The Tickle Talker is a multiple channel electrotactile speech processor, developed for use by profoundly hearing-impaired adults and children. The device is intended to be used in combination with lipreading and aided residual hearing, to assist the greatest potential range of users. Sound detection and speech reception threshold levels for a group of 14 congenitally hearing-impaired children were shown to be lower when using the Tickle Talker than for hearing aids across the speech frequency range. Tactile-alone feature contrast testing with adults demonstrated that both segmental and suprasegmental speech feature information was available from the tactual display presented by the Tickle Talker. Clinical results from an ongoing program involving fourteen hearing-impaired children demonstrate benefits in speech perception achieved through use of the Tickle Talker. The children have a range of degree of hearing impairment and educational setting. Results show improvements in discrimination scores for vowel and consonant speech features, and increased scores for recognition of closed-set words and for open-set words and sentences. In addition, anecdotal evidence indicates changes in speech production which may be attributed to perceptual input from the device (both from perception of other speakers, and from voice self-monitoring). Results from a group of 4 adult patients show that tactile input may be effectively combined with either aided residual hearing, or aided residual hearing and lipreading to improve speech discrimination across a similar range of closed and open-set word and sentence tests and on speechtracking. The results indicate that some specific tailoring of the speech information provided through the device for the needs of users with differing degrees of hearing-impairment may be required to optimize potential benefits to speech discrimination.

Although the fingers are acknowledged to possess superior tactual sensitivity and a larger cerebral representational area than other body parts, commercially-available tactile devices have generally avoided the fingers because the design of tactile transducers employed would limit the normal functional role of the hands. In 1985, Blamey and Clark first reported development of the Tickle Talker, a wearable electrotactile device, which used the fingers as a stimulus site, without restricting normal everyday function of the hand.

The Tickle Talker consists of an ear-level or lapel microphone; a combined speech processor/stimulator unit; and an electrode handset combining eight stainless steel finger electrodes overlying the digital nerve bundles on the sides of the four fingers of the non-dominant hand (in earlier models, a common return electrode was located on the underside of the wrist). Stimulation of nerve bundles was one of the novel features of the device, giving larger dynamic ranges, a more pleasant quality of sensation than electrocutaneous stimulation of nerve endings at other body sites, and a well-ordered and easily-discriminated set of stimulus sites. In addition, the speech processor used similar hardware and software to that successfully employed in the University of Melbourne 22-channel cochlear implant manufactured by Cochlear Pty. Ltd.

In assessing any tactile or hearing device, it is important to evaluate the contribution to speech discrimination at a number of linguistic levels. The framework used in our evaluation of the Tickle Talker includes information available for sound/speech detection, feature-level discrimination of prosodic cues, word and sentence level discrimination, and ultimately connected discourse.

Sound/Speech Detection

Fourteen children who used the Tickle Talker as an everyday communication device were evaluated. All of the children were prelinguistically severely-to-profoundly hearing-impaired, and were in the age range of 6-14 years. All of the children were fitted with hearing aids, and attended a range of educational settings, including total communication, aural/oral with a cued-speech supplement, and aural/oral programs. Length of training with the Tickle Talker prior to the evaluations varied from three months to two and one-half years. A more detailed description of these results is presented in Cowan et al (1990).

Figure 1 shows mean “tactual” and “aided auditory” sound detection thresholds for short duration pure tones presented free-field (dB SPL), averaged for the fourteen children. The upper and lower dotted lines represent the limits of the average speech spectrum. As shown, tactual thresholds overall were at lower levels than for hearing aids,
Mean Sound Detection Thresholds (n=14)

![Graph showing mean sound detection thresholds for profoundly hearing-impaired children using hearing aids and Tickle Talker. Points show thresholds for short duration pure tones presented free-field (dB SPL).](image)

especially above 2000Hz, where the mean hearing aid response drops below the speech spectrum limits. Although low-frequency speech cues such as time/intensity and vowel length would be available through both hearing aids and the Tickle Talker, higher-frequency speech information such as vowel formant and consonant manner presented through the Tickle Talker would be especially important, since it would be inaudible through the children's hearing aids.

