time this has involved amplification which varies according to frequency as well as some form of automatic volume control that keeps sounds audible but not uncomfortable or injurious. Although we are still not finished with understanding the competent use of frequency-dependent amplification and automatic volume control, the focus is shifting. Digital processing, which allows us to place a miniature computer on each ear, offers us the chance to ask questions as to “what else can we do to improve the listening experience ?” and ultimately “can we restore hearing to ‘normal’?”. Answering these does require quite sophisticated forms of processing, such as reducing interfering sounds or adjusting the aid settings automatically for the user, depending on their listening environment. But I want to focus on why “one size does not fit all”.

I identify the challenges arising from this question in two sections. Firstly:

Device Effectiveness

A) Diagnosis

(*SLIDE: peripheral*) Diagnosis involves not only quantifying the loss, but also determining the site of the hearing loss. In the peripheral hearing system alone candidate sites are the (*Animate:*1) middle ear, (*Animate:*2) the cochlea or (*Animate:*3) the auditory nerve. From these basic measures a remediation strategy can be planned. However, the stage of quantifying the loss involves measuring the quietest tone that can be detected through the affected ear. From the graph of hearing loss as a function of frequency, called the audiogram, the hearing prosthesis is typically set up to make sounds audible. In practice, audibility also requires not only that the sound can be detected, but that the information in the sound can be extracted, a process called discrimination. But the process of detecting a quiet sound is very different from the process of discriminating what was in the sound, and takes place at a different sound level, such as when we listen in a busy room. There is therefore a mismatch between how hearing is measured compared to how it is being used.

(*SLIDE: cochlear X-section*) Hearing loss implies that some dysfunction has occurred. For example, in the cochlea, the organ of Corti runs the full length of the cochlear spiral. (*Animate: OC ring*) Here alone, there are at least two sites of potential damage: one to a set of cells that perform amplification of the physical vibrations that result from sound, the outer hair cells (OHCs), and one to a set of cells that behave like microphones, the inner hair cells (IHCs), converting the vibrations into nerve impulses that can be assessed by the brain.

(*SLIDE: OC surface+advance*) The health of the OHC "amplifier" cells can be assessed by a technique now used routinely in neonatal hearing screening, oto-acoustic emissions (OAEs), developed in this country over the past 30 years. OAE screening produces one of two outcomes: pass or fail. OAEs have also been used as an early diagnostic tool to identify potential noise exposure risks in industrial and military settings.

(*SLIDE: OC surface+advance*) The health of the "microphone" IHCs has only recently begun receiving attention. The laboratory that I work in has produced a clinical test to check these cells, but also only gives a pass/fail verdict on their health. This is called the TEN test. Charles Liberman's group at the Massachusetts Eye & Ear Infirmary have been looking at these cells in noise-exposed animals. They have produced evidence that physiological decay propagates long after an episode of noise abuse has ceased. The damage can also be manifest much more subtly than just visible physical damage to cell structures: his group has also identified the loss of nerve contact to the inner hair cells, which would lead to a loss of information flow to the brain. Although the ability to detect the signal available to the brain is little changed, the ability to discriminate information in the signal will be much reduced. In our laboratory, testing of noise-exposed rock musicians has shown similar, supporting evidence for a loss of discrimination. Again, this loss of discrimination occurred with no loss of detection ability, and again this work with humans would predict that the consequences of such damage may not impede daily listening for many years.

One research need therefore is for more sensitive clinical measures that can detect early signs of hearing damage, at a level of more than just "pass" or "fail".

Secondly, the use of these more sophisticated screening tests, such as OAEs and the TEN test can (a) guide fitting strategies and (b) generate realistic expectations in the user of the effectiveness of the prosthesis.

The downside is that these extra tests will extend the time and hence cost of diagnosis. One way to reduce this cost is to use automated diagnostics: the patient is set a suite of tasks that are run under computer control, and left alone for about half-an-hour. The computer summarises and presents the results for evaluation by a clinician. We have already seen some early tools, but primarily limited to measuring the audiogram, which is the most basic of hearing tests. *(BLANK SLIDE)*

B) Fitting

To a certain extent, what I have mentioned under "Diagnosis" has implications for the choice and methods of fitting hearing prostheses. The signal, corrupted in its capture by the impaired ear, meets the brain: so there is corruption from the "bottom up". As we are well aware, not all brains are the same, and the ageing brain shows declines in its capacity and speed to process information: so there is potentially also corruption of the signal from the "top down". The late Stuart Gatehouse, of the Institute of Hearing Research in Glasgow, demonstrated a link between real-world abilities of listeners with hearing aids and measures of their mental faculty and regular listening experience. If users have reduced faculty or never operate in demanding listening situations, the processing should be set up to produce minimal interference with the signal so as not to tax the limited capacity of the user. So not only does the user drive the choice of settings on a prosthesis, but again realistic expectations can be predicted for the same user.

