Factors in the Development of a Training Program for Use with Tactile Devices

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ABSTRACT

A review of the literature suggests that, in order to maximize the benefits available through a tactile device, it must be accompanied by an effective and adaptive training program. There are a number of factors to consider in the design of such a training program, including the type of tasks and response formats to include, the amount of training, subject motivation and device use, the characteristics of the potential user population, the specific device to be used and the type of information it provides, and the evaluation procedures to be followed. The type and saliency of the information provided by a particular tactile device are highlighted as the most important yet neglected consideration in designing a training program. The training program used with the University of Melbourne's multiple-channel electrotactile device is presented to show how these important factors may be addressed, to indicate the flexibility required in a training program, and to provide a general framework on which researchers may base the development of programs for other tactile devices.

The last decade has seen an increased development of tactile devices designed to assist speech perception for the hearing impaired (reviewed by Lynch, Oller, & Eilers, 1989; Reed, Durlach, Delhorne, Rabinowitz, & Grant, 1989; Sherrick, 1984). Despite a concentration on hardware development, the importance of training in achieving speech perception benefits with tactile devices has been recognized. Device design faults and poor training have been suggested as the major limiting factors in speech perception results achieved to date with tactile devices (Reed et al, 1989). In addition, performance with tactile devices measured before training does not necessarily accurately reflect post-training benefits to speech perception (Engelmann & Rosov, 1975; Weisenberger, 1987; Weisenberger & Miller, 1987). Furthermore, perception of isolated words by hearing-impaired subjects using a tactile vocoder has been shown to improve with practice, and it was suggested that this was due to the training received (Engelmann & Rosov, 1975). These findings are supported by studies with profoundly hearing-impaired adult users of the University of Melbourne's multiple-channel electrotactile device, or "Tickle Talker" (Blamey & Clark, 1987), which showed continuing increases in speech tracking rate difference (i.e., difference between word per minute rate in tactually aided and unaided conditions) with additional training sessions (Cowan, Blamey, Sarant, Galvin, Alcántara, Whitford, & Clark, 1991). Significant training effects on speech feature perception using the Tickle Talker have also been demonstrated with children (Alcántara, Whitford, Blamey, Cowan, & Clark, 1990b).

Given the importance of training in achieving potential benefits to speech perception, researchers developing tactile speech perception devices for use by hearing-impaired children must also address the need for an effective training program for use with the device. Obviously, the contents of any specific program will depend on the aim of device use, the desired outcome of the training program, and the characteristics of the target population. Table 1 shows a summary of some of the important factors in the design of a training program. Although the concept of matched groups of hearing-impaired adults and children trained with different programs is attractive from the statistical aspect of assessing the relative importance of each of these factors, the use of matched groups is clearly impractical and unacceptable for researchers and teachers, whose primary aim is to provide maximum device benefits to the users. Studies with normally hearing subjects are also impractical, because the effects of hearing impairment, knowledge of language, and performance/motivation cannot be considered. However, descriptions of successful training programs will allow the general premises of these programs to be adapted to suit the individual device and subject population, thereby easing the task for researchers wishing to develop a training program for a particular tactile device. The rationale for this article is to highlight the general issues which must be considered in designing effective training programs, and second, based on our own specific work with tactile training, to provide a framework for other research groups to use in developing training programs specific to their own tactile device.

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Table 1. Important factors in the development of a training program for use with tactile devices.

- Type of training tasks
- Amount of training
- Motivation and device use
- User characteristics
- Response formats used in training
- Information presented by the tactile device
- Evaluation procedures

General Issues Relevant in the Design of a Tactile Training Program

Type of Training Tasks. Although the literature clearly supports the benefits of training, it is unclear what level of structure in the training tasks and what balance of analytic and synthetic training is most effective. In the study of Walden, Erdman, Montgomery, Schwartz, and Prosek (1981), hearing-impaired adults who received consonant recognition training in addition to a standard aural rehabilitation program improved on audiovisual sentence recognition significantly more than subjects who received only the standard program. However, Rubinstein and Boothroyd (1987) trained one group of mild to moderately hearing-impaired adults with activities incorporating sentence perception and perceptual strategy. A second subject group also received this type of training, but spent 50% of its training time on activities involving consonant recognition. Results showed significant post-training improvements in speech recognition for both approaches, but no significant difference between the two training programs.

