PART 7

REHABILITATION ENGINEERING
30.1 INTRODUCTION

This chapter is about the design of electronic assistive devices and the roles they play in the lives of people who have disabilities. It is also a chapter about the role that rehabilitation engineers play in the design and application of these devices and the unique design constraints placed on them in meeting the needs of people who have disabilities. Electronic assistive technologies have a relatively brief history that parallels the development of electronics in general. However, the key to successful application of electronic assistive devices for persons who have disabilities lies in the development of a thorough understanding of the needs that the person has, the context in which the technology will be used, and the skills that the person brings to the task.

30.2 THE CONTEXT FOR REHABILITATION ENGINEERING

Rehabilitation engineering can be described as the design, development, and application of engineering methods and devices to amelioration of the problems faced by persons who have disabilities. Future developments in assistive technologies and the successful application of these technologies to meet the needs of people who have disabilities will be driven by the combination of rapid technological advances and the requirement to meet the needs of persons with disabilities. We must design devices that are accessible to people who have disabilities, if possible. When this is not possible, then we must provide adaptations that ensure accessibility in a timely manner. If we do not meet these objectives, then individuals with disabilities may be left behind as technological advances occur.
30.3 A WORKING DEFINITION OF ASSISTIVE TECHNOLOGIES

One widely used definition of assistive technologies is that provided in Public Law 100–407, the Technical Assistance to the States Act in the United States. The definition of an assistive technology device is

Any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase or improve functional capabilities of individuals with disabilities.

This definition also has been incorporated into other legislation in the United States and is used as a working definition in other countries as well (Cook and Hussey, 2002). Note that the definition includes commercial, modified, and customized devices. This allows us to include products made for the general population in our working definition of assistive technologies. This definition also emphasizes functional capabilities of individuals who have disabilities. The inclusion of customized devices emphasizes the role of the rehabilitation engineer in designing or modifying devices to meet the unique needs of an individual person who has a disability.

30.4 CONTROL INTERFACES FOR ELECTRONIC ASSISTIVE TECHNOLOGIES

There are three elements that make up the user interface for assistive technologies: the control interface, the selection set, and the selection method (Cook and Hussey, 2002). The control interface is the boundary between the user and an electronic or mechanical assistive technology device. This is what allows the individual to operate or control the device. For electronic assistive technology systems, control interfaces include joysticks for powered wheelchairs, keyboards and mouse input for computers, and communication devices and single switches used to control household devices such as lights or radios.

The selection set is a presentation of the items from which the user makes choices. The elements in the selection set correspond to the elements of a specific activity output. Selection sets may have written letters, words and sentences, symbols used to represent ideas, computer icons, or line drawings/pictures. They may be presented in visual (e.g., letters on keys), tactile (e.g., Braille), or auditory (e.g., voice synthesis) form. We can define two selection methods through which the user makes selections using the control interface: direct selection and indirect selection (Cook and Hussey, 2002). For any particular application, the three elements of the human-technology interface will be chosen based on the best match to the consumer’s skills (motor, sensory, linguistic, and cognitive) (Cook and Hussey, 2002).

The fastest and easiest selection method to understand and use is direct selection. In this method, each possible choice in the selection set is available at all times, and the user merely chooses the one that he or she wants. Indirect selection methods were developed to provide access for individuals who lacked the motor skills to use direct selection. Indirect selection methods are scanning, directed scanning, and coded access. Each of the indirect selection methods involves one or more intermediate steps between the user’s action and entry of the choice into the device. One of the most commonly used methods is scanning. Although there are a variety of implementations of scanning, they all rely on the basic principle of presenting the selection-set choices to the user sequentially and having the user indicate when his or her choice is presented. The indication may be by a single movement of any body part. Since scanning is inherently slow, there have been a number of approaches that increase the rate of selection (Cook and Hussey, 2002). These involve selecting groups of characters first to narrow the choices and then selecting the desired item from the selected group.

