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THE SOUND-TO-SPEECH TRANSLATION SYSTEM USING PHOTOGRAPHIC-QUALITY GRAPHIC SYMBOLS

The Sound-to-Speech Translation System Using Photographic-Quality Graphic Symbols (STS/Graphics System) is a voice-recognition computer-based system designed to allow people with mental retardation and/or severe physical disabilities to communicate with others and to control their environment. This includes people with quadriplegia, spinal cord injury, cerebral palsy, aging problems, arthritis, and various neurological disorders. Operation of the STS/Graphics System is through vocalization, switch closure, or keyboard input for activation of electrical appliances and/or digitized speech output. Choices available to the user for system operation are presented as customized photographic-quality symbols representing familiar items/persons in the user's environment that are displayed on a monitor. The user makes choices through direct selection, linear scanning, or row/column scanning. The system represents a powerful and versatile means by which children and adults with severe disabilities can increase their independence and productivity. Assessment and educational applications are additional uses of the system.

INTRODUCTION

The American Association on Mental Retardation states that

> Mental retardation refers to substantial limitations in present functioning. It is characterized by significantly subaverage intellectual functioning, existing concurrently with related limitations in two or more of the following applicable adaptive skill areas: communication, self-care, home living, social skills, community use, self-direction, health and safety, functional academics, leisure and work. Mental retardation manifests before age 18.[1]

A person with mental retardation may need one of four possible levels of support: (1) intermittent, does not require constant support; (2) limited, requires certain supports consistently over time; (3) extensive, needs daily support in some aspects of daily living; and (4) pervasive, requires constant, high-intensity support for all aspects of life.[2] Although information is limited on the number of people with mental retardation who do not communicate orally, a recent study in the state of Washington estimated that about 4% to 12% of school-aged children with mental retardation needing intermittent to limited support, and 92% to 100% of people with mental retardation needing extensive to pervasive support, were nonvocal communicators.[3] In total, more than two million children and adults in the United States have mental and/or physical limitations so severe that they are unable to communicate effectively with other persons without augmentative or alternative communication assistance.[4] As defined by the American Speech–Language–Hearing Association,

Augmentative and alternative communication (AAC) is an area of intervention in which attempts are made to compensate and facilitate, temporarily or permanently, for the impairment and disability patterns of individuals with severe expressive, and/or language comprehension disorders.[5]

Many users of AAC devices have multiple handicaps, that is, they might have any combination of severe physical impairments, sensory impairments, and mental retardation.[6] Augmentative and alternative communication systems for such people can be simple or sophisticated—for example, a cardboard sheet with pictures that depict communication needs or a computer that produces speech. Major contemporary issues in AAC research involve defining the parameters that facilitate the optimal use of these communication systems. Additionally, in the design of an AAC system, consideration is given to identifying the optimal access methods, type of speech output, and additional functions and features beyond speech, such as environmental control and data recording and analysis.

Recent studies suggest that the use of speech-output communication systems can have a significant effect on the communication skills of nonspeaking persons with cognitive disabilities.[7] Defining the parameters for optimal use by people with mental retardation needing extensive to pervasive support can be especially difficult, however, because of their delayed language comprehension and expression, the variation in their ability to process information, and their limited ability to understand the meaning of symbolic representations.[8] One of the most critical and challenging issues in using AAC systems

with people with mental retardation is the development of effective teaching strategies to ensure that the person can successfully and flexibly use the system.[9]

During the past five years, voice-recognition technology has advanced to the point where it now represents a viable and versatile means of alternative access to education and habilitation for persons with severe disabilities.[10] Speech is the most natural way to communicate and to participate in the environment; therefore, it is also a natural means by which to empower a person. A growing body of research has been conducted on the use of voice-recognition technology with people who have normal cognitive abilities but who also have unintelligible or no speech.[11,12] On the basis of this research, it is reasonable to believe that computer technology configured with voice-recognition access for communication and environmental control has the potential to compensate effectively for the limitations imposed by mental retardation and physical disabilities. Relatively little research, however, has been attempted thus far with voice-recognition technology that addresses the needs of the population subject to those limitations.[13,14]

The research described herein involves the design and development of a voice-operated AAC computer system that was used by children and young adults with mental retardation to communicate and to control their environment through no greater effort than the vocalization of simple sounds.

