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Speech training aids for hearing-impaired individuals: III. Preliminary observations in the clinic and childrens' homes

JAMES J. MAHSHIE, PhD, DIANE VARI-ALQUIST, MEd, BETTY WADDY-SMITH, MS, and LYNNE E. BERNSTEIN, PhD
Department of Audiology, Gallaudet University, Washington, DC 20002

Abstract—Preliminary evaluation of 2 related computer-based speech training and practice aids for profoundly deaf children was conducted. The Speech Training Station (STS) uses both acoustic and physiological transducers for assessment and training in a school or clinic. The Speech Practice Station (SPS) uses the acoustic signal, and was designed primarily for use in the home. A series of games and activities was implemented on the 2 systems. Use of the STS was evaluated by 2 speech clinicians during a 15-month period. Fifteen children were subjects in the evaluation. The aid was found to be easily incorporated into clinic activities and useful for diagnosis and therapy. The SPS was evaluated during a 1-to-2-week period, during which it was placed in the homes of 5 profoundly deaf children. Using an activity log and questionnaire completed by the childrens' parents, usage statistics and impressions were obtained. Potential value and problems with such aids are discussed.

Key words: *acoustic and physiological transducers, computer-based speech training aids, deaf children, electroglottograph, pneumotachograph.*

Address all correspondence and reprint requests to Dr. James J. Mahshie, Department of Audiology and Speech-Language Pathology, Gallaudet University, 800 Florida Avenue NE, Washington, DC 20002.

Diane Vari-Alquist, MEd, Speech Processing Laboratory, Johns Hopkins University, Baltimore, MD 21218.

Betty Waddy-Smith, MS, Kendall Demonstration Elementary School, Gallaudet University, Washington, DC 20002.

Lynne E. Bernstein, PhD, Center for Auditory and Speech Sciences, Gallaudet University, Washington, DC 20002.

INTRODUCTION

Hearing loss affects the ability to both receive and produce spoken language. When severe or profound hearing impairment occurs early in life, the prognosis for acquisition of intelligible speech is poor. Recent technological developments, especially in computers, have the potential for helping deaf individuals achieve improved speech production (6). Presented here is a report of initial clinical and home evaluations done in conjunction with development of 2 new computer-based speech training aids. An overview of the aids and a technical description are given in 2 companion papers in this volume (1,2). Two interrelated aids were developed, one designed to facilitate assessment and training in clinical settings (a Speech Training Station or STS), and the other for use in the home (a Speech Practice Station or SPS). Each of the speech training games is described following a brief review of the system.

STS and SPS

Speech signals for the STS are obtained from 3 transducers: a microphone (to obtain the acoustic waveform); an electroglottograph (to obtain degree of vocal fold contact); and a pneumotachograph (to obtain average oral airflow). Software for analyzing and displaying acoustic parameters is implemented on both the STS and SPS. Software for physiological parameters, obtained from the electroglotto-

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graph and pneumotachograph, is implemented only for the STS. The decision not to implement physiological measures on the SPS was an outcome of consideration of transducer cost and complexity with regard to calibration, and proper physical placement on the child.

STS and SPS software

The goals for software design were to facilitate: 1) assessment of skills through provision of objective measures; and, 2) practice through drill in a game format. These goals were derived from considerations about the needs of therapists[1] and children involved in the process of speech training. It was posited that assessment and therapy can be facilitated by providing therapists with information about the underlying physiologic mechanisms of speech, which they cannot obtain from listening alone. Further, the computer can provide the opportunity for the child and therapist to have equal access to objective information about speech production, and therapy may proceed more efficiently, with less time spent in attempting to convey the desired targets to the child.

The need for repeated drill is clear to all involved in speech training, and the computer is ideally suited for this activity. The goal of providing drill in a game format derives directly from the concept that speech training will proceed best when the child's interest is aroused and he/she is motivated to produce a large quantity of directed and monitored practice. Game development was made somewhat more demanding because of the desire to implement games that would be appealing to very young deaf children. This objective is consistent, however, with the idea that speech training of prelingually, profoundly deaf children should begin as soon after identification as possible, in order to promote more normal speech and language patterns.

Access to software on both systems is through menus. The speech therapist can quickly change from one game to another, and can easily change parameters for controlling games, depending on the child's level of speech/language skills.

Software was written to teach speech attributes such as sustained vocalization, production of repeated syllables, and control of voice intensity and fundamental frequency (F_o). Timing and intensity information is obtained primarily from the acoustic signal. F_o is obtained from the electroglottograph (EGG) (3) or from acoustic signals. The extent of vocal fold abduction is also obtained from the EGG. The pneumotachograph signal provides information concerning initiation and termination of phonation as well as information about appropriate vocal fold gestures for production of voiceless versus voiced segmental distinctions.

The *Sustained Duration Game* was developed to teach the child to produce sustained vocalizations for 1 to 7 seconds. The ability to sustain voicing (or even produce voicing on demand) is frequently lacking in young, prelingually deaf children, and is considered a prerequisite to production of connected speech (4). The display for this game consists of a series of rectangles, with lengths proportionate to the target duration of each vocalization (**Figure 1**). Using menus, the therapist can easily set parameters for the target duration, criteria for success (i.e., percentage of time during which phonation must occur to receive a reward), and voice intensity. The option to set these parameters facilitates individualized training. Once variables have been set by the therapist, 5 rectangles are outlined on the left side of the screen. Voice initiates the graphic display. While the child sustains vocalizations, the rectangles are filled with a color from left to right. Whenever the child fails to vocalize, or his/her vocalizations fall below the criterion intensity level, the rectangle is left blank in proportion to the unsatisfactory period of time, and no reward is given. A successful vocalization results in a graphic reward to the right of the filled rectangle. Following each attempt, the program is ready for the next trial.

The graphic reward consists of animated color figures such as a bunny that dances, a bear that waves and wiggles its ears, a star that flashes color, a happy face that winks, and a chick that pops from an egg. The child can choose a specific reward, or rewards can be selected randomly by the computer. The set of rewards is used in all the games that involve intensity.