C) Validation

I have already mentioned potential causes within a user that limit the ability to extract information from a signal, arising from both "bottom-up" and "top-down" processes. The consequences are that a user finds it much harder to cope with listening situations in which others are having little difficulty. Besides improving audibility, advanced hearing aids incorporate extra processing of the signal to try to remove irrelevant information. However, there is a dearth of data to validate such an approach: one may show in the laboratory that the background noise has been reduced more than the foreground, and therefore expect an improvement in intelligibility. But how does this improvement manifest in the user ? To date, processing has been shown mainly to improve comfort and thereby reduce fatigue from long-term listening in that sort of environment. Measures in terms of how intelligibility has changed have rarely shown any substantial increase. Any benefit is therefore primarily indirect. But we should not take this as a failure: devices are now available that deliver real benefit compared to devices of even ten years ago: I will come on to reasons why later. Aids are now available that, when fitted properly, can help users in difficult situations, but we need objective tools to quantify the benefit that the more esoteric forms of signal processing are offering over and above frequency-dependent amplification and volume control. Subjective tools do exist, primarily in the form of user questionnaires on before-and-after experiences, but they do not expressly indicate what aspect of the multi-faceted intervention has produced the benefit. Since adoption of technologies by the NHS is driven by an evidence base, there is a mismatch between what is available and what can realistically be expected to be provided on the basis of proven benefit.

Techniques

In an institute dedicated to advancing technology, and as an engineer by training, it may seem surprising that I appear to be downbeat on the use of advanced processing techniques. That is not the case, but what I had to admit after only a few years in this field is that the brain is far smarter than us at decoding signals with degraded information content.

The demonstrable benefits that I have already alluded to come from a simple philosophy, but which requires high technology to achieve it. The young, healthy ear can respond to signals with a frequency range from 20 to about 20000 cycles per second using an organ buried inside the head at the end of a sheltered canal. In real acoustic situations, we could cope with a slightly smaller range of frequencies, about 100 to 10000 cycles per second. (*SLIDE: Techniques: miniaturisation*) Designing microphones and loudspeakers that can reproduce that range and that are small enough to sit close to and take advantage of the external ear and canal has been a big challenge. Other constraints are that both microphone and loudspeaker should achieve these goals with (a) very little distortion either in time or frequency, (b) fit in a miniature package and (c) run off a single small battery. Once these goals are approached, and verified in real ears, we have drastically reduced the external corruptions of the signal before it suffers further corruption inside the ear and brain of the user.

One further desirable property of microphones that has been successfully implemented in hearing aids is the ability to collect sound preferentially from in front of the user while reducing sound coming from the side and behind the user. These, “directional”, microphones, although simple in concept, in certain listening situations do result in measurably improved intelligibility. We have come a long way from even 20 years ago.

(*SLIDE: BTE photo*) But we are not there yet: for reasons of cost, acoustic hearing aids provided by the NHS are primarily of the “behind-the-ear” (BTE) type. (*SLIDE: advance*) BTEs locate the microphone in a non-ideal place, just above the external ear where it cannot take advantage of the cues to direction provided by this flap of skin and cartilage that to the layperson appears to have little function other than from which to suspend jewellery. The NHS practice is to aid both ears where relevant, which is of great benefit in difficult laboratory-based listening situations, a benefit hard-to-prove directly in a clinical situation. However, further benefit would be available from locating the microphone closer to the entrance of the ear canal. (*SLIDE: advance*) Additionally, with the BTE location of the aid, the delivery from the loudspeaker is typically via a hollow tube leading into a custom mould inserted in the user's ear canal. (*SLIDE: advance*) Besides the mould being fiddly to insert, especially for the less dexterous, the tubing is a major obstacle to the simple philosophy I outlined earlier: it impedes the delivery of a smooth frequency response. The commercial market is now dominated by aids that connect to a miniature loudspeaker placed in the ear canal, held in place by a skeletal plug that is not customised to the user. An alternative way of achieving these better placements of microphone and loudspeaker is also via the in-the-ear (ITE) aid. Here for comparison is a photo of a disposable ITE from 6 years ago. The closer proximity of the loudspeaker to the eardrum makes it easier to deliver a wider range of frequencies, with a smoother response and with a lower power consumption than is possible with delivery via tubing. In-ear loudspeakers have yet to reach the NHS, despite their potential advantages, including the fact that they are "instant fit". Additionally, we are only at the early stages of understanding how much of, and when, this wider range of frequencies needs to be delivered to the impaired ear. Once we do, then we may have devices that are demonstrably beneficial for a wider range of hearing impairments and therefore leading to a wider take-up by the population than is currently experienced.

I leave you with a summary of what I have covered.

(*SLIDE: Summary*)

<u>Summary Slide on Future Needs</u>

Diagnostic tests that are:

(a) sensitive/early warning

(b) measures of discrimination in addition to detection

(c) automated

(*SLIDE: Advance*)

Fitting procedures that select:

(a) signal processing strategies integrated with residual acoustic faculty (bottom-up)

(b) signal processing strategies integrated with residual mental faculty (top-down)

(c) choice (and expense) of technology appropriate for degree of loss and other patient factors

(*SLIDE: Advance*)

Validation:

(a) objective measures of real-world benefit (1) from the fitted aid and (2) from the user

(*SLIDE: Advance*)

Technology components and computation:

(a) sound capture and delivery : wider frequency range

(b) ability for user to operate in sound environments that the bulk of the population work in