THE SOUND-TO-SPEECH/GRAPHICS SYSTEM

The Sound-to-Speech Translation System Using Photographic-Quality Graphic Symbols (STS/Graphics System) is designed to explore the potential of voice-recognition technology for persons with mental retardation. It is an extension of previous research and development conducted by Brown and Cavalier and their colleagues at The Arc. (The Arc was formerly the Association for Retarded Citizens of the United States.) In earlier research, a voice-activated computer system was developed and evaluated with a woman diagnosed with mental retardation and severe multiple disabilities, who needed pervasive support. The woman learned to voice activate the system to control electrical devices in her immediate environment.[13,15] This study was followed by research on a multi-user system with environmental control and speech output capabilities.[16] Neither of these studies employed a picture-based display to assist the user in making choices.

The next generation of this research track, the STS/Graphics System, incorporates a graphics display. Key features of the STS/Graphics System are as follows: (1) photographic-quality computer-generated images of items/persons in the user's natural environment that are presented on a display to represent choices among spoken communications and environmental control activations; (2) vocalizations, whether intelligible or not, that are used to select choices from the image display; (3) physical switch activations and traditional keyboard inputs that are alternative access modes; (4) voice and keyboard access modes to make choices via direct selection; (5) voice and switch input to make choices via linear scanning and row/column scanning; (6) speech output that is in the form of digitized, easily understood speech and that is age and sex appropriate; and (7) data on system use that are automatically recorded, thereby facilitating the development of appropriate training strategies.

Hardware

The following list of hardware components represents the minimum configuration required for the operation of the STS/Graphics System. Enhanced performance can be obtained with a 386 or 486 microprocessor and greater hard disk capacity. Additional random access memory will not enhance performance.

1. IBM-PC advanced technology (AT) or compatible with a 286 central processing unit.
2. 30 MB of hard disk space.
3. Super vector graphics adapter monitor.
4. Paradise graphics board.
5. Votan 2000 voice-recognition board.
6. Image capturing device with color capability.
7. X-10 Powerhouse controller and various wall modules.
8. 640 KB of random access memory.
9. Floppy disk drive.
10. MS-DOS 3.30 or greater.

A schematic diagram of these components with enhancements is shown in Figure 1.

Voice Input

The voice-recognition system incorporates the Votan 2000 voice-recognition circuit board (Votan, Inc., Fremont, Calif.) and software routines unique to the system developed at The Arc. When operating the STS/Graphics System, the user's vocalizations function as switches, and the user "trains" the computer by speaking the target vocalizations into the microphone. This sound is recorded digitally on the hard disk. The training is repeated three times, and each vocalization is recorded separately. After the three trainings are stored in a user-specific voice template, the STS/Graphics System software analyzes the three recordings and averages them. For scanning access to the system (see the discussion in the Access Modes section), the user-specific template is composed of trainings for one unique utterance. For direct-selection access to the system (see the discussion in the Access Modes section), the user-specific template is composed of multiple unique vocalization trainings. After all of the trainings are stored, the system verifies that the user's target vocalization matches one of the sounds stored in the voice template. If the match is not similar enough to the original trainings, then the user must retrain the voice template for that particular utterance.

When the user is actually operating the system and produces a vocalization, the system checks to see if the vocalization matches any of the trained vocalizations stored in the voice template. If a match occurs, the system acknowledges the vocalization by activating the appropriate speech output message or environmental control function; if the vocalization does not match any of the trainings closely enough, the system will not respond. If the system does not respond, two optional corrective actions

Figure 1. Hardware configuration of the Sound-to-Speech/Graphics System.
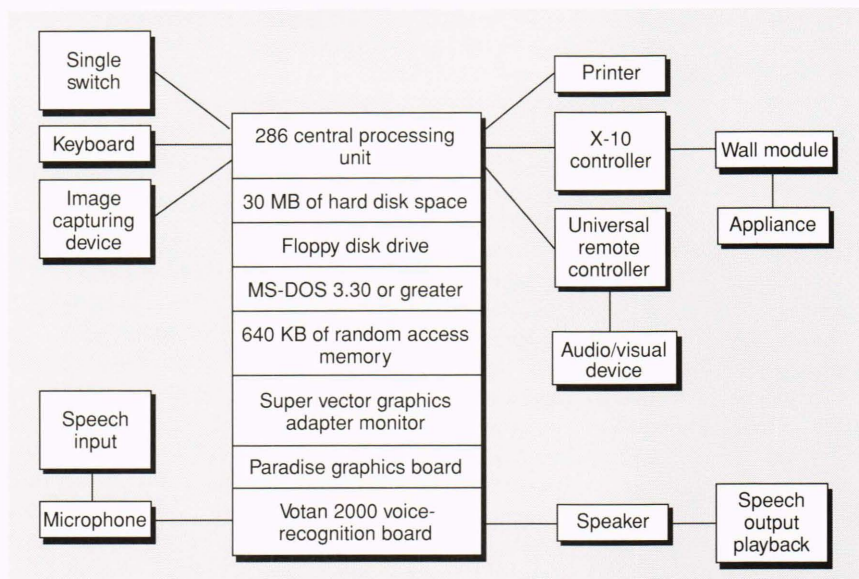
can be taken. First, the accuracy used by the system to match a vocalization to the stored voice trainings can be made less sensitive so that the system is less demanding in its matching requirements. Second, the user may choose to repeat the training process to refine a vocalization stored in the template for better recognition accuracy.