In a combined approach, called directed scanning, the user first activates the control interface to
select the direction (vertically or horizontally) in which the selection set is scanned by the device. The user then sends a signal (either by waiting or by hitting an additional switch) to the processor to make the selection when the desired choice is reached. Joysticks or other arrays of switches (two to eight switches, including diagonal directions) are the control interfaces that typically are used with directed scanning.

**Coded access** requires the individual to use a unique sequence of movements to select a code corresponding to each item in the selection set. These movements constitute a set of intermediate steps that are required to make the selection using either a single switch or an array of switches as the control interface. One example of coded access used in electronic assistive devices is Morse code, in which the selection set is the alphabet. An intermediate step [e.g., holding longer (dash) or shorter (dot)] is necessary to make a selection. Two-switch Morse code is also used, in which one switch sends dots and the other sends dashes. As long as either switch is held down, the dots or dashes are sent. A major goal in the development of Morse code was its efficiency, and this can be very useful when speed of entry is the goal. Codes are usually memorized, and this means that the selection set need not be visually displayed. This allows use by individuals who have visual limitations. Coded access also requires limited physical skill but significant cognitive skill, especially memory and sequencing.

### 30.4.1 Methods of Activation Used for Control Interfaces

Control interfaces may be characterized by the way in which the consumer activates them (Cook and Hussey, 2002). Three types of actions by the user can result in activation of the control interface: movement, respiration, and phonation. These are shown in Table 30.1. Movements can be detected in three basic ways. First, a force may be generated by a body movement and detected by the control interface. These mechanical control interfaces (e.g., switches, keyboard keys, joysticks, mouse, and trackball) represent the largest category. Many mechanically activated switches are available for control of assistive devices. Most often movement of the hand, head, arm, leg, or foot activates these switches. Hand, foot, or head movement (e.g., chin) is generally used to activate multiple-switch

<table>
<thead>
<tr>
<th>Signal sent, user action (what the body does)</th>
<th>Signal detected</th>
<th>Examples</th>
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<tbody>
<tr>
<td>1. Movement (eye, head, tongue, arms, legs)</td>
<td>a. Mechanical control interface activation by the application of a force</td>
<td>a. Joystick, keyboard, tread switch</td>
</tr>
<tr>
<td></td>
<td>b. Electromagnetic control interface: activation by the receipt of electromagnetic energy such as light or radio waves</td>
<td>b. Light pointer, light detector, remote radio transmitter</td>
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<td></td>
<td>c. Electrical control interface: activation by detection of electrical signals from the surface of the body</td>
<td>c. EMG, EOG, capacitive or contact switch</td>
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<td></td>
<td>d. Proximity control interface: activation is by a movement close to the detector, but without contact</td>
<td>d. Heat-sensitive switches</td>
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<td>2. Respiration (inhalation/expiration)</td>
<td>2. Pneumatic control interface: activation by the detection of respiratory air flow or pressure</td>
<td>2. Puff and sip</td>
</tr>
<tr>
<td>3. Phonation</td>
<td>3. Sound or speech control interface: activation by the detection of articulated sounds or speech</td>
<td>3. Sound switch, whistle switch, automatic speech recognition</td>
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</table>

arrays, including some joysticks. These vary in the amount of force required, the sensory feedback provided, and the degree to which the consumer can mount them for easy access.

Electromagnetic control interfaces can also be used to detect movement at a distance through either light (visible or infrared) or radiofrequency (rf) energy. These interfaces include head-mounted light sources or detectors and transmitters used with environmental control systems for remote control.

The third type of movement detection is electrical. These control interfaces sense bioelectric signals. Switches of this type require no force, and a common example of this type of interface is capacitive switches used on some elevator buttons. Bioelectrical switches detect muscle electrical activity (EMGs) or eye movement (EOG) by attaching electrodes to the skin.

