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# ISSUES IN THE DEVELOPMENT C MULTICHANNEL TACTILE DEVICES FOR HEARING-IMPAIRED CHILDREN AND ADULTS

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Levitt, Pickett, and Houde (1980), in their landmark monograph, noted that the history of tactile aid development has been characterized by periodic bursts of enthusiasm and research, often culminating in identification of new avenues to be explored for improving tactile perception of speech. While several research groups have maintained long-term interest in tactile research (Boothroyd, 1985; Oller, Payne, & Gavin, 1980; Saunders, 1985), there was a marked increase in reports of new multichannel tactile devices during the 1980s (reviewed in McGarr, 1989). This upsurge may have been spurred in part by the rapid increase world-wide in the number of hearing-impaired children and adults using cochlear implants as everyday communication devices, and the perceived need for a non-surgical approach to assisting hearing-impaired children. Despite this increase in tactile research, no tactile device has yet achieved widespread commercial use by the hearing-impaired community. It is, therefore, of interest to question why cochlear implants have been more widely accepted than tactile devices.

A primary reason would be the relative speech perception benefits available to users of either cochlear implants or tactile devices. However, direct comparison of speech perception benefits is difficult, because few hearing-impaired children or adults have used both types of devices, and it is also difficult to generalize the results of matched group studies to the population as a whole. It would seem logical that stimulation of auditory nerve fibres by implanted electrodes would have a significant advantage over tactile stimulation of the skin, because it might exploit the normal higher-level auditory pathways, and in postlinguistically deafened children and adults, the "learned" step from auditory sensations to speech comprehension. Studies of psychophysical discrimination in patients using multichannel cochlear implants and multichannel electrotactile devices have shown similar scores for electrode identification and pulse width discrimination tasks with both devices (Blamey & Cowan, 1992). Speech perception studies in the literature have also reported similar levels of benefit in supplementation of lipreading from use

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of either multichannel cochlear implants or multichannel tactile devices (Brooks, Frost, Mason, & Gibson, 1986; Cowan et al., 1990, 1995b; Osberger et al., 1991; Weisenberger, Broadstone, & Kozma-Spytek, 1991). However, in a comparative study of speech perception benefits for triads of hearing-impaired children matched on a number of criteria including degree of hearing loss, Geers and Tobey (1995) reported that children using multichannel cochlear implants showed greater benefits to both speech perception and speech production than those shown for hearing aid or tactile aid. Although psychophysical evaluations and measures of supplementation of lipreading might suggest some comparable speech perception benefits from use of multichannel cochlear implants and tactile devices, many postlinguistically deafened adults and children are able to understand significant levels of open-set words and sentences using their cochlear implant alone, particularly when using new speech processing strategies (Skinner et al., 1994). In contrast, while the abilities of practiced deaf-blind users of the Tadoma method to recognize open-set speech materials have been documented, hearing-impaired adults and children using multichannel tactile devices alone have not achieved similar scores on open-set speech perception tests.

## ISSUES AFFECTING SUCCESSFUL USE

Given these findings, the question arises, "Is there a role for tactile devices in the management of hearing-impaired children or adults?" Some hearing-impaired adults and children may be unable to proceed with cochlear implantation due to malformation of the cochlea, obliteration of the cochlear duct by bone as a sequelae to meningitis, or the presence of acoustic neuromas. Adults, parents, or children may also be unwilling to accept the risks associated with major surgery, or be unwilling to jeopardize their remaining residual hearing. Severely hearing-impaired patients may have too much residual hearing to be suitable candidates for cochlear implantation, yet still be unable to perceive all speech sounds through hearing aids. In all of these cases, tactile devices may provide a viable option in management, with the patient benefiting from additional speech information delivered through the tactual modality.

Given acceptance of this role, a second question arises, "What factors are important in enabling tactile devices to achieve significant levels of market penetration and acceptance amongst hearing-impaired children, parents, and professionals?" It is also important to ensure that research funds for tactile development, which have become limited in the face of competition for support from cochlear implant research programs, are effectively focused on developing successful commercially available tactile devices that meet the real communication needs of hearing-impaired adults and children. Important factors might include:

- the individual user's hearing thresholds, and the associated communication handicap;
- the speech information available to the user of the particular device;
- the cosmetic design, risks, and ease of use associated with the particular device;
- the user's motivation and the management program; and
- the habilitation program used with the particular device.

To evaluate these factors in a realistic context, the influence of each in the development program of the Tickle Talker™ will be discussed. The Tickle Talker multichannel electrotactile speech processor resulted from research at the University of Melbourne to develop a nonsurgical approach for hearing-impaired adults and children who did not proceed with cochlear implantation (Blamey & Clark, 1987). Although the device has been developed for both adults and children, in this discussion we will focus on the needs of hearing-impaired children, who arguably have greater needs for communication devices to not only assist speech perception, but also to allow for development of speech production skills and language acquisition.

The main elements of the Tickle Talker are an externally worn speech processor/stimulator unit and an electrode handset (Figure 1). The speech processor is based on hardware used in the Nucleus Mini-22 speech processor, and employs a formant extraction speech processing strategy, providing cues to fundamental frequency (F0), second formant frequency (F2), speech waveform amplitude (A), and high-frequency spectral components (HF). This information is conveyed to the user as a pattern of electrical stimuli delivered to the skin, which results in stimulation of the digital nerve bundles in the fingers of the nondominant hand (via eight electrodes, mounted in pairs in four rings as shown).