Mean Speech Detection Thresholds for Ling 5-Sound Test (n=14)

![Graph showing mean speech detection thresholds for the Ling 5-Sound Test for fourteen children using the Tickle Talker, measured free-field in dB SPL.](image)

Figure 2 shows tactual thresholds for live-voice presentation of the Ling 5-Sound Test. The results confirm that the children were capable of detecting speech sounds at normal conversational levels using only tactual information supplied through the Tickle Talker. Again, the high frequency consonant information provided through the tactual display of the Tickle Talker would be inaudible to the children through their hearing aids. Similar results have been found with hearing-impaired adults.

(i) Results with Adults

Figure 3 shows results for a group of eight adult subjects on a test battery assessing tactual perception of feature contrasts presented through the Tickle Talker. This test battery consisted of eleven subtests, each containing 24 two-alternative forced-choice feature contrasts, and one subtest of 24 three-alternative forced-choice contrasts (Plant 1989). The format of the tests was ABx (or ABCx), and a variety of speech contrasts was included in each test. Results for prosodic-level contrasts show efficient encoding of time/intensity information through the Tickle Talker, with all subjects able to perceive syllable number/stress and vowel length. This time/intensity information would be tactually encoded through changes in electrode position and stimulus strength. Scores for vowel formant contrasts suggest that the tactual cue of electrode position used to encode vowel formant frequency differences is also well perceived. Subtests 7-12 evaluate initial position consonant voicing and manner feature contrasts. Scores for initial consonant voicing were not as high as for the other consonant features. This is consistent with previous findings that pulse rate differences, which convey voicing information, were not well perceived by all subjects (Blamey and Clark 1987, 1990), and current research efforts are being directed towards alternative encoding strategies for providing voicing information. The consonant manner feature scores are variable across subtests, but suggest that amplitude envelope and spectral frequency cues to consonant manner are well perceived, possibly through electrode position and stimulus strength cues. Results for subtest number 12, which contrasted the unvoiced fricative /s/ and voiced /l/ and blend /sl/ show efficient encoding of high frequency consonant fricative information through the tactual display.
above chance. However, comparison of results indicates that the Tickle Talker, with 78% of subtest scores above chance, is providing feature information more accurately through its tactual display than the other devices. A more detailed analysis of performance of the devices in encoding the various feature contrasts showed that, as expected, the single and two-channel devices efficiently encode low-frequency time/intensity information, since their displays follow the time/amplitude speech waveform. However, only the Tickle Talker was shown to provide higher frequency spectral cues to second formant frequency (Cowan et al. 1989b). Performance on the consonant features varied across devices, however, and only the Tickle Talker and Tactaid II appear to encode information allowing high-frequency fricative contrasts to be accurately perceived.

(ii) Results with Children
Figure 5 shows performance of the fourteen children currently fitted with the device on speech feature discrimination subtests of the PLOTT test (Plant 1983). Five different pairs of feature contrasts were presented in a two-alternative forced-choice format. Each member of each pair is presented five times in random order, resulting in fifty-item scores for each feature tested. As shown, mean score on vowel length contrasts improved by 11% for the group of children tested ($p<0.025$, $t=2.93$, $df=5$). Although tactually-unaided scores were reasonably high, consistent with lower frequency cues to this contrast being available through the children’s hearing aids, improvements were shown for each of the children when tactual input was provided. Each of the children showed improved scores for vowel place (formant) discrimination with the addition of tactual information to information available from hearing aids. Mean improvement was 20% ($p<0.0005$, $t=5.14$, $df=10$). PLOTT scores for consonant manner feature contrasts show a similar pattern, with mean score improved by 25% ($p<0.0005$, $t=6.82$, $df=12$) with the added tactual input. Scores in the hearing-alone condition (A) showed a very wide range (40-92%) consistent with a variety of degree of hearing-impairment across the children, while scores in the combined TA condition ranged from 82-100%, demonstrating that the tactual display is providing accessible information to all the children.

(i) Results with Children
Results for the closed-set Word Intelligibility Picture by Picture Identification (WIP1, Ross and Lehrman 1971), the open-set Phonetically Balanced Kindergarten Words (PBK, Haskins 1949), and the open-set Bamford-Kowal-Bamford Sentences (BKB, Bench and Bamford 1979) are shown in Figure 5.

The WIP1, a picture/word test, consisted of 25 test words, each presented with five response foils. The version used had been standardized for Australian usage by Weeks, McCudden and Venard (1988). The children were tested with combined Tickle Talker plus hearing aids (TA) and hearing aids alone (A). Each of the children showed improved WIP1 scores in the TA condition as compared with hearing aids alone. Mean improvement for this group was 16% ($p<0.005$, $t=5.33$, $df=5$).

