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Within-subject Comparison of Speech Perception Benefits for Congenitally Deaf Adolescents with an Electrotactile Speech Processor and a Cochlear Implant

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Abstract

This study assessed speech perception benefits for three congenitally deaf adolescents who used an electrotactile speech processor (Tickle Talker™) and subsequently went on to use a Nucleus Minisystem 22 cochlear implant. Both devices provided significant and comparable benefits for all children in the device plus lipreading condition. All children benefited from the additional information provided by either the Tickle Talker™ or the cochlear implant, and were able to perceive speech information with these devices that was not available through either aided residual hearing or lipreading. None of the three children were able to understand open-set words or sentences using either hearing aids alone or Tickle Talker™ alone, without the aid of lipreading. Two of the children showed significant open-set speech perception benefits while using their cochlear implant alone.

Key words: Cochlear implant, congenitally deaf adolescents, multiple-channel electrotactile speech processor (Tickle Talker™)

The development of multiple-channel cochlear implants and tactile devices has provided alternative means for improving the speech perception of profoundly hearing-impaired people who receive little benefit from conventional hearing aids. Recent studies have shown that the majority of profoundly hearing-impaired children using the Nucleus Minisystem 22 cochlear implant receive significant speech perception benefits from use of their device (Osberger et al, 1991; Dawson et al, 1992). The degree of benefit for individual children with cochlear implants has been shown to vary over a wide range (Osberger et al, 1991).

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Children who were hearing impaired from an early age, or who have had a longer duration of deafness prior to implantation demonstrate poorer performance on most speech perception tasks (Staller et al, 1991). More specifically, prelinguistically profoundly hearing-impaired children implanted at or after adolescence appear to have less potential for benefit with a multiple-channel implant than children implanted under the age of 10 years (Tong et al, 1988; Busby et al, 1991). Analysis of speech perception data from the Melbourne and Sydney cochlear implant clinics suggests that it is reasonable to expect that children implanted at an earlier age may develop an ability to perceive open-set speech through their implant alone without lipreading (Dowell et al, 1992; Cowan et al, 1993). However, to date, congenitally hearing-impaired children implanted during adolescence have not generally achieved open-set speech perception with their implant alone without lipreading (Dowell et al, 1991; Chute, 1993). These speech perception results for congenitally deaf adolescents suggest that a cochlear implant is of primary benefit to them as a supplement to lipreading (Dawson et al, 1992).

For adults or children unable to benefit from a cochlear implant for medical or other reasons, tactile devices are a noninvasive means of providing additional speech information (Pickett and McFarland, 1985; Cowan et al, 1992). When used in combination with aided residual hearing and lipreading, tactile devices have been shown to provide cues to speech features that can be used to improve speech perception on both closed- and open-set word and sentence tests (Brookes et al, 1986a, b; Weisenberger, 1989). Furthermore, these benefits have been established for a wide range of user groups, including postlinguistically and congenitally deaf adolescents, children, and adults. Given that benefits for most congenitally deaf adolescents with multiple-channel cochlear implants are more limited, tactile devices may provide a more viable alternative for prospective adolescent cochlear implant candidates than for younger children or adults.

To establish whether in fact a tactile device may be a more suitable choice than a cochlear implant for some groups of children, comparative performance of children with both devices should be studied. Problems exist in directly comparing speech perception results for different devices, due to the difficulties of obtaining matched groups (Geers and Moog, 1991). For this reason, a within-subject comparison may provide more reliable data, since each child acts as his/her own match with both devices. Within-subject comparisons are also affected by inherent differences in the information provided by two different devices designed to exploit very different sensory modalities. Direct comparison of the Nucleus Minisystem 22 cochlear implant and the Tickle Talker™ electrotactile speech processor has several distinct advantages. Whereas differences exist in the number and location of stimulating channels, and in the sensory modality employed, both devices are multiple channel and have similarities in speech processor hardware, speech processing schemes, and specific cues to speech features provided to the user (Blamey and Clark, 1987; Seligman, 1987). In addition, both the Tickle Talker™ and the Nucleus Minisystem 22 cochlear implant have been shown to provide benefits to speech perception for hearing-impaired adults and children (Cowan et al, 1990, 1992; Dowell et al, 1992). Comparative speech perception evaluations of these two devices using a within-subject design may provide insight into comparative communication benefits and a device of choice for congenitally deaf adolescents.