Sound-to-Speech Translation and Expansion

For communication purposes, each user can access speech output messages stored in digitized files on the hard disk. Each message can consist of speech of up to eight seconds in duration, thus permitting single words or complete sentences to be output. Someone whose voice is age- and sex-appropriate for the user records these messages into the system. The Votan board manages this process.

The system uses an algorithm to compare a user's vocalization with those previously stored in a voice template. If a match is found, the input is identified and linked to one of the speech output messages. In a sense, the user's often brief and unintelligible vocalization translates into intelligible speech and expands into a phrase or complete sentence. For example, if a user's vocalization for "water" approximates "wuh," the system can immediately output "Could I have a drink of water, please." Message files for many different users can be stored and accessed via one computer system. The number of available files depends only on the size of the system's hard disk.

Environmental Control

The system incorporates X-10 Powerhouse environmental control technology (X-10, Inc., Northvale, N.J.). The computer sends digital encoded signals over existing electrical wiring in the room or building in search of a lamp or wall module with the same identification code. The modules plug into wall outlets. The target module responds to the control signals transmitted from the computer and activates or deactivates the appliance plugged

into it. Any voice (or other) input can be linked to the activation and deactivation of designated electrical devices. A single voice input can also be linked to any combination of speech outputs and device activations; for example, the vocalization "pa" can translate into "I'm going to watch TV now," and the television set turns on.

The system also uses a One-for-All universal controller (Universal Electronics, Inc., Signal Hill, Calif.) to control any audio/visual device that operates through the use of an infrared remote controller. The universal remote controller operates via a serial input/output port located inside its battery compartment. Using a simple communications protocol, the computer system, through an RS-232 port, electronically presses the buttons of the remote control unit to operate a device.

Graphics Interface

On the video monitor, the system displays photographic-quality images of objects, appliances, and people in the user's environment. The sizes of the images, as well as the number of images appearing on the display, are customized to the user. This customization is achieved by digitally scanning photographs of items into the computer using an image-capturing device (a scanner or video camera) and then sizing the image using image-manipulation software such as PC Paintbrush. Extensive image libraries are created for the users. An image library consists of disks containing scanned images of items that have personal meaning to the user. The library is arranged by category and serves as an organizational model for the teacher or trainer. In this way, the same images are used by a variety of subjects in their customized displays.

Displays range from a single image to a 5×5 matrix of images. On a thirteen-inch monitor, the size of each of the four images in a 2×2 matrix is about 3.75×5 in.; the size of each of the twenty-five images in a 5×5 matrix is about 1.5×2 in. The graphics display can also "flip" to a second page of choices for each user. The two pages of images permit the configuration of a hierarchical

system of choices for users who understand the concept of categorical clustering. In such a system, the images displayed on page one represent superordinate categories, for example, an image for the food category, an image for the clothing category, and an image for the sports category. The selection of a page-one image displays a second page of images all related to the particular category selected on page one. It is not mandatory, however, that images on page one represent superordinate categories for the second page. On the second page, one cell is always designated as a "return" to page one.

The graphics images in this system act as cognitive prosthetic aids that remind the user of the speech outputs and device activations available. Whereas a user's voice input (or switch or keyboard input) initiates the sequence of electronic events that results in some functional output, the graphics images provide a symbolic representation of output choices that are "live," or available, at any one time.

