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Vibrotactile Stimulation: Case Study with a Profoundly Deaf Child[a]

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Abstract — This case study reports results obtained from a young, profoundly deaf child, M, who was fitted with a single-channel vibrotactile device, the Tactaid I, at 29 months of age. Her progress in speech and language development was evaluated over a 14-month period. During this period, M learned to understand 101 words through lipreading and the Tactaid I, and to produce consistent approximations of 90 words. Her scores on language tests with hearing-impaired norms progressed from below average to above average for her age. M's scores on language tests with hearing norms also reflected significant progress, although she did not achieve normal language development. These results indicate that a single-channel vibrotactile aid may facilitate the acquisition of spoken language in a profoundly deaf child who is unable to benefit from a conventional hearing aid.

INTRODUCTION

The air conduction audiograms of some profoundly deaf children reflect threshold levels that indicate response to vibrotactile stimuli; this was reported by Nober in 1967 (1). It has been argued that these children do not actually "hear" at all; rather, they are said to perceive amplified speech from hearing aids via vibrotactile receptors in their ears: see Boothroyd and Cawkwell, 1970 (2). This suggests that devices designed to convert changing sound-energy levels into changing levels of tactile stimulation may provide advantages over conventional hearing aids for profoundly deaf children. Indeed, for many years, hand-held bone conduction vibrators have been used in "auditory training" of such children to provide a stronger, more salient speech signal than can be delivered to their ears through a hearing aid: see Guberina, 1972 (3). Teachers have used these vibrators especially in beginning stages of speech training with children. The vibrator produces cues of duration and rhythm of speech sounds, cues which are useful in both the perception and production of speech: see Erber, 1982 (4). Although research studies indicate that a single channel of vibratory information alone is inadequate for conveying meaningful speech, it can provide a useful supplement to lipreading: Erber, 1978 (5). Such a device should not be thought of as a sensory substitute, but rather as a sensory aid to enhance lipreading and to help monitor voice production, as suggested by DeFilippo in 1979 (6).

Description of Device

Recently, a device became commercially available which delivers a single channel of vibrotactile information in a wearable package that is suitable for a very young child. This device, the Tactaid I,

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consists of a body-worn electronics package, weighing about 7 ounces, and a Radioear B-72 bone vibrator held on the sternum by an elastic harness (A block diagram of the Tactaid I is presented in Figure 1). The signal from the microphone increases in amplitude with increasing frequency up to about 4000 Hz. The sensitivity of the Tactaid I can be adjusted by the user. However, the internal gain of the amplifier is automatically adjusted relative to ambient noise. This is accomplished by passing the signal through an automatic gain control stage which brings acoustic inputs at sound pressure levels of 35-to-90 dB within the operating range of the vibrotactile stimulator. Then this circuitry effectively attenuates continuous ambient noise so that the desired signal will be more salient. After such processing of the input signal, the resulting envelope is detected and, if it is above a threshold value, it modulates a 250-Hz sinusoidal signal that drives the vibrator.

An earlier prototype, similar to the Tactaid I, was evaluated by Proctor and Goldstein in 1983 (7). The aid was worn by a 33-month-old profoundly-deaf child, T. Over a 10-month training period using traditional aural/oral techniques, T's receptive vocabulary increased dramatically. Her receptive vocabulary doubled in size each month during the last 6 months of the period and her developmental pattern of vocabulary acquisition was very similar to that of normal hearing children, in both rate of growth and in stages of lexical comprehension. Since such growth in comprehension of spoken language is unusual for a profoundly deaf child, the results suggest that use of the Tactaid may facilitate language acquisition in deaf children. Of course, it would be dangerous to base such a conclusion on the findings of one case. Futhermore, such dramatic effects from a single-channel vibrotactile aid seem unwarranted, considering (for example) an estimated gain of only 10 percent provided by adding a single vibratory channel to lipreading alone, as reported by Erber in 1978 (5).