The *Repeated Short Vocalizations Game* was designed to facilitate production of a series of distinct syllables (for example, [ba, ba, ba, ba, ba]), such as CV (consonant-vowel) or CVC, within a specified period of time. This vocal activity is intended to facilitate production of basic motor-

[1]We will use the terms "clinicians" or "therapists" interchangeably to refer to all individuals, regardless of training, whose responsibility is to provide speech therapy to deaf children.

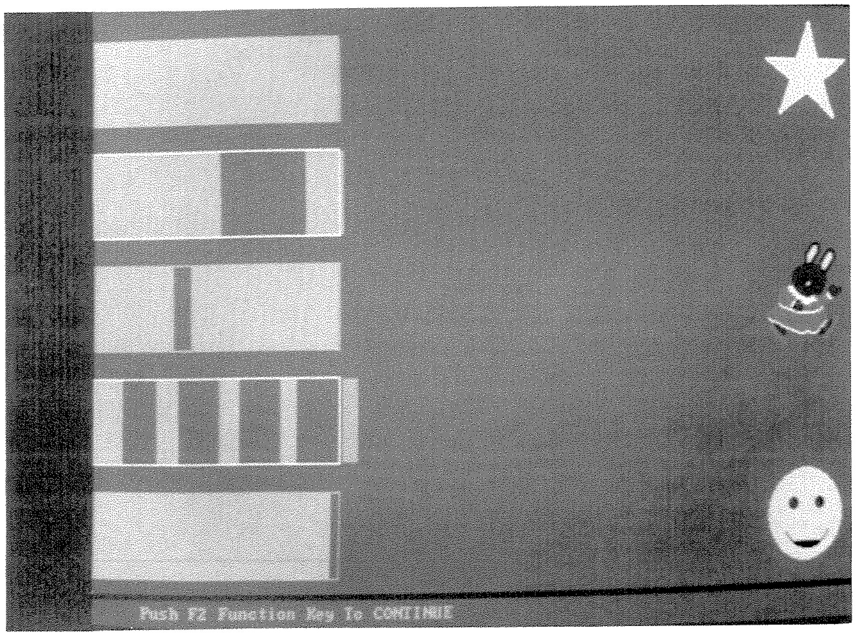

Figure 1.
A display from the *Sustained Vocalization Game.* The horizontal dimension of the rectangles corresponds to a 2-second vocalization duration (c). Vocalizing causes the rectangle to fill with color from left-to-right, with interruptions in vocalization resulting in gaps in the fill (b). Rewards are administered when the criteria set by the clinician for the vocalization have been met (a).

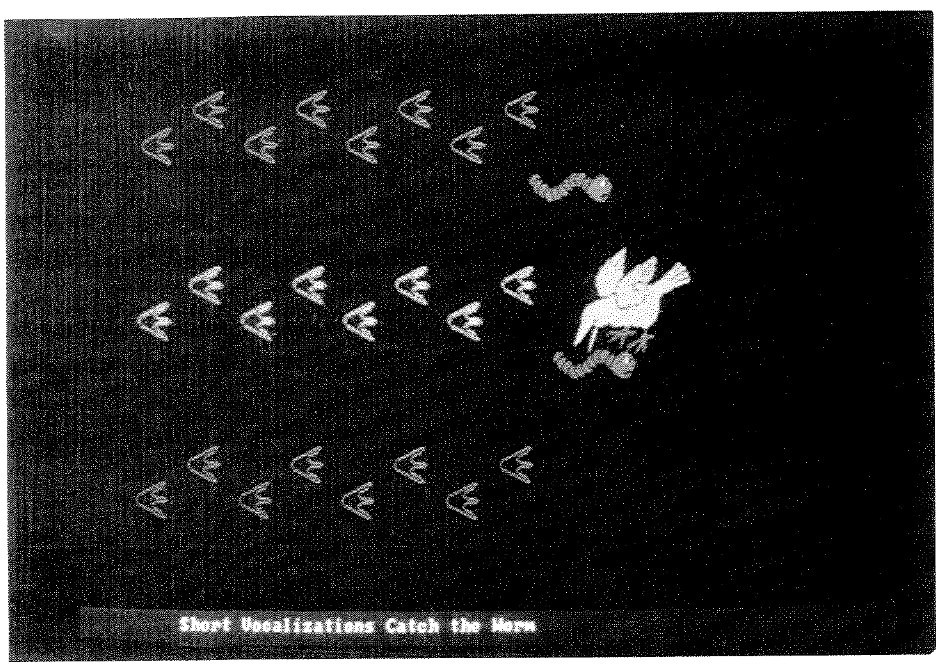

Figure 2.
A display from the *Repeated Short Vocalizations Game.* Each footprint corresponds to a target syllable production. Three trials of 8 syllables each are shown on the displayed screen. At the onset of vocalization, a worm appears below the footprint and begins to move across the screen at a speed proportional to the selected speaking rate. The bird jumps from one footprint to the next after each distinct vocalization. If the bird beats the worm in the race across the screen, it picks up the worm and flies off the screen.