Aim

The aim of the present study was to assess comparative speech perception benefits for three adolescents who used both a multiple-channel electrotactile device (Tickle Talker™) and the Nucleus Minisystem 22 cochlear implant.

METHOD

Patients

Each patient is referred to by number in order of operation date at the Royal Victorian Eye and Ear Hospital Cochlear Implant Clinic.

Patient 114

Patient 114 had a congenital profound bilateral sensorineural hearing loss of unknown etiology. She was fitted with hearing aids from 18 months of age and wore them consistently from that time. She had bilateral aided thresholds (50–60 dB SPL) within the 70 dB SPL speech range (Byrne, 1977) from 250 to 1000 Hz. Patient 114 was enrolled in a total communication program from ages 3 to 11, and subsequently attended an oral school. She communicated both orally and with Australasian sign language and was intelligible to listeners experienced in understanding deaf speech.

At 12 years, 10 months, she was fitted with the Tickle Talker,™ which she wore until she received a cochlear implant. She received the Nucleus Minisystem 22 cochlear implant in her right ear at age 13 years, 8 months, and had 12 months postoperative experience with the implant at evaluation. Patient 114 had 22 functional channels in her implant system.

Patient 144

Patient 144 had a congenital profound bilateral sensorineural hearing loss due to maternal rubella. She was fitted with hearing aids from 16 months of age and wore them consistently from that age. She had bilateral aided thresholds (50–55 dB SPL) within the 70 dB SPL speech range from 250 to 1500 Hz. Patient 144 attended oral communication educational settings from age 2. She communicated orally and was intelligible to listeners experienced in understanding deaf speech. At age 8, she was fitted with a Tickle Talker,™ which she wore until age 12. At age 12, patient 144 received the Nucleus Minisystem 22 cochlear implant in her left ear, and had 12 months postoperative experience at the time of evaluation. She had 18 functional channels in her implant system.

Patient 165

Patient 165 had a congenital profound bilateral sensorineural hearing loss of genetic etiology. She was fitted with hearing aids from 20 months of age and wore them consistently from that age. At age 5, her hearing deteriorated further to a total loss. Patient 165 attended oral communication settings from age 2. She communicated orally but was often unintelligible to listeners experienced in understanding deaf speech. At age 8 years, 5 months, she was fitted with a Tickle Talker,™ which she wore until she received a cochlear implant. At age 13 years, 6 months, patient 165 received a Nucleus Minisystem 22 cochlear implant in her right ear, and had 12 months postoperative experience at the time of evaluation. She had 22 functional channels in her implant system.

Devices

Nucleus Minisystem 22 Cochlear Implant

The multiple-channel cochlear implant system used in this study was the 22-channel cochlear implant developed by Cochlear Pty. Ltd. and the University of Melbourne (Clark et al, 1990). All patients used the Multipeak speech processing strategy, summarized in Table 1 (Dowell et al, 1991).

Electrotactile Speech Processor (Tickle Talker™)

The multiple-channel tactile device used in this study was the Tickle Talker,™ an electrotactile speech processor that stimulates the digital nerve bundles in the fingers. The original device has been described in detail by Blamey and Clark (1987), and more recent hardware developments are reported by Cowan et al (1992). The Tickle Talker™ consists of an electrode handset worn on the fingers of the nondominant hand and an integrated speech processor/stimulator. The speech processing hardware and strategy was adapted from that originally used in the multiple-channel cochlear implant, and is shown in Table 1.