The present study was designed to evaluate the effectiveness of the Tactaid I for another young profoundly deaf child similar to T in age and hearing loss, and to compare the language development of this child with that reported for T and other deaf children.

METHODS AND MATERIALS

Subject

The child selected for evaluation of the aid was a profoundly deaf two-year-old (M) enrolled in the Parent-Infant Program at Central Institute for the Deaf. The cause of her hearing loss is unknown, although it is known that she experienced anoxia at birth and exhibited some early balance problems.

M's audiologic results are presented in Figure 2. It can be seen that she does not respond to pure tones under earphones, even with an audiometer that provides a 20-dB boost to the maximum signal level. With her hearing aid she responds in a sound field to noise bands centered at 125 Hz and 250 Hz—but to no other frequencies. The subject does, however, respond throughout the frequency range to signals presented through the Tactaid at about 65 dB hearing level (HL). Because all input frequencies are converted to a 250-Hz vibrotactile stimulus, the variation in response level across frequencies plotted in Figure 2 is merely the result of test variability.

M responds to speech through her hearing aid at 91 dB HL and to speech through the Tactaid at 65 dB HL. The CID Preschool Performance Scale, of Geers and Lane, 1984 (8), a test of nonverbal intelligence designed to estimate learning potential in deaf children, was administered when M was 36 months old. She scored within the average range with an IQ score of 109.

Subject's Progress Before the Tactaid

M was 24 months old when she was enrolled in the CID Parent-Infant Program. Her profound hearing loss had just been diagnosed and she had been fitted with an Oticon P11P conventional body hearing aid. The subject and her mother attended 50-minute individual sessions with a teacher/counselor each week and the subject was enrolled in a nursery class of five 2-year-old deaf children which met 2 mornings per week for 2 hours each morning. The class provided language stimulation in the context of nursery-school-type activities, and a teacher also worked individually with M for 20 minutes each class period. These individual sessions focused on developing listening and lipreading skills, and some beginning speech skills.

Within a few months, most of the children in the class had developed the habit of vocalizing when they wanted something and demonstrated the ability to detect speech through their hearing aids. Some could differentiate words through listening and seemed to understand the give-and-take of conver-

