Commentary on "The Development of Speech Processing Strategies for the University of Melbourne/Cochlear Hearing Prosthesis" by Graeme Clark

Commentaires au sujet de "Élaboration de stratégies sur le traitement de la parole pour l'implant cochléaire multi-canal de l'Université de Melbourne" par Graeme Clark

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There are two major schools of thought with respect to the transfer of information from the acoustic environment using a cochlear prosthesis. The first school, which is represented essentially by Dr. Clark and his team and which is implemented in the cochlear device, is the concept that important cues in the speech signal should be extracted by an external device prior to coding for electrical stimulation of the cochlear nerve. This concept embraces the idea that there is a limited amount of information that can be transferred to the auditory system, that limit being introduced by the number of separate stimulating channels and, importantly, by the number of residual cochlear nerve fibres remaining in the eighth nerve. Recognizing this bottleneck, Clark's strategy is to separate out the important (and predetermined) cues in speech and input this information relatively unambiguously.

The second school of thought can be described as an attempt to emulate, as well as possible, normal cochlear function. In this strategy, the external device simply might be a set of band pass filters, the output of which stimulate neural groups at different frequency positions along the cochlear length. The important concept here is that the onus is on the residual capacity of the auditory system to extract the relevant speech cues from a more general input. Unfortunately, the development and commercial production of cochlear implant devices that follow this second strategy have not yet been implemented successfully on a large scale. (Indeed, although my theoretical preference is for the latter, I currently direct the cochlear implant program at the Hospital for Sick Children where we are using Clark's system!)

Clearly many individuals who have acquired a profound hearing loss after the development of speech and language abilities do well with the speech cue extraction strategy of the Cochlear device. Perhaps, to be over simplistic, we might assume that the auditory system and the associated speech areas have developed in a relatively normal fashion and that they are primed for the sort of formant and fundamental cues which the Cochlear device offers.The question is: Does this type of device, however, offer optimal benefits to the congenitally deaf.

In the congenitally or prelingually deaf child there is another role to be played by a device that artificially activates the cochlear nerve; that role is to aid the development of the central auditory pathways. We now know from a number of studies in both the somatosensory and visual systems, and more recently in the auditory system (Robertson & Irvine, 1989; Harrison et al., 1991), that the patterns of excitation of the cochlear neural array are extremely influential in moulding the functional organization of higher auditory centres (particularly auditory cortex but probably brainstem and midbrain areas also). The implication of such studies is that electrical stimulation of the cochlear nerve via an implant during the early stages of development actually will determine the organization of the auditory central nervous system (CNS).

If one region of the cochlear neural array is preferentially excited, compared with the other regions, then the CNS representation of that particular area may become massively over-developed. The supposition here is that the young infant implanted with a particular cochlear prothesis will develop a brain which is specifically formed according to the input which the prothesis provides.

Again, to be over simplistic, it may well be that children implanted early on with the Cochlear device develop a "cochlear" cortex. My point is that perhaps the strategy of extracting certain cues from speech for input to the cochlear nerve may not constitute the optimal signal for stimulating development of central auditory areas. Perhaps the better strategy would be the one that attempts to emulate the normal system, for example, the simple bank of band pass filters (the second school of thought).

Another issue that I would like to raise and invite Clark's comments on also concerns developmental aspects, but at a more practical level. At present our own pediatric cochlear implant program and, I suppose most others, will not accept infants who are less than three years of age. This is mainly due to: (1) the need to have reliable behavioural thresholds to confirm a profound hearing loss, and (2) the need to have a child who can respond reliably and behaviourally to the auditory sensations that he/she will experience when implanted. However, basic animal research concerning, for example, critical periods of development in the visual system (e.g., Hubel & Wiesel, 1965), and other data on auditory CNS plasticity (see references cited above) suggest that the excitation of the cochlear periphery is an important factor in the development and maturation of central auditory pathways. There well may be significant benefits to implanting children at a much younger age than three years. This of course poses a new range of potential problems. Perhaps Dr. Clark might provide us with his perspectives with respect to the implantation of very young infants.
R.V.H.

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Reply to Commentary

I appreciate the opportunity to reply to the comments of Professor Robert Harrison. He has raised a number of important issues regarding the future directions for cochlear implant work. The first issue is whether feature and signal extraction schemes are likely to be better than ones which simulate closely the physiology. On this point I would like to comment that a good physiological simulation of the temporal coding of frequency still does not appear possible due to the deterministic rather than stochastic firing patterns of units to electrical stimulation. This is confirmed by experimental animal behavioral and human psychophysical findings which show limited rate and pitch discrimination above about 300 pulses/s. There is also a limit to the number of electrodes one can use to spatially represent spectral information. In the case of the Cochlear device this is 21.

In favour of feature or cue extraction schemes are the physiological studies (Young & Sachs, 1979; Delgutte, 1980; Deng & Geisler, 1981) which have shown that the formants predominate in the spatial representation of speech. Speech perception studies have also shown that certain cues are more important than others. For the foreseeable future it would seem preferable to use a speech processing system designed to make so-called "intelligent" use of a limited interface with the auditory nervous system by extracting appropriate cues.

The second issue raised is whether a feature or signal extraction system is the optimal one for congenitally deaf children and whether children may develop a cortex specifically for a particular speech processing system (e.g., "a Cochlear cortex"). In the management of these children there is also increasing, however incomplete, animal experimental evidence for the protective effects of electrical stimulation on the maturing nervous system (Matsushima et al., 1991) as well as its plasticity. Even when our knowledge of the effects of electrical stimulation on the plasticity of the experimental animal's auditory nervous system is more complete, we still cannot apply it necessarily to psychophysics and speech perception in patients. In this regard we have carried out psychophysical studies on prelinguistically deaf children and adults (Busby et al., in press) who have recently had a cochlear implant and found that for some of these patients the spatial coding of frequency is worse than for postlinguistically deaf people. These findings suggest that it is important to stimulate a number of different sites in the cochlea at a young age to ensure that spatial coding of frequency occurs. This is achieved with 21 electrodes and the Cochlear device. Furthermore, other psychophysical studies of ours on prelinguistically deaf implanted children do not show that the format-based speech processing system limits the development of the spatial processing of frequency information (Tong et al., 1988).

The final issue to be discussed is whether we can operate on very young children. In this regard we have developed an improved evoked response system that can be used to diagnose a hearing loss accurately at low as well as high frequencies. This is carried out by doing a Fourier analysis on the averaged evoked potentials in response to amplitude modulated sounds (Rickards & Clark, 1984; Cohen et al., 1991). This ABR system, or alternatively a frequency specific one together with behavioral testing by an experienced audiologist, will now provide an accurate assessment of hearing at least as young as two years of age. Furthermore, our studies under the NIH contract "Studies on Pediatric Auditory Prosthesis Implants" have shown that head growth can be adequately allowed for when using the present Cochlear device in children two years of age and above. Studies are also in progress to determine how best to design a device that can accommodate temporal bone growth under two years of age. Other relevant studies being undertaken prior to implanting infants are the effects of implantation on skull growth, the prevention of middle ear infection post-implantation that leads to labyrinthitis, and the effects of electrical stimulation on the young cochlea and auditory nervous system. More information about these studies can be obtained from Dr. William J. Heetderks, Neural Prosthesis Program, Room 916, Federal Building, National Institutes of Health, Bethesda, Maryland 20892 for contract N1H NO1-DC-7-2342f "Studies on Pediatric Auditory Prothesis Implants."

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