Assessment Materials and Conditions

Open-set word discrimination was assessed using phonetically balanced kindergarten (PBK) word lists (Haskins, 1949). Half-lists of 25 words were presented in each condition. Use of lists was balanced across evaluation conditions and children. PBK phoneme scores, and not word scores, are presented to more reliably reflect the amount of phonemic information perceived. Patients were tested with one list in each condition.

Open-set sentence discrimination was assessed using Bamford-Kowal-Bench (BKB)

Table 1 Comparison of Speech Encoding Strategies for the Tickle Talker™ and the Minisystem 22 Cochlear Implant

Device	*Speech Parameter*	*Electrical Parameter*	*Patient Perception*
Cochlear Implant*			
	Second formant frequency (F_2)	Electrode number (range 1–17)	Place pitch
	First formant frequency (F_1)	Electrode number (range 17–22)	Place pitch
	Fundamental frequency (F_0)	Pulse rate	Rate pitch
	Amplitude	Charge per pulse	Loudness
	Amplitude of high-frequency bands (three bands)	Charge per pulse on three fixed electrodes	Loudness of three high-pitched components
Tickle Talker™†			
	Second formant frequency (F_2)	Electrode number (range 1–7)	Stimulated electrode position
	Fundamental frequency (F_0)	Pulse rate	Rough/smooth quality
	Amplitude	Pulse width	Stimulus strength
	High-frequency energy (> 4 kHz)	Pulse width (electrode #8)	Presence/absence and strength (electrode #8)

*Multipeak strategy; †second generation strategy, not including voiced/voiceless contrast.

sentences (Bench et al, 1979). This test consisted of lists of 16 simple sentences that contained 50 key words. Use of lists was balanced across evaluation conditions and children. Patients were tested with one list in each condition. Each sentence list was scored by the number of key words correct.

Test materials were presented live-voice, by a familiar female speaker, at a distance of 1 meter, and at an intensity of 70 dBA as measured on a Quest 815 sound level meter. Patients wrote their responses for both tests, and feedback on performance was not provided throughout test procedures. With the exception of patient 114, who was tested after only 10 months experience with the Tickle Talker,™ patients were tested after at least 12 months experience with the Tickle Talker,™ and after exactly 12 months experience with the cochlear implant. Speech perception scores in different conditions were analyzed using the binomial model and significance table developed by Thornton and Raffin (1978).

To simplify presentation of the data, results for the period of time during which the Tickle Talker™ was used are noted as preoperative, and those with the cochlear implant as postoperative. Testing was conducted in a number of conditions including:

1. hearing aid/s alone (A), pre- and postoperatively;
2. lipreading plus hearing aid/s (LA), pre- and postoperatively;
3. lipreading alone (L), pre- and postoperatively;
4. Tickle Talker™ plus lipreading plus hearing aids (TLA), preoperatively only;
5. cochlear implant plus lipreading (CL), postoperatively only; and
6. cochlear implant alone (C), postoperatively only.

For testing in conditions using hearing aids (i.e., TLA, LA, and A), all measurements were conducted with binaural hearing aids preoperatively, and with monaural hearing aids postoperatively (i.e., nonimplanted ear).

Due to the range in aided residual hearing thresholds for the three patients, some further explanation of test conditions is necessary. Although patient 114 usually wore a hearing aid in her nonimplanted ear, results for the CL condition only are presented, as minimal differences in speech perception scores were observed between the CL and cochlear implant plus lipreading plus hearing aid (CLA) conditions on all tests, and this simplified comparison with the results of the other patients. Patient 114 also maintained that she could not discriminate any speech with her hearing aid(s) alone, and refused to cooperate with any testing in the A condition either pre- or postoperatively. Patient 144, after 4 months of cochlear implant use, decided to discontinue using her hearing aid, and was therefore tested in CL and C conditions. Due to the fact that patient 165 had a total hearing loss, testing in the A, LA, or TLA conditions was not possible. Results reported for the TLA condition for this subject are in fact Tickle Talker™ plus lipreading (TL) results.