## Hearing Levels and Communication Handicap

The critical aspects of speech that are important for speech perception include the suprasegmental features such as rhythm, stress, and intonation; and segmental features such as vowel formant frequencies, consonant voicing, consonant manner, and place of articulation. Cues to these important features are spread across the frequency spectrum from approximately 80–6000 Hz. Information on vowel formants and consonant manner and voicing are critical to hearing-impaired children, as this information is not available from lipreading. The characteristic spectral and temporal features of the speech waveform provide multiple acoustic cues for distinguishing particular speech sounds. Although these cues are highly variable, additional redundant cues are present in English in the effects of context, familiarity with speaker and subject, and the grammatical and phonetic rules that limit the potential alternatives in phonemes in words, and words in sentences. Hearing impairment not only reduces the range of acoustic cues and redundant information available to the listener, but in cases of prelinguistic onset of deafness, also introduces delays in acquiring knowledge of vocabulary and grammar.

The communication handicap of any individual severely or profoundly hearing-impaired child will vary due to differences

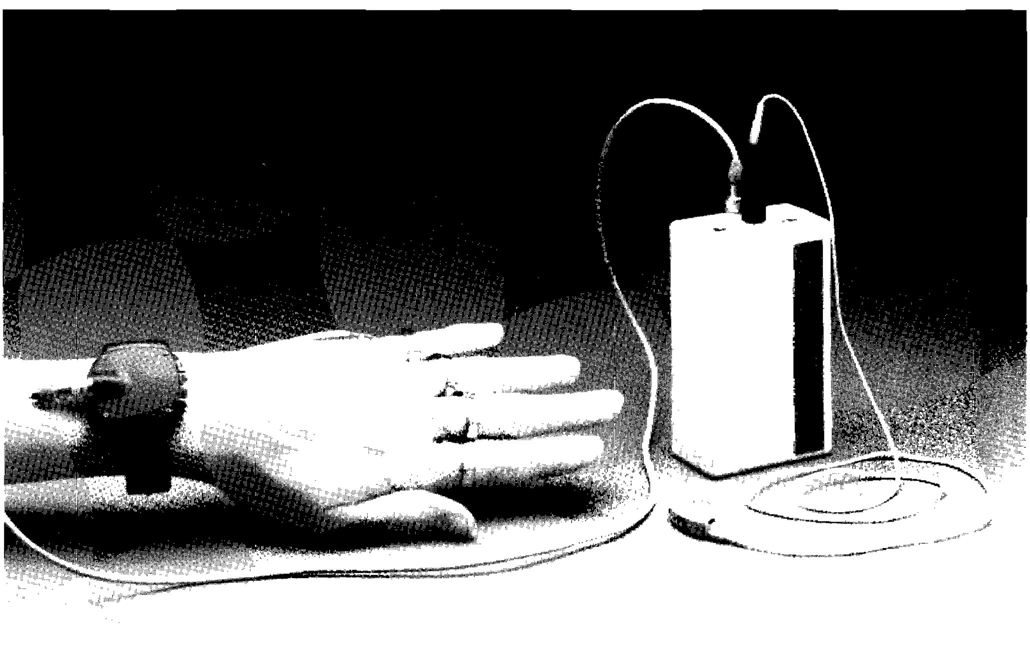

**Figure 1.** Photograph of MK3 Tickle Talker, showing integrated speech processor stimulator, wide-band directional microphone, and electrode handset.

in etiology, age at onset of deafness, duration of profound deafness, aided residual hearing thresholds, use of hearing aids, communication system employed (i.e., oral, total communication, or manual), or the presence of other disabilities. These factors not only contribute to defining the communication needs of the individual child, but also influence potential benefits for any individual from use of any device, through their effects on the ability of the child or adult to perceive speech features across the speech spectrum and to integrate this information into word recognition and comprehension. In addressing the issue of hearing thresholds and communication handicap, we are, therefore, interested in how much benefit individual children receive from use of lipreading and hearing aids, and what additional benefits might be available from use of a tactile device. Although the effects of the particular device on speech production and on subsequent language development of the child are also important, they are dependent on the speech information that the user perceives through their device.

The issues involved in residual hearing levels are illustrated in Figure 2, which shows mean speech detection thresholds on the Ling 5-Sound Test for a group of 14 profoundly hearing-impaired children using hearing aids or the Tickle Talker. Mean thresholds with hearing aids were within the normal speech spectrum up to 1000 Hz, but drop well below at 2000–4000 Hz. This suggests that the children would be able to access cues to the three vowel sounds with their hearing aids but would be unable to perceive higher frequency consonants. In contrast, thresholds for detection of both lower and higher frequency stimuli were within the normal speech spectrum when using the Tickle Talker. Because high-frequency elements are critical to word intelligibility and also convey important grammatical markers (e.g., /s/ in plurals and possessives), it is vital for children to have access to this high frequency spectral information.