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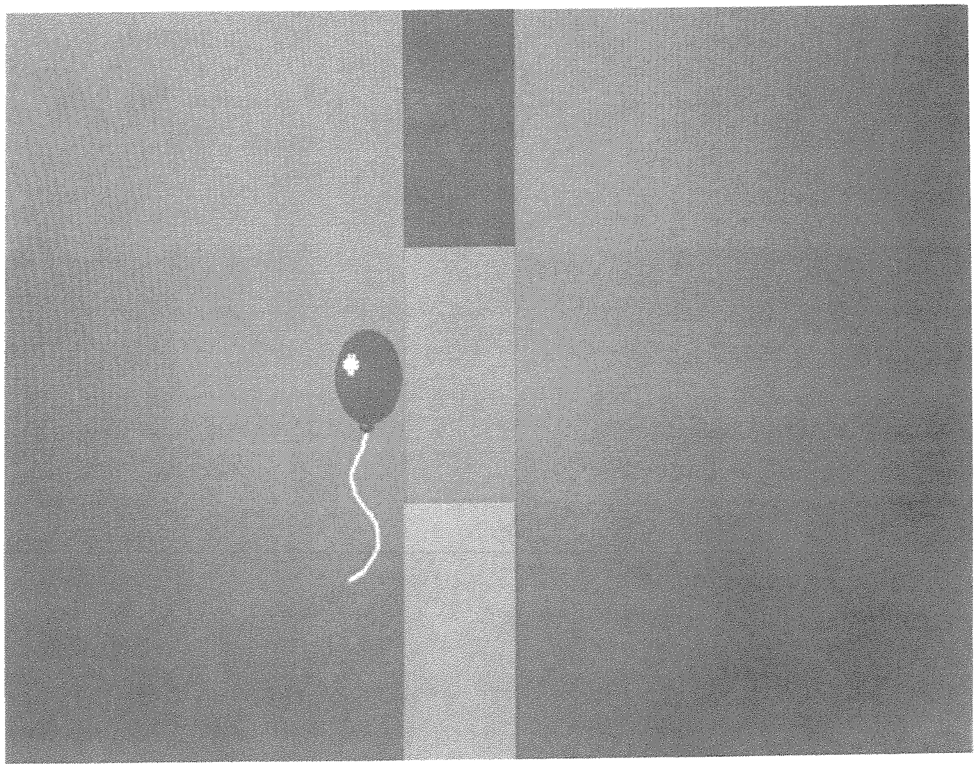

Figure 3.
A display from the *Intensity Game with Immediate Feedback*. This game is designed to teach the child an association between acoustic intensity and the height of the balloon on the display. As the child vocalizes, the balloon rises and falls next to the bar, in proportion to the child's vocal intensity. The 3 color regions on the bar correspond to low, moderate, and high intensity levels.

kinesthetic patterns required for correct syllabification (4). The clinician can specify independently the number of syllables and the rate of production. The total number of syllables can be varied between 1 and 15, with the rate varied from 1 to 3 syllables per second. The system checks to make sure that the child does not produce voicing between syllables, and considers multiple syllables with continuous voicing to be a single production (for example, when the vocal folds continue to vibrate between 2 "ba" segments, such that there is minimal reduction in acoustic energy during the consonant segment).

The initial display for this program is a series of bird's footprints, each footprint corresponding to a target syllable production (**Figure 2**). At the onset of vocalization, a worm appears below the footprints and begins to move across the screen at a speed proportional to the selected speaking rate. The bird jumps from one footprint to the next after each distinct vocalization. If the bird beats the worm in the "race" across the screen, it picks up the worm and flies off the screen. If the child fails to produce the desired number of syllables at the desired rate, no animation follows, and the bird is simply positioned at the next set of footprints.

The *Intensity Game with Immediate Feedback* provides real time visual feedback for acoustic intensity, which is used to familiarize the child with a loudness scale, and to train the child to control acoustic intensity prior to attempting subsequent intensity games.

This game is designed to help the child learn an association between color and height on the monitor screen, and the motor-kinesthetic patterns required for controlling intensity. This is accomplished by having the speaker's acoustic intensity, converted to a perceptual loudness scale, control the vertical position of a balloon along a vertical bar (**Figure 3**). The bar is divided into blocks of 3 different colors. Colors on the bar correspond to 3 different intensity levels. Blue, at the bottom, corresponds to low-intensity speech; green, in the middle, corresponds

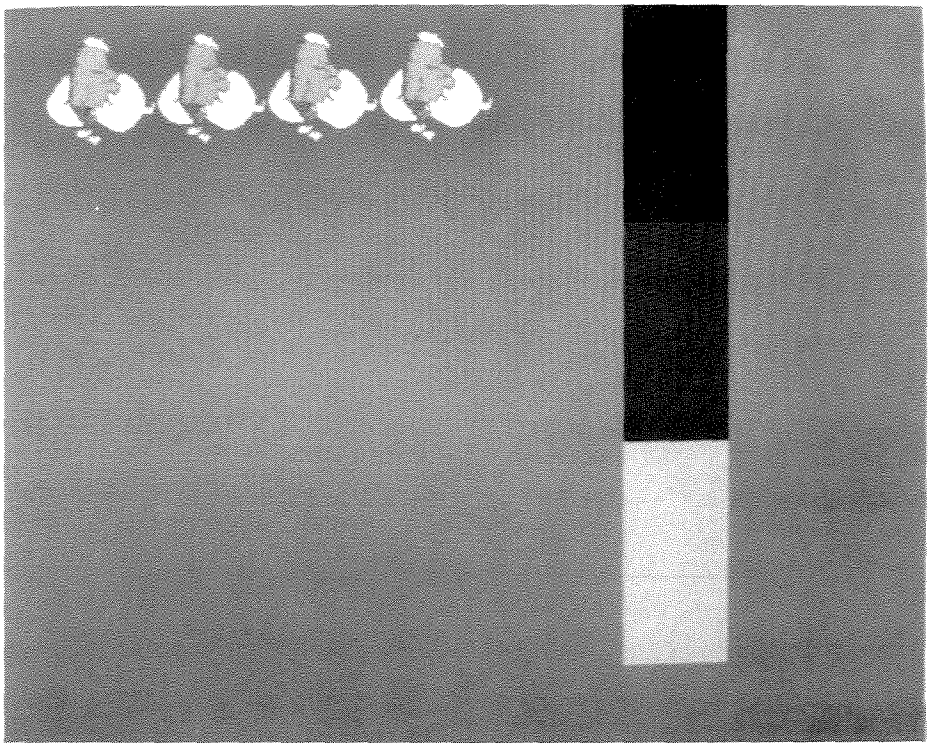

Figure 4.
A display from the *Intensity Game with Delayed Feedback Game.* A target intensity level is shown by the pointing hand, and the child is required to produce voice at that level. The vocalization is then compared to a criterion and a reward issued if the production is judged to be correct. Feedback is also provided by movement of the balloon to the level corresponding to the vocalization produced.

to conversational speech levels; and red, at the top, corresponds to loud speech. As the child vocalizes, the balloon rises and falls next to the bar in proportion to the child's vocal intensity. The therapist can also select specific target intensity for the child to attempt.