Habilitation

Patients attended twice-weekly individual habilitation sessions of 45 minutes duration. These were conducted at the children's school by the same female audiologist throughout the study, and were in addition to any auditory habilitation provided as part of the patients' school programs. The habilitation program used consisted of a hierarchical series of speech perception tasks that were built upon as patients' proficiency with their respective devices increased (Galvin et al, 1993).

During the Tickle Talker™ program, habilitation was conducted in the A, LA, and TLA conditions. After cochlear implantation, habilitation was conducted in the CL and C conditions. As mentioned previously, patient 144 decided to discontinue wearing her hearing aid, and was trained and tested in C and CL modes. Patient 165 received habilitation in the L, TL, C, and CL conditions.

RESULTS

Table 2 shows speech perception tests results for the three patients.

Cochlear Implant Benefits

All three patients showed high scores in the CL condition on both PBKs and BKBs. Two of the three patients also showed significant implant-alone scores on both materials.

For patient 114, CL scores were greater than either LA or L postoperative scores by 25 percent and 28 percent on PBKs and by 18 percent and 52 percent on BKBs. Statistical analysis showed that scores in the CL condition were significantly greater ($p < .05$) than L or LA scores on both tests. Patient 114 also showed

Table 2 Summary of Results for Open-set Word and Sentence Tests for Patients 114, 144, and 165

*Condition**	*Scores (%)*					
	Patient 114		*Patient 144*		*Patient 165*	
	Preop	*Postop*	*Preop*	*Postop*	*Preop*	*Postop*
PBK Phonemes						
A	NA	NA	22	3	NA	NA
L	65	58	42	54	58	81
LA	61	61	81	55	NA	NA
TLA	56	—	91	—	77†	—
CL	—	86	—	91	—	75
C	—	45	—	40	—	12
BKB Sentences						
A	NA	NA	6	4	NA	NA
L	60	44	46	50	48	76
LA	68	78	74	60	NA	NA
TLA	86	—	74	—	76	—
CL	—	96	—	78	—	94
C	—	34	—	48	—	2

*Phoneme scores for PBK words and word scores for BKB sentences are in percentage correct. (A and LA measures are binaural preoperatively and monaural postoperatively).
†Results listed in TLA condition for patient 165 are actually TL results, as patient 165 had a total hearing loss.
NA = not applicable.

open-set cochlear implant alone scores on both tests.

Scores in the CL condition for patient 144 were higher than postoperative LA scores by 18 percent on BKBs and by 36 percent on PBKs. Statistical analysis showed that CL scores were significantly higher than L scores on both tests. CL scores were significantly higher ($p < .05$) than postoperative LA scores on the PBK word test, but not on the BKB sentence test. In the C condition, patient 144 scored 40 percent on PBKs and 48 percent on BKBs.

Scores in the CL condition for patient 165 were higher than the postoperative L score by 18 percent on BKBs only. Statistical analysis showed that the CL score was significantly higher ($p < .05$) than the L score on BKBs, but not on PBKs. In the C condition, scores for patient 165 were lower than for the other patients: 12 percent on PBKs and 2 percent on BKBs.

Tactile Benefits

Supplementary benefits are also evident in the TLA versus LA or L results for all three patients.

The TLA score for patient 114 was greater than either preoperative LA or L scores by 18 percent and 26 percent on BKBs. However, the TLA score was lower than both LA and L scores on PBKs. Statistical analysis showed that the TLA score was significantly higher ($p < .05$) than preoperative LA and L scores on BKBs.

The TLA score on PBKs for patient 144 was greater than preoperative LA and L scores by 10 percent and 49 percent, respectively. On BKBs, TLA and LA scores were equal (74%), and the TLA score was higher than the L score by 28 percent. Statistical analysis showed TLA scores were significantly higher ($p < .05$) than preoperative L scores on both tests. However, analysis of TLA versus preoperative LA scores showed no significant supplemental benefit for either test.