The performance of adult Tickle Talker users trained with a combined analytic/synthetic training program (including both speech feature discrimination and conversational tasks) was found to be comparable to adults trained with a synthetic-only training program. Results showed that performance of subjects trained with the two approaches differed only for tactile recognition of vowels and consonants (Alcántara, Cowan, Blamey, & Clark, 1990a). However, further studies with normally hearing and hearing-impaired adult users of this device found that a combination of systematic speech feature training tasks and conversational material improved the subjects' ability to use the tactile input (Cowan, Alcántara, Whitford, Blamey, & Clark, 1989a). Initial training programs used with the Tickle Talker for hearing-impaired children used a combined analytic/synthetic training approach, with structured speech feature discrimination tasks, and closed-set sentence and connected discourse style training (Alcántara et al, 1990b). Evaluation revealed that speech feature perception improved in the post-training as compared to pretraining and training phases, performance was maintained after the cessation of training, and skills were generalized from trained to untrained words. However, informal assessment of connected discourse perception suggested that the tactile information was not being integrated to the extent considered possible from the speech feature perception results.

These studies show that training in both phoneme reception and comprehension of running speech may be beneficial, and that a training program should include a choice of tasks from these two categories.

Amount of Training. The amount of training required by hearing-impaired adults and children to achieve maximum benefit from a tactile device is also a major factor to be considered in the design of a training program. Improvements in speech feature perception scores on closed-set word tests have been shown without substantial training (Oller, Payne, & Gavin, 1980). However, studies with multiple-channel tactile devices have shown that considerable training with a tactile device is necessary before significant improvements in open-set word and sentence perception can be observed (Blamey, Cowan, Alcántara, Whitford, & Clark, 1989; Brooks, Frost, Mason, & Gibson, 1987; Cowan, Alcántara, Blamey, & Clark, 1988; Cowan et al, 1989a). Experience with normally hearing subjects has suggested that learning times for new sensory codes may be similar to those for recognition of the sounds of connected discourse in a foreign language (Watson, 1980). The results of Blamey, Cowan, Alcántara, and Clark (1988) suggested that 70 hr of training provided to normally hearing subjects was insufficient to maximize device benefits in open-set word recognition. Further studies showed that the benefits of tactually encoded speech feature information for connected discourse tracking continued to increase for two hearing-impaired subjects over 28 and 43 weekly sessions, respectively, and that no plateau in improvement was noted (Cowan et al, 1991).

In the report of the Working Group on Communication Aids for the Hearing-Impaired (Committee on Hearing, Bioacoustics, and Biomechanics, Commission on Behavioural and Social Sciences and Education, 1991), it was considered that, as experimental devices were often not used for extended periods, the capacity of the hearing-impaired person to learn new sensory codes may not have been reached. Research is presently unable to specify the time required to gain maximum running speech perception benefits from a tactile device; however, it seems evident that significant periods of training and practice are required. Obviously, the desire and necessity of providing long periods of training must be considered in terms of the cost of providing the training, especially in the provision of specialist intervention time.

A further consideration is the frequency of the train-

ing sessions provided to the device user. Weisenberger (1987) reported that subjects trained daily achieved higher performance levels. However, this frequency of training is not always practical. It is yet to be established how less frequent training sessions affect speech perception performance, and if this effect can be counteracted by extending the number of sessions over time. The frequency of sessions may also depend on the amount of device adjustment and maintenance required.

Motivation and Device Use. The performance and consistency of device use (for hearing aids, cochlear implants, and tactile devices) by children may be affected by other factors such as motivation, peer pressure and reinforcement by teachers and parents. The attitude toward tactile device use shown by the professionals and other adults involved with the child's training program is a significant factor, which may vary in importance for any particular child (Galvin, Cowan, Sarant, Alcántara, Blamey, & Clark, 1991). It is important that parents and teachers understand the use of and potential benefits available from a specific tactile device, and that they provide positive support for the child. Linked to this is the requirement that the training program must be easily applied by the child's teachers and parents without specialized training or facilities. This is important to ensure that specialist intervention should only be required for the initial stages of device introduction and training, ongoing device maintenance, and the provision of information sessions, thereby reducing the long-term costs of device use.