Open-set PBK words were used to evaluate speech discrimination on a more difficult task. Lists of 50 words were presented in both the Tickle Talker plus lipreading plus hearing aids (TLA) and lipreading plus hearing aids (LA) conditions. Each of the children showed improved scores in the TLA condition, with a mean increase of 18.3% ($p<0.005$, $t=4.496$, $df=6$).

Figure 5 also shows sentence-level discrimination results for open-set BKB sentences in both the combined tactually-aided TLA and tactually-unaided LA conditions. Increased scores were noted in the TLA condition for all children. Mean improvement for the group was 21% ($p<0.0005$, $t=8.73$, $df=6$), and all children scored 75% or better for this test when using the tactual input. These results indicate that children receiving sufficient training with the device are capable of integrating feature-level information, provided through the Tickle Talker, with information available from aided residual hearing and lipreading to improve word and sentence-level speech discrimination.

(ii) Results with Adults
Figure 6 shows results of evaluation of benefits to speech discrimination for hearing-impaired adults with different levels of residual hearing. Analysis of these results will help to clarify the range of patients who may potentially benefit from use of the Tickle Talker.

Patient 1 was an 82 year old profoundly hearing-impaired
male, totally deaf for 15 years from a step-wise progressive hearing loss due to otosclerosis. He was previously implanted with a Nucleus multichannel cochlear implant in 1982. However in early 1986, a CAT scan detected the presence of an acoustic neuroma on the implanted right side, which necessitated removal of the implant. Involvement of the facial nerve resulted in some residual visual problems, and the patient’s left ear was deemed unsuitable for cochlear implantation due to ossification of the cochlea and the patient’s age and general health. As shown, the Tickle Talker is now providing substantial benefits for this patient, both for feature-level discrimination of vowels and consonants, and for discrimination of words and sentences. Although the scores for words and sentences remain quite low, the patient himself says that without the Tickle Talker he is totally unaware of sounds or speech around him, and feels completely lost.

Patient 2 was a 31 year old male, profoundly hearing-impaired since age 4 due to meningitis. He did not wear hearing aids. Although Patient 2 met audiological/medical criteria for cochlear implantation, he elected not to proceed. Results for Patient 2 are shown following approximately 60 hours of training over a two-year period. As shown, substantial improvement was shown for vowels and consonants, AB words, BKB sentences and on speechtracking in the combined TLA condition, as compared with lipreading alone (L). Although Patient 2 was an adept lipreader, as shown by the L scores, integration of the tactual input allowed him to score 100% for vowel identification, 80% for consonants, and 90% for BKB sentences. In addition, he was able to improve his speechtracking rate by an average of 21 words-per-minute. Analysis of speechtracking measured over an 18-month period showed a significant increase in difference between TL and L speechtracking rates over time, indicating that speechtracking continues to improve with additional training and experience with the device.

Patient 3 was a 27 year old male, profoundly hearing-impaired since birth. He wore a single postauricular hearing aid on the left ear. The left ear could not be fitted due to tolerance problems. Assessment of open-set word discrimination with hearing aids alone showed scores of 30%, which did not meet selection criteria for cochlear implantation in use at that time. Figure 6 shows speech discrimination test results for JC, using the Tickle Talker in combination with hearing aids and lipreading (TLA) compared with the tactualy-unaided condition (LA). As shown, improvements were evident on all tests with the added tactual input, with the exception of vowel recognition, where tactualy-unaided scores reached 100%. This score would be expected given the levels of aided residual hearing. However, it is of note that although scores were high in the LA condition, with the combined tactual input, scores reached 100% for vowels, consonants, AB words, and BKB sentences, indicating that high frequency information was perceived through the Tickle Talker which was inaudible through hearing aids. Speechtracking rate also increased by 23 words-per-minute and, similarly to Patient 2, results of tracking rate measured over a period of 24 months showed continuing increases in tracking rate difference with additional training and experience.