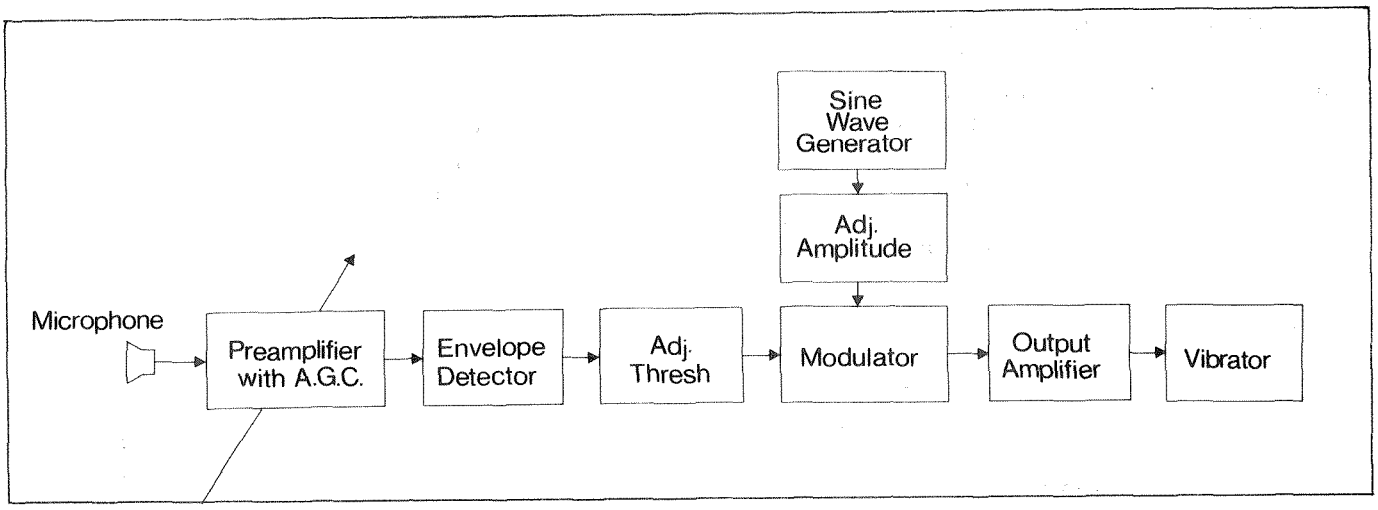


FIGURE 1
Block diagram of the Tactaid I. The body-worn electronics package weighs about 7 ounces: the final stage is a Radioear B-72 bone vibrator held to the sternum by an elastic harness.