For patient 165, TL scores on PBKs and BKBs were higher than the preoperative L scores by 19 percent and 28 percent, respectively. Statistical analysis showed TL scores were significantly higher than preoperative L scores on both tests.

Hearing Aid Benefits

Comparison of LA and L scores either pre- or postoperatively allows some assessment of hearing aid benefits to speechreading.

For patient 114, in either the pre- or postoperative period, LA scores were not significantly higher than L scores, with the exception of LA versus L postoperative scores on BKBs. Benefits in the A condition could not be assessed.

Comparison of LA with L scores for patient 144 showed LA scores to be significantly higher ($p < .05$) for BKBs and PBKs in the preoperative period only.

Patient 165 had a total hearing loss; therefore, it was not possible to assess the effects of hearing aids alone or as a supplement to lipreading.

Comparative Benefits

Figure 1 shows a graphic comparison of TLA and CL scores for the three patients.

Scores for patient 114 in the CL condition were greater than in the TLA condition on both BKBs and PBKs. Statistical analysis showed CL scores were significantly higher ($p < .05$) than TLA scores on PBKs, but not on BKBs. C versus A scores could not be assessed for this patient.

Scores for patient 144 in the CL condition were not significantly greater than TLA scores on either BKBs or PBKs. Scores in the C condition

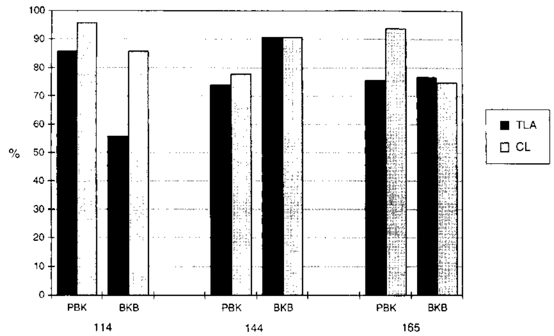

Figure 1 PBK phoneme and BKB word scores for three patients in the TLA (Tickle Talker™ plus lipreading plus audition) and CL (cochlear implant plus lipreading) conditions.

were significantly greater ($p < .05$) than A scores on both tests.

CL scores on BKBs for patient 165 were significantly ($p < .05$) greater than TL scores, but not on PBKs. C versus A scores for this patient could not be assessed.

DISCUSSION

All of the children in this study received significant supplementation to lipreading and aided residual hearing from use of information provided by either the Tickle Talker™ or the cochlear implant. Results showed that both devices provided significantly more information than was available through hearing aids, and test scores were high overall in multimodal conditions. The finding that two children in this study achieved some open-set speech perception without lipreading with the cochlear implant is of note, as speech perception benefits achieved to date by congenitally deaf adolescents have not extended to open-set comprehension of words and sentences using the implant alone (Dawson et al, 1992; Chute, 1993). However, both of these patients had some aided residual hearing prior to implantation and communicated orally, and these factors have been shown to be correlated with increased benefits from cochlear implants in children (Eisenberg et al, 1983; Somers, 1991; Staller et al, 1991). The possibility that preimplant use of the Tickle Talker™ contributed in some manner to the open-set implant-alone speech perception results cannot be excluded, but this was not directly assessed.

Comparison of scores on open-set word and sentence tests in the TLA condition for all children showed that, overall, the children were receiving significant supplementation to their lipreading and aided residual hearing from the tactile device. It was not possible to formally assess speech perception with the Tickle Talker™ alone, as none of the children felt confident enough to attempt the evaluation in this condition.

Although LA scores were with only one exception higher than L scores for patients 114 and 144, these differences were significant only for patient 144 before she was implanted, and postoperatively for patient 114 on BKBs. This suggests that the level of supplementary benefit gained from aided residual hearing was minimal. The changes in benefits from residual hearing postoperatively could be due simply to the change from binaural hearing aids to cochlear implant plus monaural hearing aid postoperatively. The children may also have been relying less on their hearing aid postoperatively, although this was not strictly assessed. Previous experience with cochlear implant patients using a hearing aid in the nonimplanted ear has noted a mismatch between the outputs of each device, and, in many cases, patients have discontinued use of their hearing aid, as did patient 144 in this study.