A further consideration in assessing residual hearing levels and communication handicap is the proposed function of the device. Most tactile devices, including the Tickle Talker, have been designed to provide supplemental information to be used in combination with input from other modalities. This is in contrast to cochlear implants, which in many cases allow significant understanding of speech using the device alone, opening the possibility of telephone use, conversations without the need

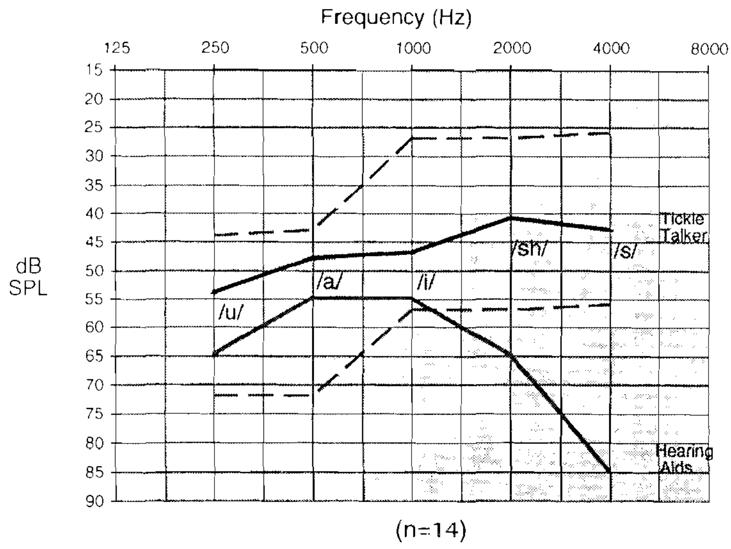


**Figure 2.** Comparison of mean speech detection thresholds for 14 profoundly hearing-impaired children using hearing aids and Tickle Talker.

for visual regard, or communication in situations of poor visibility. Figure 3 illustrates how tactile input can effectively supplement information available from hearing aids to overcome some perceptual limitations. Individual consonant manner discrimination scores on the PLOTT test for 13 profoundly hearing-impaired children using hearing aids alone versus the Tickle Talker plus hearing aids are shown. With hearing aids alone, there was a wide range in score (40–90%), consistent with the differing levels of aided residual hearing of individual children. These results suggest that many of the children would be unable to discriminate important manner differences in initial and final consonants using input from hearing aids alone. This information is also not available from lipreading, because consonant manner differences are homophenous. However, with added tactile input supplied through the Tickle Talker, the range of scores was narrowed to 85–100%, suggesting that all of the children were able to perceive this contrast by means of the supplemental tactual cues. It was evident that children with the lowest consonant manner scores using hearing aids alone made the greatest gains from the additional tactile input, although benefits for those with higher scores may have been limited by ceiling effects on this test.

In the everyday communication environment, severely and profoundly hearing-impaired children rely not only on aided residual hearing, but also on lipreading to provide cues to speech. Figure 4 illustrates how tactile input can be used to provide additional cues to be used in combination with either aided residual hearing or aided residual hearing and lipreading. Mean scores for a group of eight profoundly hearing-impaired children on six different speech feature discrimination measures were significantly lower ($p < 0.05$) with hearing aids alone than mean scores in the combined Tickle Talker plus hearing aid condition. Figure 4 also shows mean scores on Phonetically Balanced Kindergarten (PBK) Words and on Bamford-Kowal-Bench (BKB) Sentences. In this case, the ability of the children to access speech information using hearing aids plus lipreading is compared with the combined use of Tickle Talker, lipreading, and hearing aids. On both materials, children scored significantly

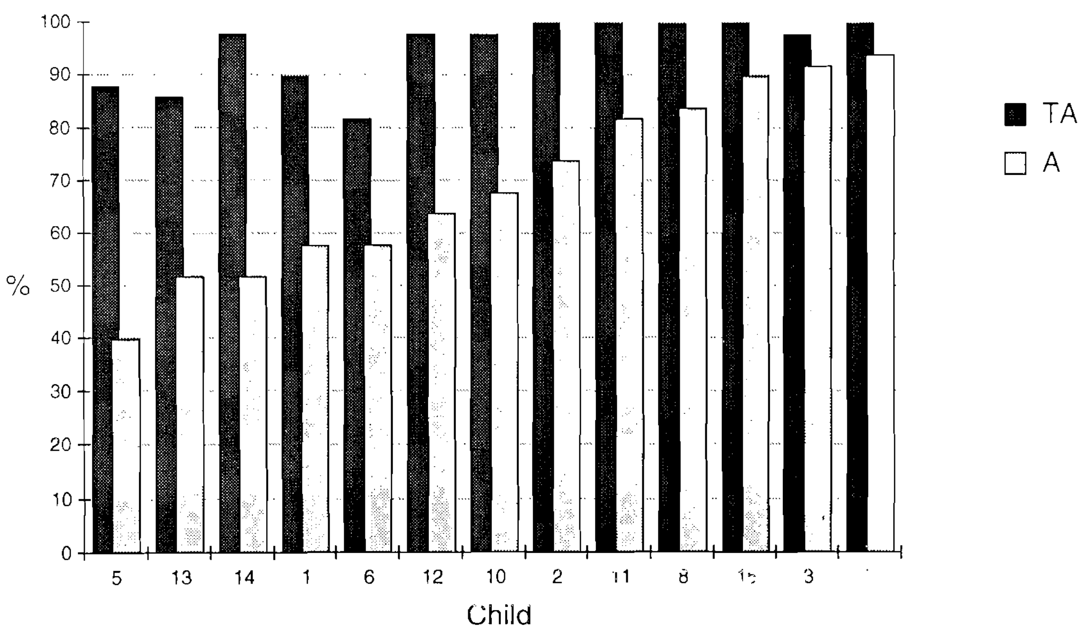


**Figure 3.** Consonant manner discrimination for profoundly hearing-impaired children using hearing aids alone, and hearing aids plus Tickle Talker.