Access Modes

The STS/Graphics System software provides two methods of accessing the system: direct selection and scanning. In the direct-selection mode, a user vocalizes a different sound for each image presented on the display. The scanning mode is operated in two ways: linear scanning or row/column scanning. In either scan mode, the system requires only a single vocalization to access all choices, and the vocalization does not have to be pronounced consistently from one occurrence to the next. The vocalization serves to stop the scanning sequence.

Once the scan halts, the functions associated with the image on which the scan stopped are executed (i.e., speech output, environmental control, or both). Alternatively, the scanning can be stopped by using a single switch.

Software Design

The customized system software has three major components: speech manager, setup, and sound-to-speech, as shown in Figure 2.

The speech manager has two discrete functions: the record function and the recognition function. The record function, shown in Figure 3, creates the speech output message files and groups these audio messages into categories appropriate for the user or setting. New categories and messages can quickly and easily be added or deleted. Each audio message has a corresponding text description in its storage file. The recognition function, shown in Figure 4, creates and manages the voice template that contains the user's recordings of single or multiple vocalizations. In the direct-selection mode, a different vocalization is linked to each image on the display. In the scanning mode, only one vocalization is stored in the system, and it serves to halt the scan sequence on the desired image, resulting in a selection.

The setup component of the software, shown in Figure 5, is used to combine image files, audio output messages, environmental control, and infrared commands and to assign them to specific cells in a matrix (from 1 × 1 to 5 × 5). When all of the desired cells in a matrix are filled with images (it is not mandatory to put an image in each
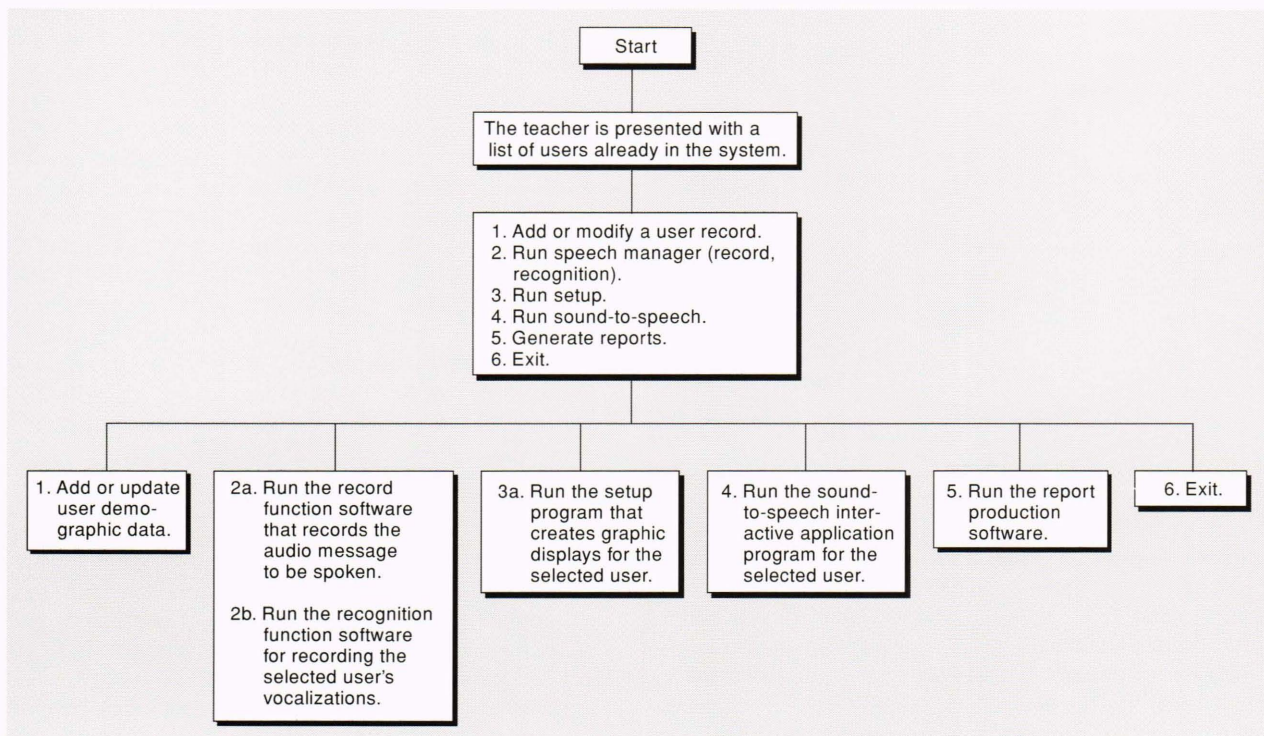