It is important that the child's everyday use of the device at school and at home is supported by teachers and parents, as it has been suggested that their attitude is influential (Galvin et al, 1991). The attitudes of peers are also likely to have an effect. Daily use encourages integration of the new information provided by a device as rapidly as possible, through practice outside formal training sessions and maximizing exposure in different situations. These external influences need to be accommodated by a training program.

User Characteristics. When designing a training program, it is necessary to consider potential users of the device. Characteristics such as age, use of residual hearing, formal knowledge of language, communication skill, and the ability to integrate speech information from more than one modality are important. These factors should be considered in the choice of training tasks and expectations for each child's performance, and the program must be flexible in these areas to ensure its applicability to a wide range of hearing-impaired children.

Response Formats. Response formats must also be considered when preparing a training program. Subjects trained with closed-set tasks have been found to improve more on closed-set tests, whereas subjects trained with open-set tasks improved more on open-set tests (Alcántara et al, 1990b; Bode & Oyer, 1970). Studies with adults using the Tickle Talker showed closed-set speech feature training to be important for training initial recognition of the tactile information, but indicated that open-set synthetic material was necessary to encourage and facilitate the integration of tactile information into the perception of running speech (Alcántara et al, 1990a; Cowan et al, 1989a). These results suggest that training should concentrate on the level of performance required of the device by the user in daily communication. Bode and Oyer (1970) supported the inclusion of both closed- and open-set response formats in training, because everyday speech perception includes both closed- and open-set decisions.

The Tactile Device. A critical factor relevant to the development of a training program for use with any speech perception device is the speech information available through that specific device and the salience of that information to the particular population of users. Devices differ both in the speech information provided and the manner in which it is presented to the user. For example, Weisenberger (1987) compared single-channel and two-channel devices and concluded that the latter were much more effective in providing high-frequency information, such as the presence of /s/. Studies with the Tickle Talker have shown initial consonant voicing to be less effectively encoded and perceived, whereas fricatives were relatively easy to perceive (Cowan, Blamey, Alcántara, Whitford, & Clark, 1989b). Table 2 provides further illustration of the differences in information provided by a number of tactile devices. These results, taken from studies by Plant (1989) and Cowan et al (1989b), clearly show differences in ease of discriminating tactile information through different devices. For example, although users of the single-channel and two-channel devices (MiniFonator, Tactaid II, Minivib, TAM) were able to discriminate prosodic information, information on vowel second formant frequency difference was only available in the output of the Tickle Talker, which specifically encodes this feature.

A clear understanding of the information provided by a device and the way that it is presented is necessary for the choice and development of training tasks and determination of the order of their presentation to maximize the benefits of device use in the shortest period of training. Obviously, based on the above findings, it would be inappropriate to include vowel F2 discrimination tasks in training programs for use with the single- or two-channel devices tested. It is also important to consider the auditory and visual information available to the individual device user to further

Table 2. Number of subjects scoring significantly above chance ($p < 0.05$) for the 12 subtests in two studies.

	Subtest Number[a]													
Device	1	2	3	4	5	6	7	8	9	10	11	12	Total	Percent[b]
Mini Fonator[c]	3	1	3	1	1	0	1	2	1	2	0	1	16	27
Tactaid II[c]	2	3	2	3	2	0	2	2	2	2	0	3	23	38
Minivib[c]	5	5	5	5	3	0	4	2	2	1	1	2	35	58
Tam[c]	3	2	5	2	4	0	0	2	0	0	4	0	22	37
Tacticon[c]	0	0	1	0	4	0	3	4	3	2	1	2	20	33
Tickle Talker[d]	8	6	8	8	7	7	3	4	7	4	6	8	76	79

[a] *Speech feature contrasts of subtests: 1–2, syllable number and stress pattern; 3–4, vowel duration; 5, vowel first formant; 6, vowel second formant; 7, initial consonant voicing; 8, initial nasal versus voiced stop; 9–10, fricatives versus stops; 11, nasals versus fricatives; 12, speech feature information above 3 kHz.*

[b] *Percentage of subtest scores significantly above chance from total possible score for device.*

[c] *Number of subjects (n = 5) scoring significantly above chance, with a total possible score of 60 (from Plant, 1989).*

[d] *Number of subjects (n = 8) scoring significantly above chance, with a total possible score of 96 (from Cowan et al, 1989b).*

clarify the areas in which the tactile information, and, therefore, training with the tactile device, will be most beneficial.