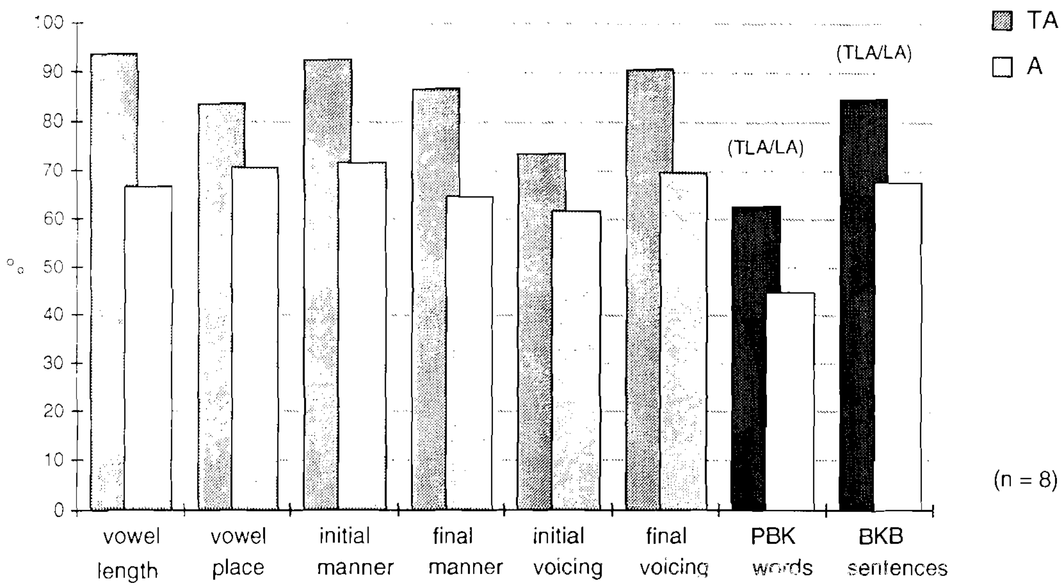


**Figure 4.** Speech feature discrimination, and open-set monosyllabic word and sentence perception scores for profoundly hearing-impaired children using Tickle Talker (TLA & TA) versus tactually unaided condition (LA and A).

higher with the additional tactile input ($p < 0.005$). These results illustrate the difficulties imposed on hearing-impaired children who receive limited benefit from hearing aids and lipreading, and the potential benefits available from increased access to speech information through the use of a tactile device used in combination with lipreading or aided residual hearing.

Hearing-impaired children often develop speech patterns that are not consistent with those of their normally-hearing peers, imposing an additional handicap to communication with the normally-hearing community. Although other factors may be involved, the ability of children to perceive and monitor their own speech patterns through their damaged auditory systems, even with the help of hearing aids, may be very limited. For this reason, an additional factor in assessing the communication needs of the child in relation to use of tactile devices may be the role for the tactile device in speech self-monitoring and resultant speech production. Galvin et al. (1995) noted improvements in articulation when tactile feedback through the Tickle Talker was provided. In this study, the children's conversation was recorded in two conditions, one with the child using lipreading and hearing aids (if fitted), and the other with the Tickle Talker used in addition ("device-on"). Figure 5 illustrates the potential benefits from use of tactile input for three of the six children, whose accuracy of articulation of vowels, consonants, and phonemes was significantly improved in the device-on condition.

## Speech Information Provided by the Device

The results shown in Figures 1–5 illustrate that cues to specific speech features important to vowel and consonant discrimination are accurately encoded in the tactile output of the Tickle Talker, and that these cues can be effectively used by hearing-impaired children to overcome limitations to communication from use of hearing aids or lipreading used in isolation. To ensure maximum access to speech cues not available from lipreading or aided residual hearing, a detailed analysis of speech feature encoding was completed (Cowan et al., 1990), and new encoding strategies based on multiple electrode recognition devel-