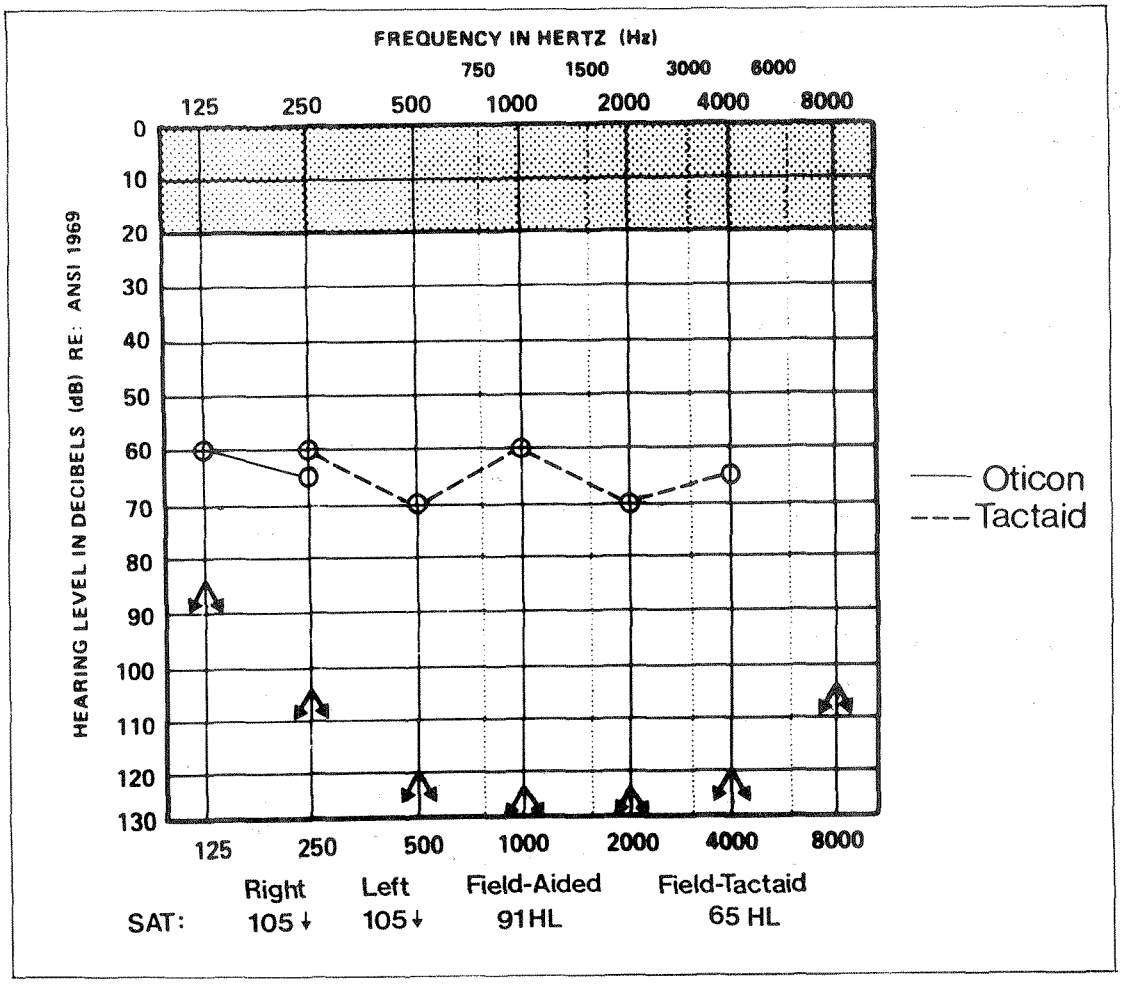


FIGURE 2
Subject M's audiologic results: unaided, with conventional amplification, and with the Tactaid I. (Note: because all input frequencies presented through the Tactaid are converted to a 250-Hz vibrotactile stimulus, the variation in response level across frequencies plotted in Figure 2 is merely the result of test variability.)

sation. M, on the other hand, exhibited more than the usual amount of difficulty producing and understanding speech. She learned to comprehend only 2 words during the first 5 months of the class and did not learn to produce any words. She did not vocalize very much during play situations, and when she attempted to vocalize in imitation of a modeled word, syllable, or vowel sound, her voice quality was strained and guttural. She did not respond at all to attempts at developing listening skills, nor did she demonstrate awareness of speech in either structured lessons or in natural situations.

The Subject's Progress With the Tactaid I

M began wearing the Tactaid I in addition to her conventional body aid when she was 29 months of age. Initially, she wore the Tactaid only during her individual sessions in the nursery class. Within a week after receiving the device, M began producing "mama" with a fairly good voice quality, and an approximation of "oo", as in "cookie." However, she did not automatically associate the vibrotactile sensation with voicing or speech; she needed some training to make the appropriate association between voicing and the vibration of the Tactaid.

Approximately 2 months after receiving the Tactaid, the subject began wearing it at home as well as at school. Her mother reported that M's spontaneous vocalizations increased dramatically shortly thereafter; a greater variety of vocalizations were also observed at school. By the end of her year in the Parent-Infant Program, after wearing the Tactaid for 6 months, M was able to use 11 words expressively and understood 16 words. Her approximations of the 11 expressive words matched the intended word in duration and one phoneme, usually the vowel and/or the initial consonant. M's teacher noted that the Tactaid now served as a useful cue to get her to use her voice. The teacher commented: "If she mouthed one of her expressive vocabulary words without voice, I simply drew her attention to her vibrator and she would use voice on her second imitation attempt."

When M was a 3-year-old, she was enrolled in a full-day program in the School of Central Institute for the Deaf, starting in the fall. Her program there was highly individualized with about 50 percent of each day devoted to individual or small group instruction in speech and language. During the other half of the day, she was involved in typical nursery-school-type activities that provided opportunities to use her newly acquired speech and language skills to communicate in a conversational setting. With this daily instruction in both structured and natural situations, M's vocabulary continued to grow. By the end of the first few weeks in school, her receptive vocabulary had increased to 25 words and she was able to produce 20 words on her own. This rate of growth continued into October as her receptive vocabulary increased to 53 words and her expressive vocabulary to 49 words. When school closed for Christmas recess, the subject had a receptive vocabulary of 60 words and an expressive vocabulary of 56 words. By that time, M had learned to produce one syllable for one-syllable words and two syllables for two-syllable words. Initially, her vowels were often elongated and her voice quality was often strained, but as the year progressed her production began to approximate more closely the intended words, and less practice was needed to learn new words.

When M was 3 years, 5 months old (and had been in school 5 months) she understood 101 words and could produce consistent approximations of 90 of these words. Her vocabulary consisted primarily of 66 nouns and 23 verbs, but it also included 9 adjectives and 3 prepositions. Although she communicated primarily in single words, she began occasionally to combine two words into sentence-like utterances, as in "Mommy bye-bye" for Mommy went bye-bye or "Baby home" for The baby is at home.