Evaluation. To monitor subject progress, to identify areas requiring training, to improve a training program, and to provide accurate information to other researchers, evaluation of subject performance is a vital part of a training program. Evaluation procedures should also monitor the safety aspects of long-term device use, including the maintenance of acceptable stimulation percepts, which must be assessed to ensure the device will be acceptable to the user as a long-term daily aid to their speech perception.

Design of a Training Program for a Multiple-Channel Electrotactile Speech Processor

As discussed, a number of general issues need to be considered in the design of a training program for any tactile device. In order to better illustrate how these factors impact, and to provide examples of strategies and materials which may be useful in the development of tactile training programs, these factors will be discussed in terms of the training program for the University of Melbourne's multiple-channel electrotactile Tickle Talker. Although these strategies and materials are specific to the device, they may provide a basis for other researchers in the design of tactile training programs.

Device. The Tickle Talker is a wearable, battery-powered electrotactile device consisting of a speech processor, a lapel microphone, and an electrode handset. The speech processor is a modified version of the hardware used in the Nucleus 22-channel Cochlear Implant (Seligman, 1987). In the speech processor, estimates of the fundamental frequency (F_0), the second formant frequency (F_2), and the speech amplitude are extracted from the speech signal. These parameters are then encoded as a series of biphasic 1.5 mA constant current electrical pulses and presented to the user through the electrode handset. The site of stimulation conveys F_2 frequency, changes in pulse rate signify differences in F_0, and changes in speech amplitude are conveyed by altering the strength of the stimulus through pulse width differences. Table 3 summarizes the speech features encoded by the device.

The electrode handset is worn on the nondominant hand and consists of two electrodes in each of four rings. The electrodes are positioned on either side of the four fingers, so activation of the electrodes stimulates the digital nerve bundles. This stimulation site has been found to provide a pleasant sensation with a wide dynamic range and a well-ordered spatial display with very high electrode position recognition scores (Blamey & Clark, 1987).

Threshold (T-level) and maximum comfortable (C-level) pulse widths are set for each electrode by the user. These levels are monitored and adjusted throughout the training program to maintain the comfort of the tactile sensation and the optimum dynamic range for each electrode, thereby encouraging long-term, consistent device use. Extensive safety studies have monitored the movement of T- and C-levels (and other parameters, such as finger temperature and blood flow) and have demonstrated that the device is safe and comfortable for long-term use (Cowan, Blamey, Alcántara, Blombery, Hopkins, Whitford, & Clark, 1992). More details of the device may be found in work by Blamey and Clark (1987) and Cowan et al (1988, 1989a).

Information Provided by the Device. The Tickle Talker provides cues to syllable number and stress, vowel length and formant, and some consonant manner and voicing contrasts. As discussed above, the speech processor extracts F_0, F_2, and amplitude from the speech signal. F_0 is encoded as the pulse rate and sensed as

"roughness" of stimulation. This provides information on syllable stress. F_2 is encoded as the particular electrode stimulated over the range of 800 Hz to 6 kHz, providing frequency information on vowel formants and higher frequency fricatives. Specifically, high-frequency information in the range from 4 to 6 kHz is signaled by the stimulation of electrode 8. Stimulation of electrode 1 indicates an unvoiced consonant. The speech amplitude is encoded as the width of biphasic pulses and sensed as changes in the intensity of stimulation. This provides information on syllable number and stress, vowel duration, and consonant manner and voicing (see Table 3).

Initial psychophysical testing found that the salience of the information provided by the Tickle Talker decreases through the parameters of electrode position, pulse width, and pulse rate (Blamey & Clark, 1987). For this reason, encoding of information such as voicing and high frequency, commonly difficult for the profoundly hearing-impaired to perceive auditorily or visually, has used electrode position.