Another type of body-generated signal is respiration, which is detected by measuring either airflow or air pressure using what is called a sip-and-puff switch activated by blowing air into the switch or sucking air out of it. Arrays of single puff-and-sip switches are often used for multiple functions. The most common use has been two puff-and-sip switches mounted side by side for wheelchair control. Puffing on both causes forward motion, sipping on both leads to reverse, and puffing on only one results in a turn in that direction.

30.4.2 Control Interfaces for Direct Selection

The most common control interface for direct selection is the keyboard. However, there are many different types of keyboards, and each requires unique user skills. Some consumers have limited range of movement but good fine motor control. In this case, a contracted keyboard (closely spaced keys over a small range) can be more effective than the standard keyboard. Other individuals have difficulty accessing small targets, but they have good range of movement. In this case, an expanded keyboard, in which the size of each key can be up to several inches, may allow direct selection. Different keyboard layouts can also be used (e.g., for left-hand- or right-hand-only typing). It is also possible to make the keys in different sizes and different shapes on the same keyboard. Touch screens allow a user choice from the selection set by pointing directly to the item on the screen. Because the item chosen is the one that is pointed at, this method can be easier for some users to understand.

Automatic speech recognition (ASR), in which the individual uses sounds, letters, or words as a selection method, is another alternative to keyboard input. In most such systems, the speech recognition is speaker-dependent, and the user “trains” the system to recognize his or her voice by producing several samples of the same element (Comerford et al., 1997). ASR system use is increasing in the mainstream commercial market for use on the Internet, dictation, general telephone use, and most other computer activities. Persons with disabilities will be the beneficiaries of this expanded use of ASR systems. These systems all use continuous ASR techniques in which the user can speak in almost normal patterns with slight pauses between words.

Speaker-independent systems recognize speech patterns of different individuals without training (Gallant, 1989). These systems are developed using samples of speech from hundreds of people and information provided by phonologists on the various pronunciations of words (Baker, 1981). The total recognition vocabulary is generally small. Discrete ASR systems are used in assistive technology applications for wheelchair control and electronic aids to daily living for appliance control. These systems require the user to pause between words and result in very abnormal speech patterns. They are only used in limited applications requiring a few commands to be recognized.

Often the microphones supplied with ASR systems are not adequate when the user has limited breath support, special positioning requirements, or low-volume speech (Anson, 1997). Many individuals who have disabilities may not be able to independently don and doff headset microphones that are normally supplied with commercial ASR systems. In these cases, desk-mounted types are often used. Current ASR systems utilize commonly available sound cards rather than separate hardware installed in the computer (Anson, 1999).
30.4.3 Control Interfaces for Indirect Access

Indirect methods of selection use a single switch or an array of switches. Cook and Hussey (2002) describe a number of interfaces that are used for indirect selection.

30.5 COMPUTER ACCESS BY PERSONS WITH DISABILITIES

Computer use by persons who have disabilities has opened up new opportunities for education, employment, and recreation. The computer offers (1) flexibility (multiple options with the same hardware), (2) adaptability (e.g., as user’s skills change over time), (3) customization to a specific user and need (e.g., settings of scanning rate for indirect selection), and (4) specific applications and/or upgrades that can be based on software rather than hardware (e.g., specific user profile for Internet browsing in Braille) (Cook and Hussey, 2002). Computer use is often difficult for individuals who have motor and/or sensory impairments. Successful computer use requires sensory and perceptual abilities for processing computer outputs, motor control for generating input to the computer, and cognitive skills (e.g., problem solving, decision making, memory, and language) for understanding the computer functions. When a person with one or more disabilities has difficulty carrying out these functions, engineers are called on to adapt the computer to make it accessible.