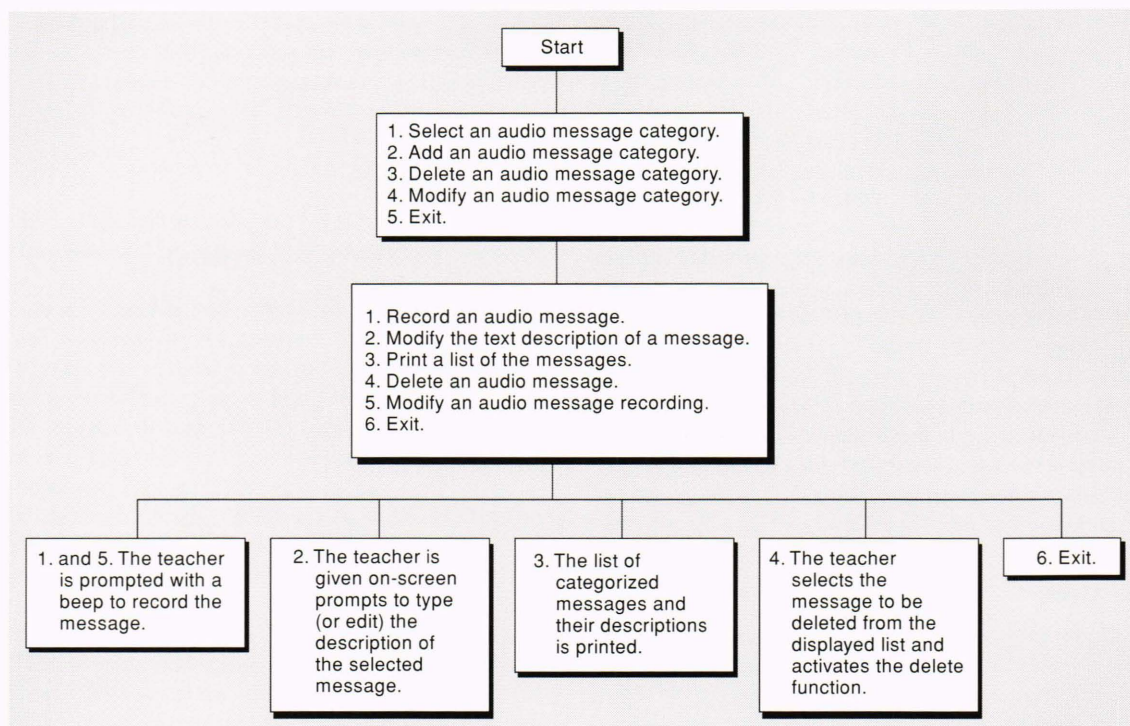**Figure 2.** Main menu of the Sound-to-Speech/Graphics System software.

Figure 3. Record function of the speech manager component of the Sound-to-Speech/Graphics System software.

cell), then the information is stored as a "page" file. Each page contains different graphics choices, and the user can flip between two pages, as explained in the Graphics Interface section.

Once the system has been configured for use, the sound-to-speech component presents the pages to the user, as shown in Figure 6. It is the interactive portion of the system and the only one with which a user interacts for communication and environmental control. Data collection on user activity occurs whenever the sound-to-speech component is active. The collected data can be output as a report.

Reports

The STS/Graphics System generates activity reports regarding its operation. As each user's choice is activated, a record of the interaction is written to a data file. This record consists of the time of day, the number of the cell selected on the matrix display, the name of the image that is displayed in the cell at that time, and the text of the speech output or the name of the activated environmental device. The report also includes demographic information on the user, the access mode, the name of the particular matrix display, the dimensions of the matrix, the sensitivity setting on the voice-recognition board, the matrix and scanning box (if one is used), colors, the names of the various images and their cell locations, their associated speech outputs or device activations, and phonetically spelled approximations of the user's voice inputs for the images. When the teacher or user so desires, the software can aggregate and analyze these data on the

user's activities and can generate on-screen and/or hard-copy printouts.