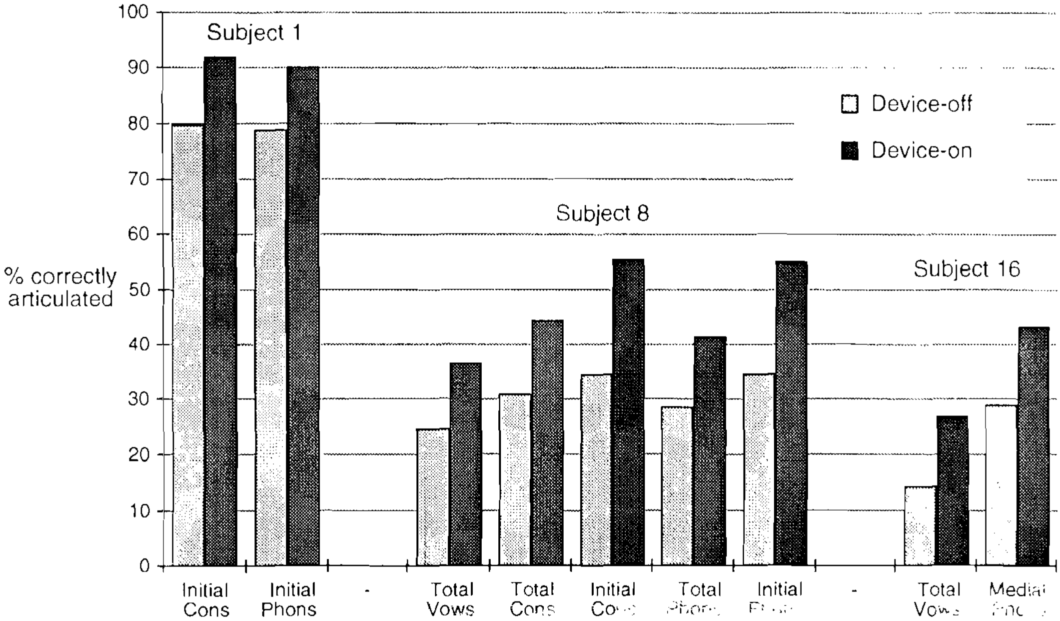


**Figure 5.** Articulation accuracy for three children using on-line tactile self-monitoring.

oped to address identified limitations (Cowan et al., 1995a). For example, results suggested that tactual cues to high-frequency spectral components in the voices of children and female speakers were not well transmitted by the initial speech processing strategy employed in the Tickle Talker, which encoded only F0, A, and F2. This led to development of the second-generation F2HF strategy, which encoded F0, A, F2, and, in addition, a specific cue to high-frequency spectral energy in the frequency band 4000–8000 Hz. Similarly, analysis of speech feature discrimination suggested that cues to initial consonant voicing, conveyed by changes in the rate of tactile stimulation, were not well perceived by adults or children using only tactile input. Cues to this contrast are also not available from lipreading. To overcome this limitation, a third-generation UF2 encoder strategy was developed, which provided a specific tactile cue to the voiced/voiceless contrast in addition to F0, A, F2, and HF.

Figure 6 illustrates the effectiveness of this development program in addressing the communication needs of users by tactually encoding additional speech cues not available through other modalities. Mean scores for discrimination of speech features and open-set PBK words and BKB sentences using the F2HF and UF2 encoding strategies are shown for a small group of profoundly hearing-impaired children. Mean scores on vowel length, vowel place, and initial and final consonant manner were better than 80% with either strategy. Scores for initial and final consonant voicing were, however, significantly improved ($p < 0.05$) using the UF2 strategy. Analysis of phoneme discrimination suggested that the observed significant improvement shown with the UF2 on PBK word recognition scores was, in fact, due to improved perception of initial and final consonant voicing. These results suggest that speech perception benefits for the individual child may be increased by providing specific speech feature information that is not accessible through lipreading and/or aided residual hearing.