By the spring (age 3 years, 8 months) the subject's vocabulary was expanding at a steadily increasing rate, with 150 words demonstrated both receptively and expressively in the classroom. At this point she was beginning to learn new words in conversational settings outside the classroom as well as in structured vocabulary lessons. She was able to understand and produce a variety of 2-word combinations, primarily in teaching situations.

TEST RESULTS

Six tests of language development were administered to evaluate the subject's progress. Two of the tests were designed for hearing impaired children and permitted comparison of M's performance with other deaf children her age. The other four tests were standardized on normal hearing children and were also administered to T, the child described in the Proctor & Goldstein 1983 report (7). Therefore, M's results could be compared to both of these standards.

Comparison with Hearing Impaired Norms

The Scales of Early Communication Skills (SECS) of Moog & Geers, 1975 (9) is a rating form which was completed by M's teacher before M received

the Tactaid (pretest age = 2 years, 3 months) and again after the subject had worn the Tactaid for 14 months (post-test age = 3 years, 7 months). Percentile ranks were determined in relation to other hearing impaired children her age; 2-0 to 2-11 at pretest and 3-0 to 3-11 at post-test. At pretest M's communication skills were behind those of other deaf 2-year-olds. Her receptive skills were rated at the 28th percentile and her expressive skills at the 32nd percentile. By post-test, M scored somewhat above other deaf 3-year-olds; at the 63rd percentile for receptive and at the 74th percentile for expressive skills.

The Grammatical Analysis of Elicited Language — Pre-sentence Level, GAEL-P of Moog, Kozak, and Geers, 1983 (10), is a structured test of language readiness skills, single word knowledge, and ability to use and understand 2-word and 3-word phrases. Since the GAEL-P is standardized on hearing impaired 3- to 5-year-olds, the norms could not be meaningfully applied to M's performance at age 2 when she first received the Tactaid. However, her performance over time can be compared on the basis of percent correct on each scale. The subject's results obtained at 3 administrations of the GAEL-P are presented in Table 1.

M's percentile ranks at the age of 3 years, 8 months were 65 for comprehension, 50 for production, and 35 for imitation in relation to other hearing-impaired 3½-to-4-year-olds. Thus, according the GAEL-P norms, she understood and produced spoken language at the level expected of a deaf child her age, but was still behind her peers in her ability to imitate words and phrases.

TABLE 1
Subject M's performance over time, in percent correct, at three chronologic ages for each of the three scales of the Gramatical Analysis of Elicited Language — Pre-sentence Level (10). The subject's percentile ranks at the age of 3 years, 8 months, in relation to other hearing-impaired 3¼-4-year-olds, were 65th for comprehension and 50th for production, but only 35th percentile for imitation.

	Percent correct — GAEL-P		
Scale	CA = 2-3	CA = 3-0	CA = 3-8
Comprehension	5	47	76
Production	3	32	56
Imitation	3	61	76

TABLE 2
Three tests administered when Subject M was 43 months old (and T was 41-42 months) suggest her level of development in relation to normal hearing children. Subject M had been wearing the Tactaid I for 14 months and T had been wearing hers for about 8 months.