APPLICATIONS OF THE SOUND-TO-SPEECH/GRAPHICS SYSTEM

After the development and refinement of the STS/Graphics System, we investigated whether subjects with mental retardation and/or multiple disabilities could learn the cause/effect relationship between vocalization and function. If they learned the cause/effect relationship, could they then learn that different vocalizations are associated with different functions? Would the subjects exhibit increased communication with others as a result of system use? The viability of the graphics component for this population using this type of communication/environmental control system was also an important issue. And finally, what aspects of the system, if any, need further refinement? A manuscript on the behavioral research methods and analysis of the behavioral data is in preparation. A brief summary follows.

Procedures

Two students from a local public school were selected from a pool of twenty-four potential subjects to evaluate the STS/Graphics System. Subject 1 was an eleven-year-old ambulatory female with mental retardation who needed extensive support and who used direct selection to control the system. Subject 2 was a twenty-one-year-old semi-ambulatory female with mental retardation who needed extensive support and who used scanning to control the system.
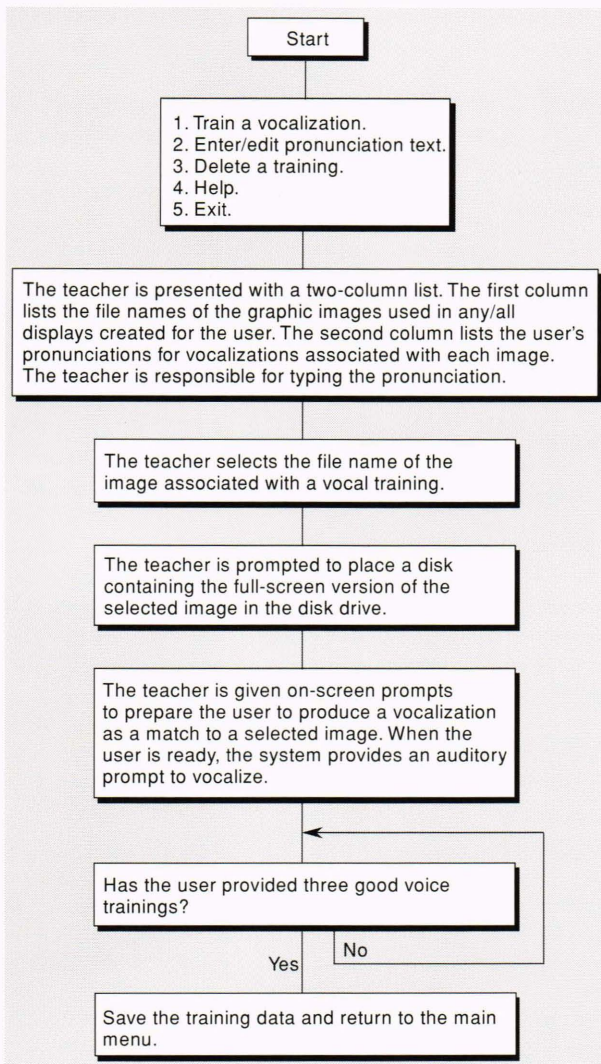
Start

1. Train a vocalization.
2. Enter/edit pronunciation text.
3. Delete a training.
4. Help.
5. Exit.

The teacher is presented with a two-column list. The first column lists the file names of the graphic images used in any/all displays created for the user. The second column lists the user's pronunciations for vocalizations associated with each image. The teacher is responsible for typing the pronunciation.

The teacher selects the file name of the image associated with a vocal training.

The teacher is prompted to place a disk containing the full-screen version of the selected image in the disk drive.

The teacher is given on-screen prompts to prepare the user to produce a vocalization as a match to a selected image. When the user is ready, the system provides an auditory prompt to vocalize.

Has the user provided three good voice trainings?

Yes   No

Save the training data and return to the main menu.

Figure 4. Recognition function of the speech manager component of the Sound-to-Speech/Graphics System software.

Start

1. Add a new display.
2. Modify a display.
3. Exit.

The teacher chooses the dimensions of the graphic display: 1x1, 2x2, 3x3, 4x4, or 5x5.

The teacher chooses the access method for the display that will be configured: linear scanning, row–column scanning, or direct selection.

The teacher is presented with a pull-down menu of actions that can occur when a user chooses a cell, and a pull-down menu of images available for the selected user. Actions include playback of an audio recording, X-10 environmental control, universal remote (infrared) control of electronics, or any combination of playback and X-10 or infrared.

The teacher is presented a miniature version of the matrix. The teacher positions the cursor inside the cell (row and column) to which an image and an action will be assigned.