## COSMETIC DESIGN, RISKS, AND EASE OF DEVICE USE

Although we have stressed the importance of providing a tactile signal to speech

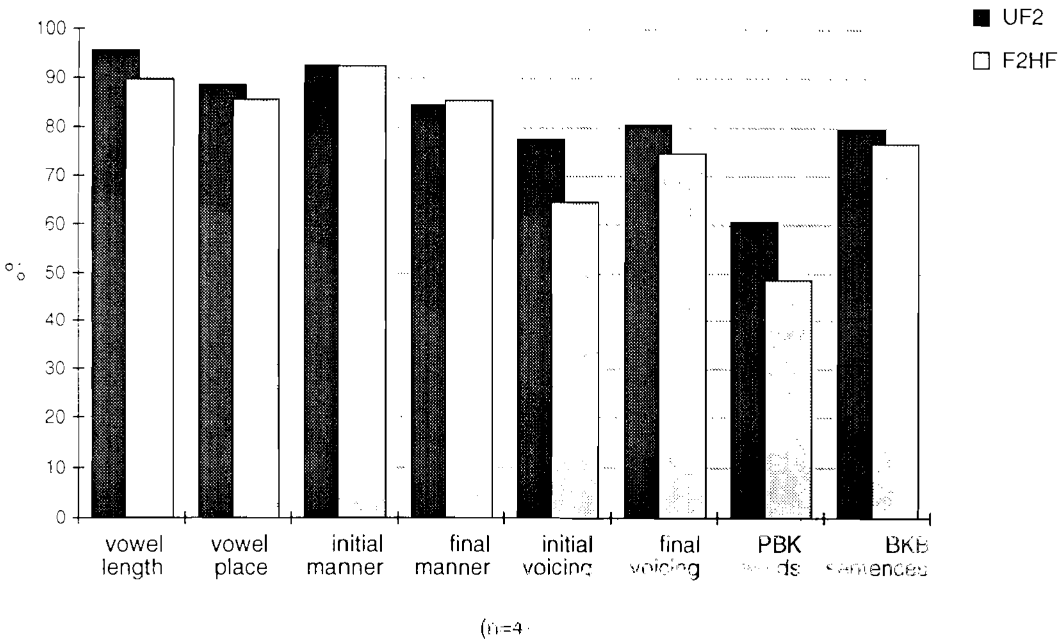


**Figure 6.** Speech test results for profoundly hearing-impaired children using two tactile encoding strategies.

cues that are unavailable from other modalities, device use will also be dependent on subjective factors such as the user's reaction to the device cosmetic design, the user's perception of the risks involved in obtaining and using the device, and the general reliability and ease of daily use of the particular device. While very young children may readily accept a device if consistently reinforced by parents and professionals, it is well known that adolescents will often forego the benefits they receive from hearing aids or cochlear implants in order to avoid appearing "different" to peers and the general community. There is little opportunity for concealment in a device, such as the Tickle Talker, which uses visually obvious cabling and finger rings. To address this cosmetic concern, other manufacturers of tactile devices have opted to position transducers in less obvious positions such as on the back of the neck, the sternum, or the inside of the wrist. A major disadvantage of these less-obvious positions is the relative psychophysical discrimination of the skin at these sites as compared with the higher tactual sensitivity of the fingers and hands. For the Tickle Talker, the ability of untrained subjects to recognize electrode position with near 100% accuracy and the potential gains from the greater tactual sensitivity and larger cerebral representation area for the hand were judged to outweigh the disadvantage of greater visibility. However, a significant research focus remains the development of an improved Tickle Talker electrode handset, which will also be cosmetically less obvious and more acceptable to users.

The potential risks associated with the surgical procedure are an obvious issue that must be considered in the decision of parents, children, or adults to proceed with cochlear implantation. With implants, the potential risks associated with any surgery must be balanced against the perceived benefits for patients with similar characteristics (i.e., hearing loss, duration of deafness, etiology, etc.) and the track record regarding complications for the particular implant system to be used. Device safety issues have not, in general, been perceived to be of such critical importance in the decision of parents and children to use tactile devices. The development program for the Tickle Talker has evaluated safety considerations in the electrical design of the device and the safety of the stimulus paradigm for long-term use (Cowan et al., 1992). Evaluation of the stimulus waveform, speech processor/stimulator circuitry, and electrode handset design showed that potential risks arising from the electrotactile nature of the device design have been addressed. The use of biphasic constant current pulses, proven biocompatible materials, and backup current output limitation circuitry ensure that the device is electrically safe. Long-term evaluations of kinesthetic sensitivity, vascular studies of hand and finger blood flow, and neurological evaluations of the effect of the electrical stimulus on EEG recordings have found no significant effects of device use on local tissue, peripheral nervous system function, or central nervous system activity that might limit long-term use of the device. Demonstrated safety for any particular device is a critical factor in reassuring parents, children, and professionals in their decision to use any tactile device as a long-term communication aid.

Reliability and ease of device use are also factors that can affect the decision of users and professionals regarding use of a device. For example, the initial designs of the electrode handset in the Tickle Talker were not robust, and required frequent changing of electrodes in the field by professionals and parents. This also resulted in children receiving an inconsistent signal, and at times missing the tactile cues important for multimodal speech perception. The initial speech processor/stimulator was also susceptible to RF interference, and was housed in two independent boxes, each of which required separate batteries. To overcome these difficulties, ongoing engineering development is focused on miniaturizing the speech processor/stimulator (to a small single unit), reducing the power requirements (allowing for 24 hours of use on a single rechargeable AA battery), and designing a robust electrode handset, which is also easy, quick, and cheap to replace if required by older children, parents, or professionals in the field.

An additional issue is the use of the tactile device as a supplemental aid to hearing aids and lipreading. For some children, this may involve use of hearing aids, the Tickle Talker, and a radio frequency (RF) unit. The number of microphones involved, and the combined weight and cabling involved can be a definite negative factor in terms of ease of use. Device development must accommodate the need for RF units by hearing-impaired children and, if possible, develop means of using wireless transmission or joint microphone access. Programming of the device is a further issue to be considered in case of device use. In contrast to other simpler single-channel and multichannel tactile devices, the Tickle Talker uses digital technology to set the dynamic range for each electrode independently, and also has the potential to implement a variety of speech processing strategies specifically tailored to the communication needs of individual children. While this is a significant advantage in terms of maximizing speech perception benefits, it also requires individual programming of the device, which is an additional inconvenience to the user and the family, because visits to the clinic are required. The development program has addressed this concern by developing software and an interface that can be implemented on a portable PC notebook computer, allowing programming to be efficiently conducted in the school or home environment.

## User Motivation and the Management Program

The motivation of any hearing-impaired child to use a particular device is critical not only to their everyday use, but also to their involvement and participation in effective habilitation. This is a very subjective factor, which is related to the user's communication needs. For example, deaf-blind users of the Tadoma method are highly motivated to learn to use the communication method, despite the difficulties imposed by the need for close physical contact with speakers, because there have been few practical alternatives available. In the case of cochlear implants, parents and users, both adults and children, may be highly motivated to use their device, because they have undergone an extensive preoperative assessment and counselling procedure, the surgery, and subsequent mapping of the processor and follow up habilitation program. The support provided by the cochlear implant team, the presence of the internal implanted electrode array and receiver stimulator package, and the great emotional commitment of the family are powerful motivators for continuing device use in the case of cochlear implants. Despite this support, clinical experience with cochlear implants has demonstrated that negative peer pressure from the Deaf Community, or from teachers and professionals opposed to cochlear implants, can influence some users to discontinue implant use, even in children with demonstrated benefits to speech perception.