The *Intensity Game with Delayed Feedback* was developed to facilitate carryover of intensity control skills. This game employs postponed feedback, intended to nurture independence from the aid. During the game, a target intensity level is chosen randomly and is indicated by a picture of a hand pointing to various positions on the intensity bar **(Figure 4)**. When the child attempts to produce a vocalization at the designated intensity level, the vocalization is sampled and compared to the criterion level. Correct vocalizations can be followed by a display of one of the previously described animated graphic characters. Numerical scores can also be given to motivate 2 or more children in the context of a competitive game. When scoring is chosen, the game begins by requesting that the child's name be typed, so that it can later appear on the screen with the child's score.

The *Intensity Game with Limited Feedback* utilizes a graphic of a clown holding balloons whose colors correspond to target intensity levels **(Figure 5)**. The game does not make use of the vertical dimension to indicate loudness, only the color-loudness association. During the game, each balloon represents a trial. A trial is initiated by a blinking balloon. The child must then produce a vocalization at the intensity corresponding to the color of the balloon. The balloon blinks for 2 seconds while speech is sampled. Success results in a graphic reward appearing over the target balloon. Incorrect vocalizations result in no action by the game. The option of offering a numeric tally of correct productions is also available for this game.

The *F_o Puzzle Game* was designed to provide feedback for F_o. This game has been used to teach children to produce speech in a prescribed F_o range

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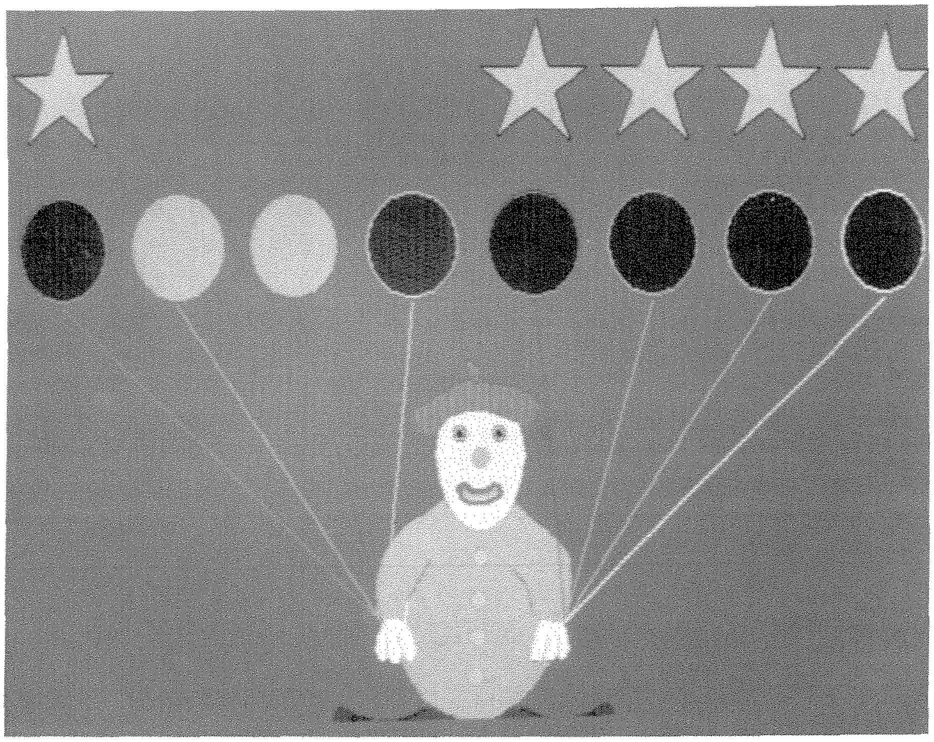

Figure 5.
A display from the *Intensity with Limited Feedback Game.* Each balloon represents a separate trial, with the color of each balloon corresponding to the intensity levels used in the earlier intensity training games. Successful production of a target intensity level results in a graphic reward appearing over the target balloon.

and to produce F_0 contour patterns associated with intonation.

Clinical experience to date has been exclusively with the F_0 information obtained from the EGG, although the current implementation of the STS and SPS is capable of F_0 extraction from either EGG or microphone signals. Cycle-to-cycle pitch periods are scaled and displayed as a function of time, with time along the abscissa and F_0 along the ordinate (**Figure 6**). The clinician can select the total duration to be displayed on the time axis, as well as the total F_0 range to be displayed.

To play the game, the therapist draws a box on the F_0 display indicating the target frequency range and duration for vocalizations. If the child's F_0 remains within the borders of the box, a small, randomly-selected piece of a puzzle appears on the upper right area of the monitor. The therapist may select from a menu the number of pieces comprising the picture (i.e., 2 to 16) and the picture the puzzle will form. When the child has produced the correct number of vocalizations to accumulate all the puzzle pieces, the scrambled puzzle pieces are enlarged to fill the entire screen. Using a cursor, the child moves the pieces to unscramble the puzzle. For younger children, for whom the puzzle is too difficult, the option of pressing a single key, (F2), was provided to assemble the puzzle.

Physiological measures

A measure of vocal fold abduction has also been implemented, making use of the EGG signal, but has not yet been incorporated into a game. The abduction measure has been shown to reflect degree of vocal fold abduction during phonation, an adjustment required for production of unvoiced segments and shown to be associated with excessive breathiness during voice production (9,10).