Once the cursor is positioned, the teacher selects an image and an action from the pull-down menu and assigns them to the selected cell.

The teacher can press <ESC> at any time to leave the program, with a prompt to save the configured display.

Figure 5. Setup component of the Sound-to-Speech/Graphics System software.

The subjects made few vocalizations, none intelligible; they understood rudimentary scanning, understood cause and effect, had adequate vision and hearing, and were able to sit in an appropriate position to use the STS/ Graphics System. Each subject used the STS/Graphics System in her school environment.

Before the introduction of the STS/Graphics System, the subjects were shown photographs of what were assumed to be high-preference items. By using a forced-choice selection procedure with each subject, the photographs were ranked according to the subject's order of preference. The photographs with the highest ranks were scanned into digitized images so that they could be presented on the STS/Graphics System display. The images were linked to spoken communications, environmental control, or a combination of both. Each subject's optimal mode of selection, that is, direct selection or scanning, was also determined. Training strategies were used to teach the subjects how to operate the system using their per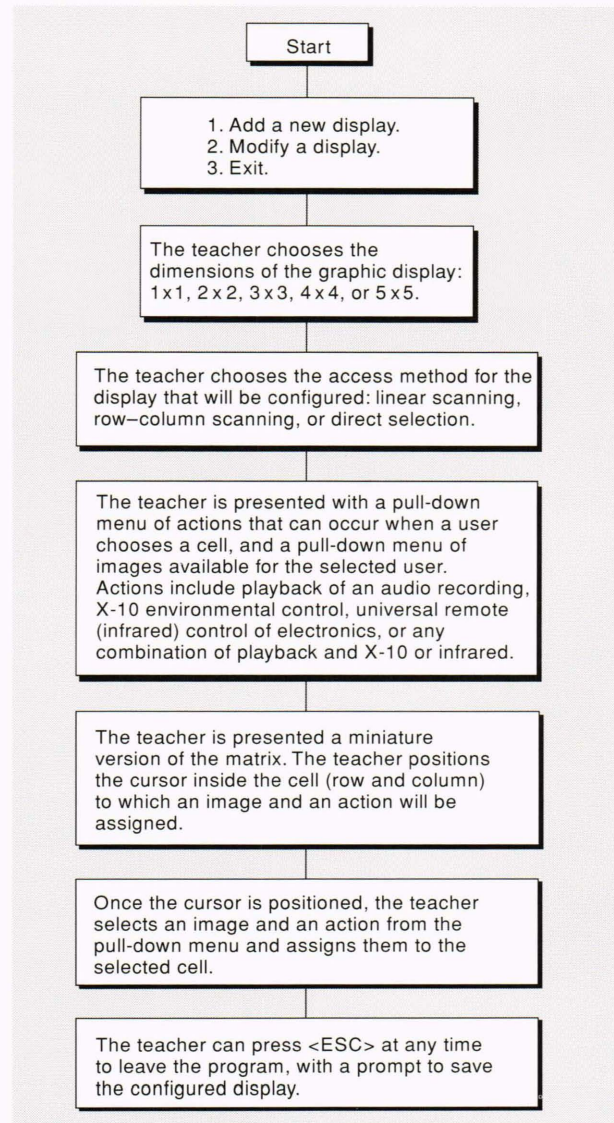sonal vocalizations. During single-image trials, only one graphics image was displayed on the monitor. Over time, additional graphics images were added to the display, and their corresponding choices were available for activation. Subjects would advance from single-image displays to multiple-image displays when they successfully completed at least nine out of twelve trials on each type of display.