In contrast to implants, tactile devices may be removed at any time and their use discontinued. Given the additional problems of cabling and RF use noted previously, they also represent an additional demand on professional staff in educational facilities and on parents. Negative reinforcement or inconsistent support from professionals or parents can be very discouraging for the child using the tactile device. Management programs for tactile devices must address these issues through provision of adequate in-service training for professionals, and counselling for families and users, to ensure strong support from professionals and parents for continuing device use. Programs should also ensure that where possible, groups of children receive and use the tactile device in one setting, which will also assist with providing peer support for continued use.

## HABILITATION PROGRAM

While we have noted the importance of motivation in continuing device use, it also plays a vital role in the user's active participation in the habilitation program. Not only must the user learn to detect and discriminate the tactually encoded speech signal, but also he/she must learn to integrate this new information in real-time as a meaningful speech message—either using tactile input alone, or tactile input in combination with information from other sense modalities. This is a formidable task, and clinical experience suggests that training must be specifically geared to the particular device and needs of the individual user. For example, if the desired outcome is effective use of the device as a supplemental aid for a severely hearing-impaired child who also uses hearing aids, the habilitation approach and training program may be quite different to the training necessary for a profoundly or totally deaf child, who would be reliant to a far greater extent on speech cues provided through the Tickle Talker. The development of a multichannel tactile device allowing significant tactile-alone perception of speech is a vital area of continuing research, particularly as tactile devices have not yet shown similar levels of benefit to that reported for experienced users of the Tadoma system. Although this may be a direct result of factors previously discussed, such as the specific speech cues encoded by the particular tactile device or the motivation of the patient to learn to use these cues, an alternative explanation could be the more limited training that has generally been employed in tactile device studies as compared with the long-term habilitation required of experienced Tadoma users.

Galvin et al. (1993) have described the development of the habilitation program used with the Tickle Talker, which has concentrated on developing integration of tactile input with information from aided residual hearing and/or lipreading to improve perception of words, sentences, and running speech. A number of important factors to be considered in development of training programs were identified, including: type of training tasks, amount of training, motivation and device use by the subject, user characteristics, response formats used in training, information presented through the device, and the evaluation procedures implemented. As noted, psychophysical and speech discrimination assessments have provided a detailed analysis of the information being tactually encoded and discriminated by users. In planning training for individual children, attention is given to these results in the choice and order of tasks, with a hierarchical series of tasks emphasizing training of perception in running speech being employed. Particular attention is given to the specific perceptual needs of the child, and monitoring of their motivation and consistency of device use. Regular evaluations are administered to monitor progress and speech perception/production benefits. Experience has shown that extensive training with the Tickle Talker is needed to maximize speech perception benefits. Basic phoneme discriminations can be made using the tactile signal without training; however, this does not necessarily generalize to perception of words and sentences without periods of intensive training over a minimum 6-month period. Training is more effective when implemented on a daily basis, and the management/habilitation program must involve the parents and teaching professionals if success is to be optimized. Current research is evaluating the effects of unimodal versus bimodal training on both integration of tactile input, and tactile-alone perception. These studies are vital to identifying key elements in tactual speech perception, and optimizing tactile training programs for use with individual devices.

## SUMMARY

We have discussed the influence of a number of individual factors in the successful use of tactile devices. Tactile devices, such as the Tickle Talker, have been primarily developed to provide additional speech information to be used in combination with speechreading, and in some cases aided residual hearing, addressing the particular individual's speech perception and communication needs. Evaluations have shown that enhancement of speech feature discrimination with the device may occur immediately on fitting, but effective integration of tactually encoded speech feature cues into combined-modality speech perception requires a minimum of 6 months habilitation. Tactile-alone perception of words and sentences has not been a priority addressed through either development of speech encoding strategies or training programs. In contrast, cochlear implants have been shown to provide significant speech information to those patients who receive little or no benefit from hearing aids. Increasingly, the documented ability of implantees to perceive open-set words and sentences in the implant-alone condition has been taken as evidence of device benefit, with the degree of supplementation of other sensory modalities such as lipreading of secondary import. The application of this evaluation philosophy to tactile devices would suggest that they provide very limited benefit only to hearing-impaired children or adults.

The importance of this issue is illustrated in Figure 7, which shows speech perception results on PBK words for three congenitally deaf adolescents, each of whom were initially fitted with the Tickle Talker, and were subsequently implanted with the Nucleus multichannel cochlear implant (Sarant et al., 1995). If we compare the devices solely on the basis of benefits in supplementing lipreading and aided residual hearing, the results show comparable benefits for two of the three children (CI-L versus T-HA-L). Given that hearing-impaired children in everyday communication would use all available speech input (i.e., the combined modality condition), it might be argued that the results suggest that children would do equally well with either of the two devices. However, all three children showed some understanding of speech through their cochlear implant alone (CI), as compared with only one child showing very limited understanding of open-set speech using Tickle Talker plus hearing aids (T-HA) or hearing aids alone (HA). This device-alone perception in the case of cochlear implants provides a distinct communication advantage, because it allows conversation without the need for visual regard, and opens the possibility of telephone conversation.