The abduction measure is based on the relative decreased duration of vocal fold contact, during a vibratory cycle of the vocal folds, associated with breathy voice production. To obtain the index of vocal fold abduction, cycle-to-cycle measures of the

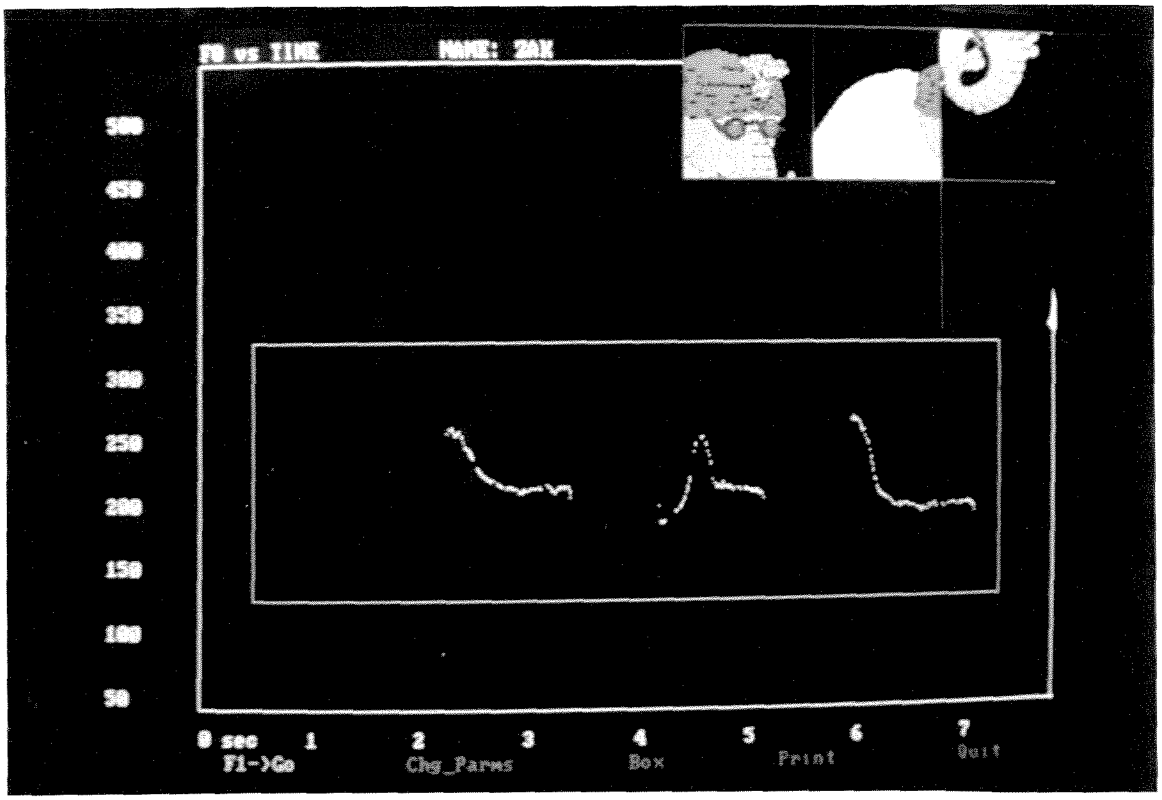

Figure 6.
A display from the *Fundamental Frequency (F_0) Puzzle Game.* Production of vocalization with F_0 that occurs within the borders of the box results in the display of a small randomly-selected piece of a puzzle on the screen. Correct production of 6 vocalizations will result in the presentation of all puzzle pieces. The child then has the opportunity to unscramble the pieces, using either arrows or a mouse. The total number of pieces, criteria for rewards, etc., are under the control of the clinician.

duration of vocal fold approximation, and the overall duration of a glottal cycle are extracted (2). This information is used to compute an abduction measure for each glottal cycle, using the procedure described by Rothenberg and Mahshie (9). The computer displays the abduction measure on a scaled screen as a function of time. The display gives time along the abscissa and degree of vocal fold approximation along the ordinate. The clinician is provided control of the total duration displayed on the time axis.

Software has also been developed to provide a simple display of airflow (from the pneumotachograph) for monitoring accurate initiation and termination of phonation as well as appropriate vocal fold gestures for production of a voiceless versus voiced distinction. Thus far, only oscillographic type displays (airflow versus time) have been developed and utilized (**Figure 7**), and only very preliminary clinical experience has been obtained. A similar display has been shown to be useful in modifying atypical devoicing behavior in deaf adults (6).

Clinical evaluation of the STS and SPS

Sixteen children between 3 and 11 years of age worked regularly with 2 clinicians who were part of the development team. As discussed in Bernstein, Goldstein, and Mahshie (1), the clinical work was intended primarily to provide human factors information to the developers, although assessment of the clinical benefit was also conducted on a limited basis. Both the SPS and STS were used by the clinicians during therapy for approximately 15 months, from September, 1985, through December, 1986. During this period, the therapists (DV-A and BW-S) kept records regarding: 1) ease of use and practicality of the aid; and, 2) benefits and/or limitations to the children and therapists. In addition, video recordings of training sessions were obtained during a 2-week period of use.