These results suggest that the Nucleus Minisystem 22 cochlear implant and the Tickle Talker™ offer comparable speech perception benefits for congenitally deaf adolescents in terms of supplementation of lipreading. Both devices offered significantly more benefit than was evident for hearing aids. However, open-set speech perception was achieved by two children in the device-alone condition only with the cochlear implant. While this confirms that the cochlear implant was providing more accessible speech information to the children, it also raises the question of why none of the children in the study were confident enough to attempt the tests using the Tickle Talker™ alone. Users of tactile devices have not achieved similar open-set speech perception benefits to cochlear implant users (Brooks et al, 1985; Skinner et al, 1988). There are many potential contributing factors that might explain the difference in scores; however, the effects of any one factor are difficult to isolate. Differences in the number of channels through which information is presented by the two devices may have been a contributing factor. The Tickle Talker,™ with 14 fewer channels through which to present information, cannot present the fine spectral discriminations of speech information that the cochlear implant can provide. In particular, it does not specifically encode the F_1 formant frequency and amplitude as does the cochlear implant.

In addition, two of the children had long-term experience using their aided residual hearing from an early age, whereas they had only a relatively short duration of experience using their tactile sense to perceive speech. Although this auditory experience occurred through a damaged auditory system, and neither child achieved significant open-set speech perception with hearing aids alone, this may have led to the establishment of patterning in their auditory pathway, providing a link between auditory sensations and speech comprehension. This established pathway could then have facilitated speech perception with the cochlear implant. Support for this theory is found in the relatively intelligible speech of the children, which suggests that auditory information has been accessed and used through residual hearing. Given that all three children had no tactile speech perception experience prior to this study, it would seem unlikely that any such patterning or link existed for tactile input. It may simply be the case that achievement of open-set speech perception through use of a tactile device requires many years of training, during which this link is established. The literature on the Tadoma method of communication supports the notion that tactile-alone perception can be achieved after very extensive periods of training (Norton et al, 1977). Alternatively, achievement of open-set speech perception with a tactile device may result from an interaction between the speech information provided by the tactile device and the user's experience in integrating this information for communication. Given the more limited speech information provided by tactile devices as compared to multiple-channel cochlear implants, similar levels of open-set speech perception may not be attained even after extensive training. Whether open-set speech perception is possible through tactile devices remains a question for further study.

The results of this study show that the Tickle Talker™ and the Nucleus cochlear implant can offer comparable benefit in terms of supplementation to lipreading for congenitally deaf adolescents. In addition, two of the adolescents achieved significant open-set speech perception using the nucleus cochlear implant, despite the poor prognosis the literature would suggest for this patient group. As this was not achieved with the Tickle Talker,™ it would seem that the cochlear implant would be the preferred option for these patients. The Tickle Talker™ may also be of use in cochlear implant preoperative programs for evaluating the capabilities of potential implantees for processing speech information presented through a different sensory modality as well as motivation. Interestingly, for the patients in this study, successful use of the Tickle Talker™ was an influencing factor in the patients' decision to proceed with cochlear implantation. It is important to note, however, that the tactile results of this study cannot necessarily be generalized to performance with other multichannel tactile aids.

CONCLUSIONS

The following conclusions can be made from this study: (1) both the Nucleus Minisystem 22 cochlear implant and the Tickle Talker™ can provide a significant level of supplementary benefit to aided residual hearing and lipreading for congenitally deaf adolescents; (2) the level of supplementary benefit provided by both devices in this study was similar for these particular patients, and was significantly greater than that provided by hearing aids; (3) open-set device-alone speech perception was achieved by two of the three subjects with cochlear implants; and (4) there may be a role for tactile devices in programmes for congenitally deaf adolescents in preoperative assessment, or for patients unable to proceed with cochlear implantation.

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