As mentioned, it is critical that developers of a training program know what information is available and can be discriminated by users of the device. In order to determine what speech feature information could be perceived through the Tickle Talker, eight adults were tested with a series of tactile speech feature discrimination tasks developed by Plant (1989). Results for the Tickle Talker as compared to other tactile devices are presented as Table 2. As the results show, at least six of the eight adult Tickle Talker subjects scored significantly above chance ($p < 0.05$) on discrimination of syllable number and stress on each subsection of varying speech phoneme contrasts. On the vowel length and vowel formant discrimination subtests, eight and six subjects, respectively, scored significantly above chance. Performance on the discrimination of initial position consonant features was more varied, depending on the specific speech phonemes being contrasted. Of the consonant manner discriminations, performance was highest for fricatives. Initial consonant voicing information was not as well perceived, with only three of the eight subjects scoring above chance. The encoding strategy was amended after these findings, and current work is centering on enhancing the encoding of initial consonant voicing.

The analysis of these psychophysical and speech perception studies determined the choice and order of training tasks used in the current training program.

Aim of Device Use. The Tickle Talker is primarily a supplemental device. Although vowels and consonants may be discriminated through the tactile sense used in isolation, the aim of device use is to provide additional information not available via hearing aids or lipreading. Some redundancy of information provided through two or more sensory modalities may also be of benefit to some individuals. It is intended that the integration of the tactile information with auditory and/or visual information will improve the speech perception performance of the user. Therefore, the emphasis of the training program is influenced by the individual's lipreading skill and use of aided residual hearing. The aim of device use requires that a significant portion of the training, once tactile speech feature recognition is achieved, is conducted in the combined modality in which the user will function daily (tactile plus lipreading, or tactile plus lipreading plus hearing aids). However, visual information is still withheld for many tasks to encourage concentration on the tactile and auditory inputs.

Current research is also assessing the success and potential of the Tickle Talker in providing feedback information to the user, in training and everyday use, to aid the self-monitoring of speech production. This may prove to be an important secondary aim/benefit of Tickle Talker use.

Table 3. Summary of information provided by the Tickle Talker.

Speech Feature	Electrical Parameter	Percept	Information Perceived
F_0	Biphasic pulse rate	Roughness of stimulation	Syllable stress
F_2	Electrode stimulation	Stimulation on electrode in range 2–7	Vowel formant
High-frequency information	Stimulation on electrode 8	Stimulation on electrode 8	High-frequency fricative
Amplitude	Biphasic pulse width	Strength of stimulation	Syllable number and stress Vowel duration Consonant manner
Voicing	Stimulation on electrode 1	Stimulation on electrode 1	Voiced or unvoiced

Aim of the Training Program. The training program aims to develop the child's perception of tactile speech information and its integration with information from other sense modalities, thereby improving speech perception performance. The program also attempts to encourage the use of tactile feedback in speech production. Due to time limitations often encountered in school situations, the program is designed to achieve its aims by training basic perceptual and integration skills, which the device user can maintain after the cessation of training and generalize to nontrained contexts (Alcántara et al, 1990b).

To achieve its aims, the Tickle Talker training program attempts to foster support for the child by encouraging the involvement of parents and teachers through the provision of information, a training session record book, and invitations to attend sessions. The program also endeavors to create a rapport between the child and the research audiologist to encourage a positive attitude toward the device and to facilitate the collection of data.

Training Sessions. Each child attends 40-min individual training sessions conducted at the schools by an audiologist from the research team. Actual training times varies greatly between sessions, as any necessary processor reprogramming, equipment repairs, and child counseling are included in the same session. Although more frequent sessions would have been preferable, constraints on available time within the school educational programs restricted the frequency of training, and a twice-weekly program was adopted. As the children use the Tickle Talker daily in the classroom, it does not appear to be necessary to use training time to refamiliarize the children with perceptual tasks trained in previous sessions. The evaluation protocol ensures that if a decline in performance occurs for a previously trained phonemic contrast, it will be recognized. Thus, integration of device use into the everyday communication environment of the child was seen as a significant factor in increasing experience and benefits.