Each of these three children were experienced users of the Tickle Talker, and each was obtaining significant speech per-

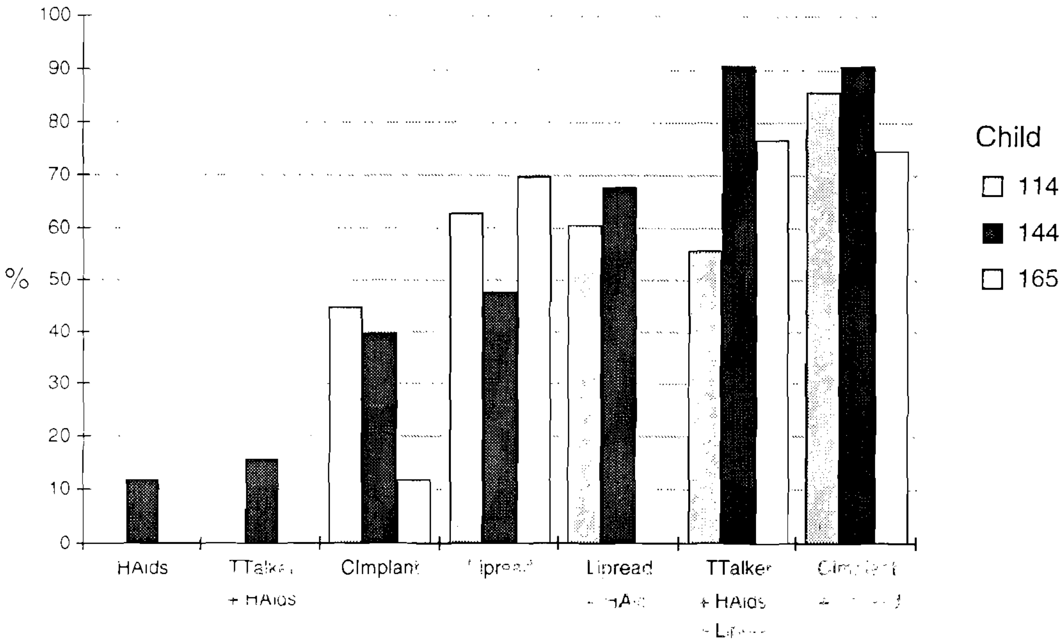


**Figure 7.** Open-set monosyllabic word recognition scores for three profoundly hearing-impaired adolescents using the Tickle Talker, Nucleus multichannel cochlear implant, and hearing aids.

ception benefits from use of the tactile device. Yet in all three cases, the children and parents decided to proceed with cochlear implantation, despite the risks involved in cochlear implantation surgery. While this suggests that tactile devices may play a role in the preimplant habilitation and evaluation program in cochlear implant clinics, it also suggests that the perceived benefits available from cochlear implants were judged by these families to be superior to that offered by the Tickle Talker. Informal conversations with the families suggested that a significant premium was placed on the perceived speech perception benefits available from cochlear implants, based on observed benefits for other implanted children. In addition, further considerations were the cosmetic issues, reliability, and ease of use of the different devices, and the fact that the cochlear implant was a commercial device in contrast to the "research" Tickle Talker.

The relative sophistication of cosmetic/engineering design for cochlear implants is dependent on the capital R&D investment of companies developing commercial cochlear implant systems for use in medical/clinical practice. Again, in contrast, only one U.S. company is a major commercial manufacturer of tactile devices, while most research organizations developing multiple channel tactile devices have focused limited resources primarily on speech perception benefits. To achieve more widespread use, tactile devices must address cosmetic issues, be robustly designed, reliable, and easy to use.

An additional issue in motivating the decision to proceed with a cochlear implant instead of a tactile device may be the funding of devices. At present, cochlear implant systems in Australia are fully funded by public hospital services or private health insurance. Private health coverage is also available for cochlear implants in the United States and in some European countries. In contrast, few provisions are made for funding of tactile devices world-wide (although a limited number of multichannel tactile devices are provided in Australia). Developers of tactile devices must, therefore, consider costs when making decisions on hardware or speech processing to be built into the tactile devices. If tactile devices can be kept relatively simple, resultant production and market costs should be much less than for cochlear implants, which may be an important factor in decisions of health programs regarding allocation of resources for the group of patients suitable for tactile devices.

In summary, given the more limited benefits to speech perception, the in-general lower level of cosmetic sophistication in the design and the necessity for extensive and intensive training, it is not surprising that tactile devices have not yet achieved a similar level of user acceptance as that for cochlear implants. It is evident from the results presented that the multichannel Tickle Talker can provide significant benefits to speech perception and speech production. However, potential candidates, who are primarily those severely or profoundly hearing-impaired adults and children who do not proceed with cochlear implantation for medical, audiological, financial, or other reasons, must still be convinced that the issues of cosmetic visibility, reliability, and ease of use have been successfully addressed. Potential communication benefits and cost factors must also be sufficiently positive to motivate them to participate in the long-term training necessary to successfully use the tactile device. The need to assess each patient's communication and to individually tailor the tactile information to their "hearing" needs is of paramount importance. Development programs for tactile devices must attempt to find better methods of tactually encoding speech information to enable both tactile-alone perception of speech and better supplementation of lipreading and aided residual hearing. These issues must be addressed if tactile devices are ever to achieve real significance in the treatment and management of severe and profound hearing impairment.

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