30.5.1 Adapted Computer Inputs

The most common user computer input is provided via either the keyboard or a mouse. We can provide adapted computer input in many ways depending on the needs of the consumer. Keyboard alternatives were discussed earlier in this chapter. There are also software adaptations for the most common problems experienced by people with disabilities when using a standard keyboard. These are shown in Table 30.2. These software adaptations are included in Accessibility Options in Windows* and Universal Access in Macintosh† operating systems. They are accessed and adjusted for an

*Microsoft Corporation, Seattle, Wash.
†Microsoft Corporation, Seattle, Wash.

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<tr>
<th>Need addressed</th>
<th>Software approach*</th>
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<tbody>
<tr>
<td>Modifier key cannot be used at same time as another key</td>
<td>StickeyKeys (M,W)</td>
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<tr>
<td>User cannot release key before it starts to repeat</td>
<td>RepeatKeys (M)</td>
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<tr>
<td>User accidentally hits wrong keys</td>
<td>SlowKeys (M)</td>
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<td></td>
<td>BounceKeys (M)</td>
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<td></td>
<td>FilterKeys (W)</td>
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<td></td>
<td>MouseKeys (M,W)</td>
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<td></td>
<td>SerialKeys (M,W)</td>
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*StickeyKeys: User can press modifier key and then press second key without holding both down simultaneously; RepeatKeys: User can adjust how long key must be held before it begins to repeat; SlowKeys: A delay can be added before the character selected by hitting a key is entered into the computer; this means that the user can release an incorrect key before it is entered; BounceKeys: Prevents double characters from being entered if the user bounces on the key when pressing and releasing; FilterKeys: The combination of SlowKeys, BounceKeys, and RepeatKeys in Microsoft Windows; MouseKeys: Substitutes arrow keys for mouse movements; SerialKeys: Allows any serial input to replace mouse and keyboard.

individual user through the control panel. Universal Access for the Macintosh includes Easy Access and Closeview. Easy Access features are those shown in Table 30.2. Closeview enables enlarged characters on the screen. It is described later in this chapter.

For persons who have cognitive difficulties, we can increase access by using **concept keyboards**. These keyboards replace the letters and numbers of the keyboard with pictures, symbols, or words that represent the concepts required by the software. For example, a program designed to teach monetary concepts might use a concept keyboard in which each key is a coin rather than a number or letter. The user can push on the coin and have that amount entered into the program. Such keyboards have been used in point-of-sale applications to allow individuals who have intellectual disabilities to work as cashiers. The Intellikeys keyboard* is often used as a concept keyboard.

Alternatives to the use of a mouse for computer input that are often used by persons with disabilities include trackballs, a head-controlled mouse, a continuous joystick, eye pointing, and the use of the arrow keys on the numeric keypad (called **mouse keys**; see Table 30.2.).† Head control for mouse emulation employs an infrared system that detects a reflected beam to measure head position relative to a fixed reference point for the cursor (the center of the screen). As the user moves his or her head away from this point in any direction, the cursor is moved on the screen. Commercial systems‡ use a wireless approach in which a reflective dot is placed on the user’s forehead and serves as the reflective target. This allows the user to move around more freely. These head-controlled systems are intended for individuals who have limited arm and hand control and who can accurately control head movement. For example, persons with high-level spinal cord injuries who cannot use any limb movement often find these head pointers to be rapid and easy to use. On the other hand, individuals who have random head movement (e.g., due to cerebral palsy) or who do not have trunk alignment with the vertical axis of the video screen because of poor sitting posture often have significantly more trouble using this type of input device.

In some severe physical disabilities, the user may only be able to move his or her eyes. In this case, we can use a system that detects the user’s eye movements to control mouse pointing. Two basic approaches are used in the design of eye-controlled systems. One of these uses an infrared video camera mounted below the computer monitor. An infrared beam is aimed at the eye and reflected back into the camera. As the user directs his or her eye gaze at different points on the computer monitor screen, signal-processing software is used to analyze the camera images and determine where and for how long the person is looking at the screen. The user makes a selection by looking at it for a specified period of time, which can be adjusted according to the user’s needs. The EyeGaze System§ and Quick Glance¶ are examples of two eye-controlled systems that emulate mouse pointing. The second approach uses a head-mounted viewer attached to one side of the frame of a standard pair of glasses in front of the eye. Eye movements are tracked and converted into keyboard input by a separate control unit. One example of this type of system is VisionKey.** An eye-controlled system is beneficial for individuals who have little or no movement in their limbs and may also have limited speech, e.g., someone who has had a brain stem stroke, has amyotrophic lateral sclerosis (ALS), or has high-level quadriplegia.