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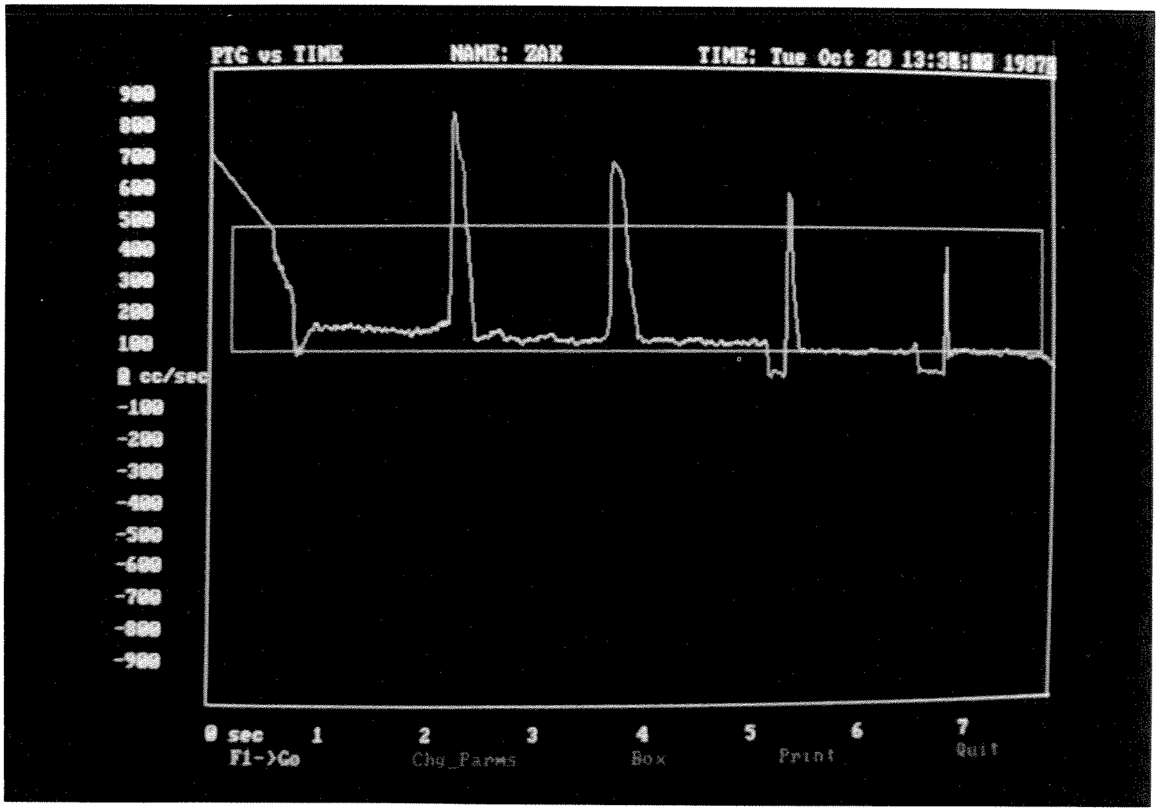

Figure 7.
A display for monitoring average airflow associated with speech production. Shown is average airflow (cc/s.) along the ordinate and time along the abscissa for production of a series of intervocalic consonant segments by a normal hearing speaker.

Subjects

Fourteen prelingually, profoundly deaf children ranging in age from 3 to 11 years, and 1 adventitiously deaf child (age 11 years), participated in the project. Each child's audiological report documents a profound bilateral sensory-neural hearing loss. All children were fitted with, and routinely used, ear-level hearing aids in school. No other handicapping conditions were noted. One of the 15 children withdrew from the project before its completion due to geographical distance and lack of interest after several months of participation. The reported etiologies of the hearing loss of the remaining 15 children were: 2 from cytomegalovirus, 2 by meningitis, 6 from hereditary factors, and 5 from unknown etiologies.

Total communication (using pidgin signed English) was used in all the children's educational settings, except for the 11-year-old adventitiously deaf child. This child was educated orally until she was 10 years old, at which time she was enrolled in a total communication program. She is still in the process of developing her signing skills. Both signs and speech were used during her therapy.

Clinical evaluation sites

STS aids were used at the Kendall Demonstration Elementary School, Gallaudet University, Washington, DC, and the Speech Processing Laboratory of The Johns Hopkins University in Baltimore, MD. The speech pathologist (BW-S) at the Kendall School used a STS with 7 of the preschool children, ages 3 to 5 years, as part of their regular in-school speech therapy program. The children were seen twice a week for 20 minutes in small groups; usually 2 to 3 children per group. For 2 weeks in the summer of 1986, BW-S used the STS with 3 primary school children (ages 8 to 9).

A STS was used clinically in the Speech Processing Laboratory at Johns Hopkins University, where

hardware and software development was ongoing. Five children ranging in age from 7 to 11 years came to the laboratory for speech therapy sessions after their normal school day. Both individual and small group therapy was conducted, with therapy sessions lasting for approximately 1 hour. DV-A conducted all the therapy sessions in the laboratory.

Evaluation

Ease of use. Both clinicians reported that the system was easy to learn. The function and arrow keys on the standard IBM-PC keyboard, used for program control, minimized the time needed to train the children to independently operate many of the games. Both therapists agreed that the simplified key arrangement permitted fairly rapid movement through the menus.

The therapists also reported that control of parameters, such as the threshold level for the intensity games, is a desirable feature that permits tailoring of games to the needs of the individual child. However, the default settings were adequate for most parameters, and saved set-up time.

The software was intended to meet the needs of children between the ages of 3 and 11 years. Among those needs are 2 systems that are easy to operate and control, even by the youngest children. BW-S observed that children as young as 2-and-a-half years of age had no difficulty understanding and controlling the games. We do not know whether even younger children would be able to attend to and utilize the aid.

Reliability. Reliability was considered in terms of dependability of the hardware/software system as a whole, and in terms of the signal processing and displays. Because evaluation took place continuously with development, signal processing and display problems did occur in the context of therapy. The clinicians felt, however, that such problems were solved expeditiously as they were discovered. Programs processed signals and generated displays as expected. That is, the clinicians usually agreed with the judgments made by the system.

Some occasions did arise when there were disagreements between the computer and the clinician. Some of these disagreements may have been due to a more lenient or different application of criteria by the clinicians than by the computer. For example, the goal of the repeated short vocalizations program is to facilitate production of syllable sequences with clear interruptions in phonation between each syllable. However, the clinicians were either less able to detect continuous voicing or were less rigorous in their application of criteria. As a result, productions in which there was some reduction, but not cessation of voicing, were considered acceptable by the clinician but not by the computer. In this case, the clinician told the student that the computer had made a mistake, and that the production was a good one.

A different class of computer-clinician disagreement was due to the ability of the clinician to monitor several attributes, while the computer was attending to only a single parameter. For instance, the clinicians often considered production of a loud voice with aberrant vocal quality as unacceptable, even though the goal of the game being used was control of loudness. Current work is directed toward signal processing and games that involve multiple levels of processing.