For the first few weeks, the device is used only in supervised training sessions. This enables the child's T-levels and C-levels to stabilize, as a previous study showed that C-levels could increase over time due to subjective acceptance of higher pulse widths (Cowan et al, 1992). Furthermore, this allows the child time to become more familiar with the parts of and control of the device, and learn to differentiate some speech sounds tactually.

Training Tasks and Response Formats. As discussed, many different training tasks offer benefits to speech perception. To provide a range of benefits, the Tickle Talker training program consists of a hierarchical series of varied speech perception tasks that build on one another as the child's skill with the device increases. In passing through this hierarchy, the child is first required to learn to discriminate speech features tactually, prior to integrating this information into the understanding of words, sentences, and, finally, running speech. This approach is intended to maintain motivation and increase confidence—significant factors in the initiation and maintenance of oral communication. Previous research has supported this structure, with superior performance shown when using closely graded training tasks leading up to conversational level training (Weisenberger, 1987).

At the most basic level, training with the Tickle Talker is conducted in the tactile alone (T) condition. T condition training allows the child to focus on and learn to recognize some basic tactile information before being required to integrate it with information from other sources (Alcántara et al, 1990b). This early experience may prevent new device users learning to consider the tactile information as being difficult to perceive (Weisenberger, 1987). Research with other devices has found early T condition training on single-word tasks can result in superior performance on connected discourse tracking (Weisenberger, 1987). In addition, early success has been found to contribute greatly to motivation (Plant, 1988). For these reasons, simple and highly structured tasks, such as speech detection, and amplitude and syllable number and stress discrimination, are used in training at this level (Blamey et al, 1988; Cowan et al, 1989b). As the Tickle Talker is a supplemental device, the early training sessions also include some easy multimodality tasks in which success is not dependent on using the tactile information.

Segmental level speech perception tasks used in training are divided into phoneme, word, sentence, and conversational work. In the initial periods of training, the clinician incorporates tasks from each of these groups into most training sessions. The proportion of time spent on sentence and conversational tasks increases with the child's skill and experience.

Initial segmental level training aims to clarify for the child the speech feature information provided by the device by using structured speech feature discrimination tasks in a limited forced-choice format. The tasks are performed in the tactile plus auditory (TA) condition. An analytic-type format is used, as it is more suited to training speech feature perception skills (Alcántara et al, 1990a). The disadvantage of this type of task is that a child may learn to complete the task only when in a training-type situation, as suggested by Robbins (1990) with cochlear implant users, and skills may not be generalized to untrained words. Furthermore, high T condition feature discrimination scores have been shown to be achieved after T condition

feature training with the Tickle Talker without the full benefit of the device being shown in combined conditions (Blamey et al, 1989). For these reasons, the analytic training is complemented by the early introduction of synthetic training into the program.

Vowels are the first phonemes trained, as they have been shown to be more easily perceived than consonants (Cowan, Blamey, Galvin, Sarant, Alcántara, & Clark, 1990). Vowel length is introduced first, as the time-intensity cues provided through the device are easily discriminated. The use of vowel formant information, graduating from gross formant contrasts in longer vowels through to finer formant discriminations in shorter vowels, is trained subsequently.

The discrimination of manner of consonant articulation is easier than the discrimination of initial consonant voicing, possibly due to the duration and amplitude envelope cues and high-frequency information available through the Tickle Talker for manner discrimination (Cowan et al, 1989b). Therefore, consonant manner is the first consonant feature to be introduced, followed by consonant voicing. As initial consonants were not as well recognized as final consonants, perhaps due to the salience of the preceding vowel duration cue to final consonants, the latter are trained first. Consonant place is not trained extensively, as it is the most difficult feature to perceive tactually, and is more easily available from lipreading (Ling, 1976).

This order of phoneme presentation is not strictly adhered to, due to the early introduction of synthetic tasks, which present all of the speech phonemes. Therefore, new speech feature information is introduced before maximum scores are obtained on easier discriminations. Once the majority of phoneme discriminations possible with the Tickle Talker are trained, this type of analytical task is not used. Table 4 summarizes the presentation of phonemes in training.