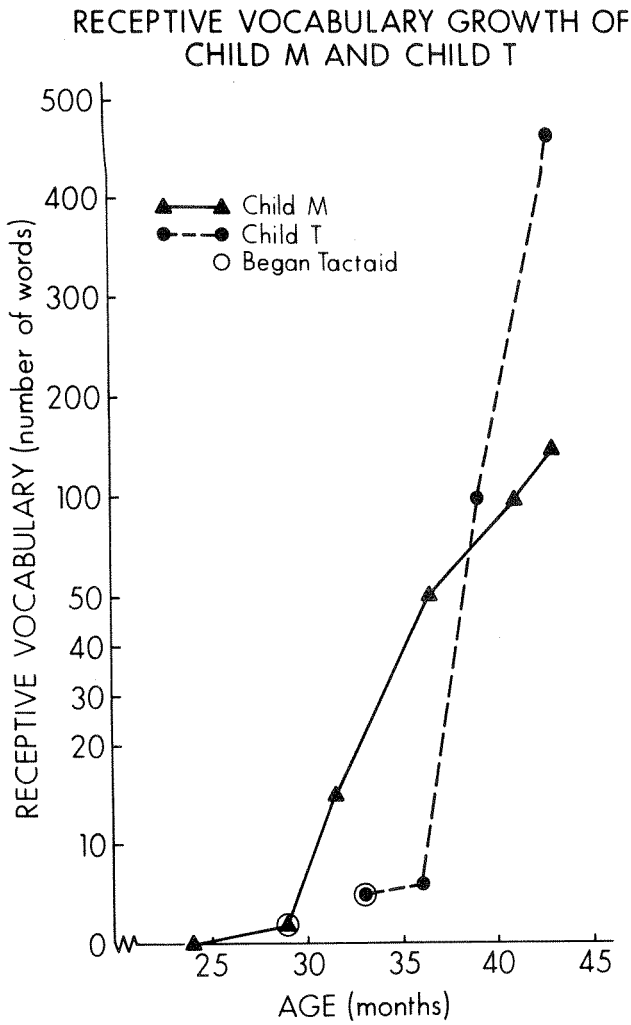
		Age Score (mos)	
Test	Scale	Subject M	Subject T
Peabody Picture Vocabulary Test (Dunn, 1965) (12)	Form B	25	30
Preschool Language Scale (Zimmerman, et al., 1979) (13)	Comprehension	20	38
	Verbal Ability	12	28
	Language	16	33
Preschool Attainment Record (Doll, 1966) (14)		42	51

Comparison with Normal Hearing Norms

The Receptive Expressive Emergent Language Scale (REEL) of Bozoch & League, published in 1970 (11), is a rating form that lists language milestones in the order in which they are observed to develop in normal hearing children between birth and 3 years of age. The subject's language skills were rated by a speech-language pathologist at four ages: 2-3, 2-10, 3-2, and 3-7. Age scores for the receptive and expressive scales are plotted in Figure 3 in relation to the normal rate of acquisition and that observed for the earlier subject. M gained 14 months in receptive language age, and 15 months in expressive language age, over a 16-month period. Although her overall language level at 3½ years was still not up to the level of the normal hearing 2-year-old, her development was proceeding at a near-normal rate. It had not, however, approached the rate of T, who progressed at more than twice the normal rate (20-month gain in language age over an 8-month period).

The other three tests (12, 13, 14) were administered at post-test only, when M was 43 months of age. Her age scores on these tests (Table 2) provide an indication of her level of development in relation to normal hearing children. At that time M had been wearing the Tactaid for 14 months. Scores are also provided for T at about the same age (41-42 months) after wearing the Tactaid for about 8 months (Table 2).

It is apparent from these results, as well as from REEL scores, that M was considerably slower than T in acquiring language. M's scores ranged from 5 to 18 months behind T's, even though M had worn the Tactaid for 6 months longer than T. This difference is also reflected in their rates of acquisition of receptive vocabulary, depicted in Figure 4. In that figure, receptive vocabulary size is plotted against chronological age. The earlier introduction of the