In each of these alternative pointing devices, input to the pointing device moves a pointer on the screen. Once the pointer is moved to the desired item, the user can make a selection by either pausing for a preset time (called **acceptance time selection**) or by pressing a switch (called **manual selection**).

The **graphic user interface** (GUI) is used as the selection set for mouse entry. There are limitations to use of a GUI for people with disabilities. The first of these is that the GUI requires significant eye-hand coordination. Pointing devices rely on a significant amount of coordination between the body site (hand, foot, or head) for most individuals with disabilities) executing the movement of the screen pointer and the eyes following the pointer on the screen and locating the targets. Second, it relies on

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†Included with Windows and Macintosh operating systems.
‡Head Mouse, OrigInstruments; www.orin.com; Tracker, Madentec Limited; http://www.madentec.com/.
**H. K. EyeCan, Ltd., Ottawa, Canada; www.cyberbus.ca/~eyecan/.
a visual image of the screen for operation. If either of these is not present (e.g., muscle weakness or blindness), then the GUI is difficult to use and must be adapted or an alternative found.

The sensory feedback provided by the particular type of pointing device can vary widely. For individuals who have some vision, a major form of feedback is vision, i.e., following the cursor on the screen. Devices controlled by the hand (e.g., mouse, trackball, or joystick) also provide rich tactile and proprioceptive feedback. Head- and eye-controlled pointing devices provide much less sensory feedback, and other means, such as a light-emitting diode (LED) that lights when the signal is being received, are included to aid the user. The type of sensory feedback affects the user’s performance, and the more feedback available, the more likely the use will be successful.

### 30.5.2 Adapted Computer Outputs

User output from the computer is typically provided by either a video display terminal (VDT), a printer, or speech or sounds. Use of any of these requires an intact sensory system. Alternatives that can be provided may substitute auditory (e.g., speech) or tactile (e.g., Braille) output for the VDT output or visual cues for sounds or speech. In the case of low vision, the standard size, contrast, and spacing of the displayed information are inadequate. For individuals who are blind, alternative computer outputs based on either auditory (hearing) or tactile (feeling) modes are used. Persons who are deaf or hard of hearing may also experience difficulties in recognizing auditory computer outputs. Adaptations that facilitate some of these functions are included in Accessibility Options* in Windows. These include ShowSounds, which displays captions for speech and sounds, and SoundSentry, which generates a visual warning when the system generates a sound.

### 30.5.3 Alternatives to Visual Input for Individuals Who Have Low Vision

The major problem with visual computer displays for individuals with low vision is that the text characters and icons are not easily readable. The three factors that affect the readability of text characters are (1) size (vertical height), (2) spacing (horizontal distance between letters and width of letters), and (3) contrast (the relationship of background and foreground color). Commercial screen magnifiers are used to compensate for several of these problems. In most cases these are software approaches only, but some include a hardware component as well. Screen-magnifying software enlarges a portion of the screen. The unmagnified screen is called the physical screen. Screen magnifiers enlarge one section of the physical screen to fit the whole display screen with a magnification of 2 to 32 times or more. The user has access to only the portion of the physical screen that appears in the magnified viewing window. In order to help the user navigate, the viewing window must track any changes that occur on the physical screen by moving the viewing window to show the portion of the physical screen in which changes are occurring or where input is required. For example, if a navigation or control box is active, then the viewing window highlights that box. If mouse movement occurs, then the viewing window can track the mouse cursor movement. If text is being typed in, then the viewing window will highlight that portion of the physical screen. Scrolling allows the user to slowly move the viewing window over the physical screen image. This may be automatic or manual.