To facilitate the integration of the tactile speech feature information with information from other modalities, word, sentence, and conversational activities are used. This is consistent with the suggestion that training material should be closely related to the everyday communication situation (Blamey et al, 1988). Word discrimination is trained mostly in the TA condition, and occasionally in the tactile plus lipreading plus hearing aids (TLA) condition. Word choice is based on the phonemes trained in the above section, and closed response sets of varying sizes are used.

Word training is followed by sentence-level work. This occurs in the TA and TLA conditions, depending on the length and difficulty of the sentences and the level of context. An open-set, but usually highly contextual response format is used with sentence-level work. At the conversational level, all work is done in the TLA condition. Conversational work uses an open-set response format. In view of the long-term aims of the training program, this may be considered the most important area of training. The conversational level training with the Tickle Talker aims to improve the perception of running speech by training feature-level discriminations under the influence of coarticulation and the use of syntax and context (Alcántara et al, 1990b). Table 5 summarizes the levels of training.

At all levels in the training program, a variety of games and other enjoyable tasks are used as rewards and motivation, and performance feedback and positive encouragement are provided. Varied practice materials have been shown to provide motivational and adaptive benefits in earlier research (Bode & Oyer, 1970; Tye-Murray, Tyler, Lansing, & Bertschy, 1989). Furthermore, these studies found feedback and encouragement to be beneficial. In all activities, turn taking is used to involve the child and maintain their interest, to provide social skills practice, and to allow the child to perceive the tactile stimulation pattern of their own voice. Previous studies have established the superiority of active participation in learning as compared to passive receptivity (Bode & Oyer, 1970). The majority of the conversational activities, and the occasional word or sentence task, are carried out in a group of two children and two clinicians. This allows for increased conversational scope, serves as a reward system, and gives the children structured practice in speech perception with another adult and child. Appendix I describes examples of the tasks used in training sessions.

Subjects. The majority of children in the current training program use the Tickle Talker to supplement

Table 4. Order of phoneme discrimination presentation/difficulty.

Vowel length
Vowel formant
Presence high-frequency information (/s/ and /sh/)
Final consonant manner
Initial consonant manner
Final consonant voicing
Initial consonant voicing

Table 5. Order of difficulty/presentation of training tasks.

Task	Condition(s)	Response Format
Speech detection Amplitude discrimination Syllable number and stress discrimination	T	Closed (<5 alternatives)
Phoneme detection and discrimination	TA	Closed (<5 alternatives)
Word discrimination	TA and TLA	Closed (large)
Sentence comprehension	TA and TLA	Open
Connected discourse comprehension	TLA	Open

lipreading and audition (see Table 6). However, child 5 and child 16 receive little or no usable auditory input and use the device primarily as a lipreading supplement. In addition, the training program has also been implemented with two children (child 13 and child 14) enrolled in a total communication school who receive very limited auditory information (Galvin et al, 1991). The performance expectations and training requirements for these children differ from those who receive meaningful auditory information from hearing aids (Hesketh & Osberger, 1990). For example, more T training is used to highlight the tactile stimulus before it is integrated with lipreading. Furthermore, with some activities, the tactile plus lipreading (TL) condition is substituted for the TA condition, and the difficulty of the activity is increased to compensate for the inclusion of vision. The important point is that the training program can be adapted to suit a wide range of residual hearing levels and communication methods and skills.

This program flexibility also allows use with a wide age range. Although the majority of children using the device when the program was designed were in the range of 9 to 12 years old, it has also been used successfully with children as young as 7 and as old as 16 (see Table 6). This requires adaptation of the games and activities to suit the age and needs of the child. Adaptation of the training program to children younger than 7 would require further changes; in particular, the handset would require modification to suit the size of younger children.

Evaluation. Each child's performance with the Tickle Talker is regularly evaluated to ensure that the device is providing benefits to speech perception, to encourage continued device use through demonstration of performance to the child, family, and teachers, and to identify new areas requiring training. The six monthly speech perception evaluation batteries consist of closed-set speech feature discrimination subtests of the PLOTT test (Plant, 1983), open-set Phonetically Balanced Kindergarten word lists (Haskins, 1949), and the open-set Bamford-Kowal-Bench sentence test (Bench & Bamford, 1979). A conversational and a picture description speech production video is obtained from each child every 6 months. These videos are analyzed to assess possible effects of use of the Tickle Talker on speech production.