The most serious engineering problem concerned the collection of intensity trials using the acoustic signal. Initially, the microphone was placed on a gooseneck so that it could be passed from child to child. The children and therapists were required to hold the microphone close to their mouths in order to reduce the effects of ambient room noise. However, at close range, small movements in mouth-to-microphone distance can result in significant differences in estimates of loudness. Therefore, a child might produce a very loud utterance at a considerable distance from the microphone, and the resultant feedback would indicate production of a quiet voice. This created confusion for some of the children, until the therapist explained that the mouth-to-microphone distance should be kept constant. Interestingly, children whose speech skills were more advanced appeared to be aware that the computer was "wrong." When the children phonated, and the aid failed to respond in the predicted manner, they would look to the therapist for an explanation. The therapist's response in these cases appeared to satisfy the children, and they generally accepted that the computer was wrong in these instances. The problem was corrected with a fixed placement of the microphone at some distance from the speaker, and with some changes in software to accommodate ambient room noise.

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Childrens' reactions to the software. Many attributes of the aid were attractive to the children. They were reported to enjoy the colorful and dynamic displays. It was observed that all the children genuinely enjoyed playing the games. Frequently, children at the Kendall School would enter the therapy room and use the computer, even when they were not scheduled for therapy.

The aid motivated the children to practice without the direct supervision of therapists. The availability of feedback encouraged increased attempts to correctly produce the desired target. DV-A reported that the older children maintained their interest in working on speech for a longer time than they might otherwise, with the computer-based sessions lasting well beyond the half-hour duration of a typical school session. BW-S reported a similar trend among the younger children. Both clinicians agreed that the children were willing to work on speech goals more frequently with the aid than they would have using more conventional therapy methods. Similar findings have been reported by Osberger, Moeller, and Kroese (8).

This increased interest may be due to the challenging tasks offered the children, and the ability to individualize the games and activities. Since it was possible to customize the criteria for each child, the clinician was able to alter the difficulty level in small increments whenever the child demonstrated sufficient consistency at the previous criterion level. As a result, children continued to be challenged, while frustration was minimized.

The element of competition was especially motivating to the older children. After working for some time with the graphic rewards, the older children continued to work when the numerical score was provided. Frequently, competition among children resulted in sustained attention to the speech tasks. Numerical scores motivated children as young as 5 to 6 years of age.

Across the age range, increased quantity of vocalization resulted from use of the F_o Puzzle Game. The clinicians reported that a number of the children exhibited greater control over pitch variations while watching the F_o display. The therapists further noted that this game provided an efficient means of eliciting a broader range of vocalized frequencies than would likely be obtained using more conventional methods.

These results are similar to those reported in the literature for older children (7) and with young adults (6), suggesting that the use of such displays, in conjunction with therapy, results in improved ability to control F_o both with and without the presence of the feedback.

Clinical benefits. Experience suggests that the aid can be used in therapy with children from 3 years old to early adolescence. The clinicians reported that the aid provided more clinical benefits than they had expected prior to using it. They were enthusiastic about the reduction in time required for them to develop creative materials intended to motivate children, and the increase in the time available for therapy. They also commented favorably about the ease with which the aid could be integrated with more traditional therapy techniques. The traditional strategy of indicating production of a sustained vocalization is by moving the finger along the child's arm or pulling a toy across the table: the Sustained Vocalization Game provides an analogous display.

When 2 or more children worked together on the aid, turn-taking and friendly competition resulted and was encouraged. Increased language output was reported among the children, as well as between the children and the clinician. The children often demonstrated an understanding of the desired speech goals by attempting to explain to each other how to produce the desired targets.

Therapy activities sometimes involved the creative use of the software. The older children created their own game with the F_o display by drawing "maps" on transparencies that could be placed on the monitor screen. The locations on the map served as the fundamental frequency targets for subsequent activities whose goal was to increase the childrens' ability to control and modify F_o. DV-A reported that this activity allowed the therapist to observe the children's self-assessment of F_o goals.

The therapists reported that with increases in vocalization, notable phonatory changes also occurred in vocal characteristics other than those addressed directly during the therapy session. One child who exhibited a weak, breathy voice improved the quality of her productions while working on increasing duration of sustained voicing.

The objective measures supplied by the aid were also reported to be positive clinical attributes. Quantification of F_o, duration, and intensity levels

enabled the therapists and children to judge the relative correctness of production across sessions.

The clinicians also agreed that use of the system helped them to attend to single speech parameters. Because displays were based on a single parameter (F_o, intensity, etc.), it was easier to "filter out" attributes of the children's speech other than those being worked on.

The ability to view individual speech parameters was also useful in training other clinicians. Ten graduate students in speech and language pathology used the aid in the school during a 2-week period. The clinical supervisors commented that the clinicians used the computer aids to establish criteria for acceptable versus unacceptable production of individual speech attributes.

When both child and therapist have equal access to objective information about speech production, rewards for incorrect production are less likely. This was found to be true with the F_o display. Also, by minimizing dependence on auditory skills alone to monitor correctness of the speech target, hearing-impaired teachers can take a more active role in the speech training of the children in their classes during drill and practice.

Evaluation of the home-based speech training aid

One of the goals of this project was to develop a home training aid. The rationale for this goal is that by extending accessibility of monitoring and feedback capability outside of the therapy room, increased speech-practice time will be achieved, and consequently, better speech. Accordingly, SPS's were placed in the homes of 5 children for periods of 1 to 2 weeks. Four of the children were 3 to 5 years old, and 1 was 10 years old.

Parent orientation and record-keeping. Before the aid was placed in a child's home, a brief orientation was provided to the parents by the project engineer and the speech/language pathologist. During the orientation, project goals were described, system operation was explained and demonstrated, and procedures were described for solving any problems that might arise. During the orientation, parents were given an opportunity to "play" the games and ask questions.

To obtain information regarding use of the SPS, 2 types of questionnaires were prepared: a session form, to be completed after each practice session; and a general impression form, to be completed at the end of the home trial period. The session forms required "yes/no" and multiple choice responses, and some brief descriptions. Space was provided for the parent/reporter to make any additional comments they felt to be useful. A parent completed the forms for the younger children. A 10-year-old female subject completed the session forms without parental assistance. The impression forms were completed by the parents at the end of the home trial period. The forms consisted of questions requiring responses on a 5-point scale (from easy to difficult), "yes/no" questions, and general comments. Procedures for completing the forms were explained during the orientation, and each family was given a packet containing instructions for completing the forms (approximately 15 session forms, and 1 impression form).