Adaptations that allow persons with low vision to access the computer screen are available in several commercial forms. Lazzaro (1999) describes several potential methods of achieving computer access for people who have low vision. The simplest and least costly are built-in screen-enlargement software programs provided by the computer manufacturer. One of these is Close View.† This program allows for magnification from 2 to 16 times and has fast and easy text handling and graphics capabilities. Magnifier‡ displays an enlarged portion of the screen (from 2 to 9 times magnification).

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*Microsoft Corporation, Seattle, Wash.
†Macintosh Operating System, Apple Computer, Cupertino, Calif.
‡Windows, Microsoft Corporation, Seattle, Wash.
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in a separate window. Software programs that are purchased separately rather than being built in offer wider ranges of magnification and have more features than built-in screen magnifiers. Hardware and software combinations have other features such as multiple enlarged windows, smoother scrolling, and a wider range of magnification. Cook and Hussey (2002) and Lazzarro (1999) describe commercial approaches to screen-magnification utilities. Most of these approaches also allow adjustment of background and foreground colors to address difficulties with contrast.

30.5.4 Alternatives to Visual Input for Individuals Who Are Blind

For individuals who are blind, computer outputs must be provided in either auditory or tactile form or both. Auditory output is typically provided through systems that use voice synthesis and tactile output as in Braille. These adaptations are generally referred to as screen readers. Commercial screen readers have two modes: application and review. In the application mode, the user can utilize all the screen features as well as the features of the application program. This mode is normally used for reading the screen contents. In review mode, the user can utilize all the screen-reading features but cannot access the features of the application program (e.g., editing of a word processor text file). Current systems eliminate the use of the two modes for most applications (e.g., word processing, spreadsheets, Web browsing) and provide full review capability while in an application program. For some applications (e.g., a complex document with multiple columns or a complicated Web page), the review mode is used.

Cursor routing allows a user to mark a location in an application so that the screen-reading cursor can return to it when the user exits the review mode and goes into application mode. Macros in screen-reader programs are useful in moving between windows or locating key areas (e.g., a dialog box or a window requiring input from the user). Screen readers are ideally suited for applications that consist of text only.

However, the power of any particular screen reader is in the degree to which the other capabilities dictated by the use of the GUI are achieved. The fundamental differences in the ways that a text-only command-line interface (CLI) and a GUI provide output to the video screen present access problems for persons who are blind. These are related to both the ways in which internal control of the computer display is accomplished and the ways in which the GUI is employed by the computer user (Boyd et al., 1990). The CLI-type interfaces use a memory buffer to store text characters for display. Since all the displayed text can be represented by ASCII code, it is relatively easy to use a software program and to divert text from the screen to a speech synthesizer or Braille display. However, this type of screen reader is unable to provide access to charts, tables, or plots because of their graphic features. This type of system is also limited in the features that can be used with text. For example, features such as size, shape, and font or alternative graphic forms are not captured in standard ASCII text code.