Experimental trials consisted of the researcher orally requesting the subject to activate a specific device or communication phrase, for example, "Tell me about the beads." A trial was scored according to whether the subject emitted the vocalization that corresponded to the requested device or communication, and whether the computer system recognized it as such and activated the proper output. Three levels of prompting could be used with subjects to help them attend to the monitor display and to learn either the direct-selection or scanning strategy. The prompts consisted of verbal instruction, tapping
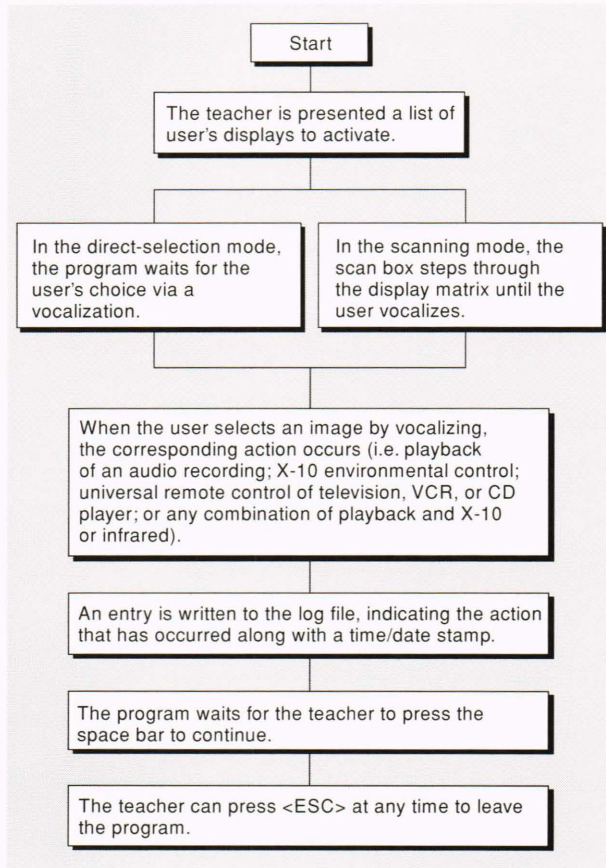
Figure 6. Sound-to-speech component of the Sound-to-Speech/ Graphics System software.

on the display, and/or modeling the user's vocalization to aid the subject in learning to control the system.

Subject 1, who used direct selection, progressed through training that began with selecting a single item on the display and ended with selecting from multiple items that were topically similar, for example, beauty aids or food items. Subject 2, who used scanning, did not progress past a single image on a 2 × 2 display at the time that data collection terminated.

Results

The two subjects learned to communicate successfully and to make choices via the STS/Graphics System. They successfully learned the cause/effect relationship between vocalization and action. Subject 1, who used the direct-selection access mode, learned that different vocalizations were associated with different functions. Variability existed between the subjects in their level of proficiency in operating the system. Subject 1 demonstrated an understanding of the use of the system with two choices available, both of which were highly motivating. Her performance deteriorated upon introduction of a third choice. It is unknown if this result was due to boredom, dissatisfaction with the choices available, inability to differentiate the target vocalizations with three choices, or lack of understanding of the use of the system with three choices. Subject 2 demonstrated an understanding of

using the scanning access mode to make choices. Although she had multiple items from which to choose, she never advanced beyond a single item on the display at one time because of a lack of time with the system. The graphics component of the system was used appropriately by the subjects in this application.

Aspects of the STS/Graphics System requiring further refinement are (1) facilitating the additional training of the system that sometimes becomes necessary because of the subjects' improved vocalization over time, (2) improving the accuracy of the system's voice recognition in noisy environments, (3) increasing the flexibility of microphone placement, and (4) improving the portability of the system.

CONCLUSIONS

The STS/Graphics System is a viable method of communication and environmental control for children and adults with mental retardation and/or physical disabilities. The system is effective in teaching persons with mental retardation to use their natural speech to communicate and to control their environment, and thereby to become more independent. The graphics interface provides a symbolic visual aid that highlights the options available to users and facilitates making selections. Vocalization is a natural means by which to empower a person, and has proved to be a robust access mode for assistive technology with people having mental retardation. Additional applications of the STS/Graphics System for assessment and educational uses will be explored. Given the enhancement in personal choice-making that the STS/Graphics System provides, as well as its potential to make contributions in other functional areas, future research on the application of voice-recognition technology to the needs of children and adults with mental retardation should be revealing.
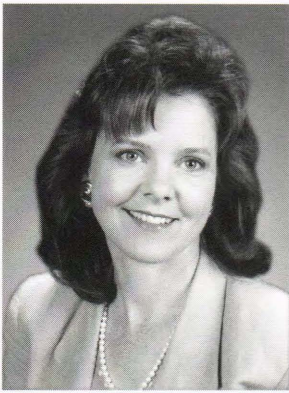
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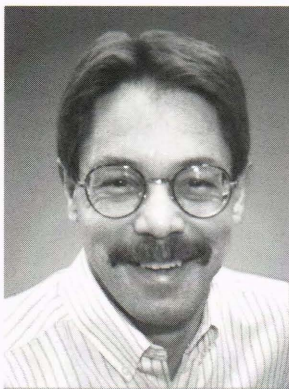
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