All of the games that used acoustic input parameters (i.e., Sustained Duration, Repeated Short Vocalizations, and Intensity with Immediate, Delayed, and Limited Feedback) were installed on the home aid. Home sessions were developed by the therapist for 4 of the children, using an interactive program that permitted selection of games to be presented, the number of times an exercise was presented, the sequence of games, display parameters, and criteria levels. Individualized games for home practice were consistent with the child's activities in school. Development of a home game disk typically required approximately 5 to 7 minutes. At the end of each therapy session during which the school device was used, a child was given a home disk. In addition to storing game parameters for home practice, this disk was used to log the time the child spent using the device. (Complete records were not obtained for all the children, so those data are not reported here.)

The 10-year-old child (Subject 5) brought the device home for a 1-week period, during which there was no simultaneous work being done in school. This child was given all the options for use at home and was allowed to select among the various games in any order desired. Certain game parameters were established by the clinician, based on the child's use of the STS during the school year. The child was also able to select other options, such as the duration of the Sustained Vocalization Game and the number of vocalizations required for the Repeated Short Vocalization Game.

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Parent observations of the home aid. Parents' questionnaire responses indicated that orientation to the computer and directions given before taking the aid home were clear and helped them in using the system. They were able to start the system and run the appropriate software. The parents further indicated that the aid and software were helping their children toward the acquisition of desired speech goals, and that use of the aid at home was a positive experience. Three of the 4 children reportedly were able to operate the games independently. One parent, however, noted that the fixed order of the presentation of games was a limitation, presumably because the child was sometimes unable to continue work on the activities in which he was most interested.

One exception to the generally favorable results was that the family of S4 experienced difficulty using the home system. While the system was in the home for 2 weeks, the parents were unable to get it to operate until day 3, and it was not until day 6 that all the games were working correctly. This family was the first to receive the home system, and some "bugs" were worked out during this 2-week period. This experience appeared to have had a negative effect on S4's enthusiasm, as well as his parents'. Four families reported some instances in which the software malfunctioned. However, described failures were not replicated in the laboratory.

The difficulty level of activities sent home appeared appropriate, and rewards were reported as "helpful." Two parents suggested, however, that rewards could have been more exciting ("like fireworks"). Perhaps the parents were commenting on their own impression of the rewards, not their children's interests, since the children have shown consistent enthusiasm for the graphic displays when used in a clinical or laboratory setting. Three of the families reported that the games seemed appropriate, but the other 2 families thought the games were too easy. Three families wanted a larger selection of games. These comments may be attributed to the extensive experience these children had with the aid at school, the relatively small number of different activities currently available, or to the difficulty the parents had making clinical judgments. All parents reported that the durations of the games seemed appropriate, and that each child had a favorite game.

Table 1 summarizes the number of sessions, total time, and mean time the children used the aid in their homes, based on logs kept by the parents. The SPS was used at home for a total of 679 minutes. Times ranged from 51 minutes to 185 minutes per week. Mean time per session for individual children ranged from 8.5 minutes to 34 minutes. It should be noted that the child who used the aid the least was the youngest child (S4), whose parents had initially experienced difficulties with the system.

Table 1.
Childrens' use of the Speech Practice Station (SPS).

Subject	Total time (mins.)	Mean time/session (mins.)	Total number of sessions	Days in home
(S1)	140	23.3	7	7
(S2)	185	20.5	9	7
(S3)	170	34.	5	7
(S4)	102	8.5	12	14
(S5)	82	10.25	8	7

Based on logs kept by the parents.

Parents commented that sessions included adults and siblings. The device served as a focal point for speech activity. Since increased interest by the family is important for realization of spoken language (5), this result suggests a very positive benefit from using the system.

SUMMARY AND CONCLUSIONS

The project goal was to develop and assess 2 related computer-based speech training aids used to facilitate speech development in deaf children. The aids appear to have promise as both an aid to, and extension of, speech activity in the therapy room. Results of assessing certain human factors, such as ease of use by clinician and children, acceptance of the aid and displays by the children, and ability to incorporate the aids into existing therapy models were promising. The general impression of the clinicians was that the aid resulted in increased willingness by the children to work on speech skills,

and thus reduced the time and effort spent attempting to motivate the children to practice speech activity. The speech parameters obtained by the systems (intensity, durational, and F_0 attributes of speech) represent the most elementary aspects of speech production that are necessary for a young deaf child to develop speech (4). Selection of such basic aspects of production resulted in incorporation of the aid into daily clinical practice with minimal effort.

Assessment of the accuracy and consistency of the aids reveals that, although certain differences do occur between computer and clinician judgments, there is reasonable agreement. Discrepancies between clinician and machine judgments may have been due to the clinicians having somewhat more lenient or altogether different criteria for the childrens' productions than the computer. Other discrepancies appeared due to the aids' provision of feedback based on individual speech parameters, while clinicians often simultaneously monitor several different attributes.

Results of home use as an extended therapy aid suggest that the device resulted in speech activity at home that would not likely have occurred otherwise. By permitting the clinician to control the performance parameters associated with the games at home, it was possible to maintain consistency between home and school speech activities that would have been difficult to establish. While use of the SPS in the home appears promising, a greater variety of games and activities was requested by the parents. Because such observations are somewhat at variance with clinical observations of the children with the same games, these comments raise a potential issue associated with bringing a speech training aid into the home. The parents' remarks may actually reflect an inability on their part to adequately judge the speech skills that children should practice. While new games are currently being developed for the STS and SPS, additional consideration of the implications of bringing therapy home is clearly needed.

The development of speech training aids for use with prelingually deaf children is feasible. While the present system has achieved many desirable features, further work remains. Additional features, such as simultaneous feedback for prosody and vowel identity, are being developed. An expanded ability to monitor attributes of consonant production features is also desirable. Clearly, future evaluation must include more formal and larger scale designs for assessment of the benefit to speech of those using the aids. Such an assessment is currently being planned.

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