The speech perception evaluations have shown a range of benefit levels across children. Previous studies have obtained the same result. Walden et al (1981) found a wide range of improvement scores in their comparison of two training strategies, but found no clear reasons to account for the differences. Rubinstein and Boothroyd (1987) also failed to significantly correlate degree of improvement with any of several variables thought to explain the range of improvements obtained by their subjects. The range of benefits obtained through the Tickle Talker program may be partly due to the scope for improvement provided for by the differences between children's lipreading skills and levels and use of aided residual hearing. Any attempt to determine the cause(s) will require a larger subject group so that a number of different variables can be

Table 6. Audiological details of subjects. Onset, age at onset of deafness; Etiol, etiology of deafness; Ed, educational environment; Thresholds, better ear in dB HL re: ANSI-1969; NR, no response at audiometer limits.

					Threshold				
Child	Age	Onset	Etiol	Ed	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
1	15	birth	unkn[a]	O[b]	100	100	105	105	105
3	10	birth	unkn	O	90	100	110	120	115
5	12	birth	gen[c]	O/C[d]	110	NR	NR	NR	NR
6	12	birth	rub[e]	O/C	90	100	110	115	NR
7	11	2 yr	vir[f]	O/C	75	95	105	115	105
8	10	birth	unkn	O/C	85	100	105	110	110
10	14	birth	unkn	TC/O	100	105	105	115	110
12	9	birth	unkn	TC[g]	75	90	105	100	120
13	11	birth	unkn	TC	70	100	115	NR	NR
14	10	9 mo	men[h]	TC	NR	NR	NR	NR	NR
16	16	9 mo	vir	TC/O	105	NR	NR	NR	NR
17	7	birth	unkn	TC/O	95	100	110	NR	NR

[a] *Unknown.*
[b] *Aural/oral.*
[c] *Genetic.*
[d] *Aural/oral with cued supplement.*
[e] *Rubella.*
[f] *Virus.*
[g] *Total communication.*
[h] *Meningitis.*

correlated with the benefit obtained from the training program.

Summary

In summary, there are a number of important factors vital to the development of an effective training program to be used with tactile devices. The importance of many of these factors has been supported in earlier studies. However, the importance of the information provided by a particular tactile device and how this complements visual and auditory information available to the device user has not been given sufficient emphasis in the development of training programs. Each of these relevant training factors can be addressed if due consideration is given to them in parallel with the development of the tactile device. The development of a suitable training program is of equal importance to the development of the hardware and speech coding schemes for any particular tactile device.

The evaluation protocol used in the Tickle Talker training program continues to indicate areas requiring further work in both training and speech encoding. The training program will be adapted to cater for any speech encoding developments made if they prove superior to current strategies. Further research effort is also being directed toward the development of a more comfortable and aesthetically acceptable handset and improved handset rings and electrodes. New designs are assessed and studied by the researchers, before being used with the children on the program. Recent speech perception results with long-term device use and speech production data are currently being analyzed by the researchers. Attempts are being made to clarify some aspects of the training program from these results. For example, the researchers intend to consider the effect on speech perception performance of suspending training (during school holidays) and the possible benefits of including formal speech production training with the Tickle Talker in the program.

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Appendix I

A Typical Training Session

The following is an example of the tasks that may be used in a training session with a child who has passed beyond the initial stage of training, and provides an indication of the time that may be devoted to each area:

0–10 min: Speech processor map is checked with the computer, quick speech feature perception test of speech processor functioning, short conversation.

10–20 min: Word lotto game constructed with minimal pairs contrasting /s/ and /t/ (TA condition).

20–25 min: Rate-tracking task, in which the child follows a story read by the clinician and fills in the gaps or chooses the correct word from a choice of three (TA condition).

25–35 min: Guess My Name game in which one player describes an item on the board and the other players must guess the item (TA condition).

35–40 min: Using picture cards of common items, a "race track" is laid out; each player takes a turn at trying to match (e.g., by usage, shape, or color) the card they turn over with each card in the race track to reach the end (TLA condition).

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