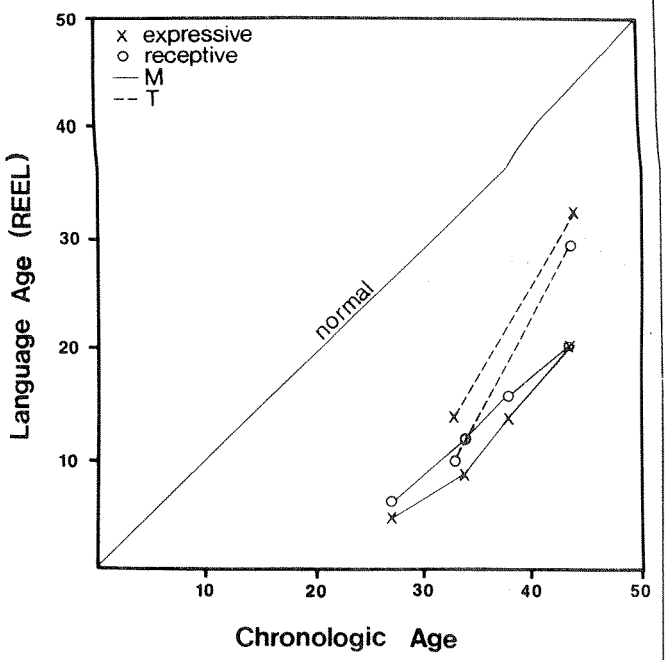


FIGURE 3 (above)
Language age scores on the Receptive Expressive Emergent Language Scale (11) are plotted against chronologic age for subjects M and T.

FIGURE 4 (left)
Size of receptive vocabulary in number of words is plotted against chronologic age for subjects M and T.

Tactaid appears to have provided an advantage for M in terms of words understood until about 3 years, 2 months of age, at which point M's rate of acquiring new words slowed down while T's continued to accelerate.

DISCUSSION

The overall impression of the three teachers who worked with the subject, M, over the 15-month period of this project was that the Tactaid helped her learn to produce and understand spoken language more easily than did her conventional hearing aids. M's teachers reported that in her general activities as well as when receiving specific instruction, M was more responsive when wearing her Tactaid than when not wearing it. Her mother and teacher both reported that when the Tactaid was not working properly or when M was not wearing her Tactaid, she had tendencies to mouth words without voicing, to be inconsistent in the volume of voice she produced, and sometimes to continue voicing when voicing should have stopped.

The Tactaid required repair on the average of twice a month. The damage was most frequently caused by M's falling on, or spilling food into, the device. Other problems involved breakage of the cord connected to the vibrator, and of the metal frame holding the vibrator onto the harness. It was necessary to have two Tactaids available to the subject to insure that she had one functioning aid to wear while the other was being repaired.

There was evidence that the Tactaid facilitated M's speech production. Quite early, her teacher observed that the Tactaid had made her aware of her own voice and the speech of others. Later, her imitations of words were found to match the teacher's model more closely with the Tactaid turned on

than with it off. To demonstrate this effect, M's imitations of 25 words were recorded (audio) as she produced them with the Tactaid turned on and with it turned off. These speech samples were subsequently played to 25 listeners in counterbalanced order, and they were asked to judge in which set M's imitations most closely matched the teacher's model. Twenty-three of the 25 listeners identified the set with the Tactaid as a better speech sample. Listeners remarked that voice quality, prosody, and segmentation were much improved with the Tactaid on.

The degree to which the Tactaid facilitated the subjects' reception of speech was less clearly demonstrated. Throughout the project, when M's receptive vocabulary words were assessed with and without the Tactaid, no difference was found in her ability to recognize these words. Although the aid may have helped M acquire new receptive vocabulary faster than she would have without it, she depended on lipreading to understand words once she had acquired them.

CONCLUSIONS

The results obtained from this subject, M, after 14 months with a Tactaid I single-channel vibrotactile aid indicate that such a device may facilitate the acquisition of spoken language in profoundly deaf children. While the findings of a normal rate of language acquisition exhibited by subject T in the 1983 Proctor and Goldstein study (7) may not be attributed solely to the use of a Tactaid, some degree of acceleration in language development was observed in both of these cases. M progressed from a relative position considerably below expectation for a deaf child her age to a level somewhat above expectation, suggesting better-than-average progress with the Tactaid. However, the degree to which such progress, as was observed in these two children, is due to the vibrotactile aid or to other educational factors and intrinsic characteristics of the children themselves can be determined only through controlled studies with groups of deaf children ■

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