Patient 4 was a 53 year old female, profoundly hearing impaired for 3 years as a result of head injuries. She wore a single postauricular hearing aid on the right ear. The right ear was deemed unsuitable for implantation due to the level of aided thresholds present. While no aided thresholds were obtained on the left ear, results of promontory stimulation were poor, and the patients general health was deemed a contraindication to surgery. As shown, increased scores were noted for Patient 4 on vowels, consonants, words, sentences and tracking. Improvements were somewhat smaller than for the other patients. However patient 4 had received only 40 hours of training prior to the evaluations.

The results clearly demonstrate that the Tickle Talker can effectively supplement information available though lipreading (Patients 1 and 2), or supplement information from lipreading and aided residual hearing when used effectively in a multimodal application (Patients 3 and 4). These benefits were available to patients not meeting medical/sociological criteria, and also to those whose levels of residual hearing were better than current audiological selection criteria. This latter group, who may not receive all the speech range through their hearing aids, would also not benefit from usage of single-channel tactile devices, since much of the time/intensity information presented would be redundant with information from their hearing aids.

(iii) Comparison with Implanted Children

The Tickle Talker has been designed to assist patients who cannot benefit from cochlear implantation due to medical criteria, and also to meet the needs of the group of adults and children who have better aided residual hearing than currently-accepted selection criteria for cochlear implantation. The former group requires a full range of prosodic and spectral speech information. The latter group already receive some speech information through hearing aids, but require additional input (generally high frequency) through the Tickle Talker. Since there is overlap between potential patient populations for the two devices, it is of interest to compare some results for sentence discrimination. Although the children compared have similar age ranges and educational settings, no systematic matching has been made. Therefore, conclusions must be limited, since children using the cochlear implant are employing a more complex F0F1F2 encoding strategy employing direct stimulation of the auditory nerve through 22 channels. Conversely, children using the Tickle Talker are employing a tactual input which does not normally
similar results have been achieved with either adults or children. The Tickle Talker results also fall in a much narrower band, which may be explained by the consistency of the tactual signal for all the children through their intact hearing. The higher "no device" scores shown for the Tickle Talker are for the Tickle Talker children, which is limited to a narrow band, which may be explained by the consistency of the tactual signal for all the children through their intact hearing. The Tickle Talker results also fall in a much narrower band, which may be explained by the consistency of the tactual signal for all the children through their intact hearing.

In summary, the Tickle Talker has been demonstrated to be cosmetically and functionally acceptable to both hearing-impaired children and adults as an everyday supplemental speech device. It can effectively provide additional information through the tactual modality to increase performance on sound and speech detection thresholds, speech feature discrimination, word and sentence discrimination and connected discourse. Benefits were available to patients using the device to supplement lipreading, or using it in combination with lipreading and aided residual hearing. Given the significant open-set implant-alone sentence discrimination scores achieved by postlinguistically deafened adults and children using the 22-channel, there remains a concern that otologists, audiologists and educators may conceive of the cochlear implant as obviating any necessity for further development or use of tactual devices. However, as demonstrated by the results, the potential patient population for multichannel tactile devices like the Tickle Talker, although overlapping with cochlear implants, includes many non-implantable groups.

This suggests a clear advantage for clinics involved in the rehabilitation of profoundly hearing-impaired adults or children to have access both to the multi-channel cochlear prosthesis and multichannel electrotactile speech processor.

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Formidable as are the symptoms of the acute form of inflammation of the drum, it is, in a healthy subject, and provided the inflammation does not extend to the bone or mastoid cells, and is early treated with modern care, scarcely dangerous to hearing: when once discharge takes place thro' the membrane, the irritation speedily abates, healing then rapidly sets in, and the hearing, if unimpaired before, is wholly restored in a few weeks or months. Not acute, but insidiously recurring, chronic affections of the mucous membrane of the tympanum destroy the hearing.

The treatment of these cases speaks for itself: free depletion by leeches (below the ear, or around the meatus, which should be closed by a small piece of sponge), or by the artificial leech, is universally recommended; the hottest fomentations, but not poultices — or if at all, for a very few hours — and warm water freely poured into the meatus; purgatives, and sedatives sufficient to give sleep; inflation of the tympanum daily by Politzer's bag, to give exit to the pent-up secretion, if it be possible, thro' the Eustachian tube. To these means I should add a mild nose douche, injecting a warm solution of borax or chlorate of potash, or common salt, thro' one nostril by a small glass syringe, and letting it escape by the other; thus fomenting the internal orifice of the Eustachian tube.

JAMES HINTON
1874

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