GUI design uses a totally different approach that creates many more options for the portrayal of graphic information to video display control. Since each character or other graphical figure is created as a combination of dots, letters may be of any size, shape, or color, and many different graphical symbols can be created. This is very useful to sighted computer users because they can rely on the use of visual metaphors (Boyd et al., 1990) to control a program. Visual metaphors use familiar objects to represent computer actions. For example, a trash can may be used for files that are to be deleted, and a file cabinet may represent a disk drive. The graphic labels used to portray these functions are referred to as icons. Screen location is important in using a GUI, and this information is not easily conveyed via alternative means such as screen readers. Visual information is spatially organized, and auditory information (including speech) is temporal (time-based). It is difficult to convey screen location of a pointer by speech alone. An exception to this is screen locations that never change (e.g., the edges of the screen, such as “right border” and “top of screen”). Another major problem is that mouse pointer location on the screen is relative, and the only information available is the direction of the movement and how far the mouse has moved. One approach to this problem is the Microsoft Screen Access Model.* This is a set of technologies designed to facilitate the development of screen
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readers and other accessibility utilities for Windows that provide alternative ways to store and access information about the contents of the computer screen. The Screen Access Model also includes software driver interfaces that provide a standard mechanism for accessibility utilities to send information to speech devices or refreshable Braille displays. GUI access also requires the ability to locate open windows, monitor them for changes, and output information to the user if changes occur. Screen-reader programs also provide assistance in this navigation function by using keyboard commands such as movement to a particular point in the text, finding the mouse cursor position, providing a spoken description of an onscreen graphic or special function key, or accessing help information. Screen readers also monitor the screen and take action when a particular block of text or a menu appears (Lazzaro, 1999). This feature allows the user to automatically have pop-up window and dialog boxes read to him or her. Screen readers can typically be set to speak by line, sentence, or paragraph.

For Windows-based computers, the majority of commercial products include both a voice synthesizer and a software-based screen reader to provide access. Many of these bundled software programs also work with computer soundboards to generate high-quality synthetic speech. Tactile (Braille) display of screen information is the other major alternative for screen readers. This requires the use of a translator program to convert from text characters to Braille cell-dot patterns. Computer output systems use either a refreshable Braille display consisting of raised pins or hard copy via Braille printers. Refreshable Braille displays consist of 20, 40, or 80 separate cells. Rather than the standard 6-cell Braille used for print materials, a unique 8-dot cell format is available in which the seventh and eighth dots are used for indicating the location of the cursor and to provide single-cell presentation of higher-level ASCII characters. The latter feature is necessary because the normal 6-cell Braille display can only generate 64 permutations and full ASCII has 132 characters. Braille embossers produce hard-copy (printed) output. Cook and Hussey (2002) describe a number of commercial approaches to screen readers with speech and Braille output as well as embossers for hard copy.

30.6 AUGMENTATIVE AND ALTERNATIVE COMMUNICATION

The term augmentative and alternative communication (AAC) is used to describe any communication that requires something other than the person’s own body. This includes things such as a pen or pencil, a letter or picture communication board, a typewriter, or an electronic communication device. There are two basic communication needs that lead to the use of augmentative and alternative communication systems: conversation and graphics (Cook, 1988).

Conversational needs are those that would typically be accomplished using speech if it were available. Conversational use typically focuses on interaction between two or more people. Light (1988) describes four types of communicative interaction: (1) expression of needs and wants, (2) information transfer, (3) social closeness, and (4) social etiquette. Each of these has unique features that dictate the AAC characteristics to be included. Since speech allows communication at a rapid rate, between 150 and 175 words per minute (Miller, 1981), an individual using an AAC system must be as rapid as possible. In all AAC systems, some form of letter or symbol selection is required, and in many cases persons who are unable to speak use a keyboard to type their messages that are then spoken by an AAC device. If the person has limited motor skills, this can result in significantly lower rates of communication than for speech (as low as a few word per minute). Cook and Hussey (2002) describe other relationships between AAC characteristics and effective conversational skills.

Graphic communication describes all the things that we normally do using a pencil and paper, typewriter, word processor, calculator, and other similar tools, and it includes writing, mathematics, and drawing and/or plotting. Each of these serves a different need, and therefore, AAC devices designed to meet each type of need have different characteristics (Cook and Hussey, 2002). For
example, all AAC systems for writing must be capable of providing output in a hard-copy format. This can either be generation of normal text (letters, numbers, and special characters) or special symbols. If spelling is difficult for the user, some devices allow the selection of whole words that are then output to a printer. While it is possible to learn basic arithmetic without being able to write the numbers down, it is much more difficult. AAC systems used for math allow the cursor to move from left to right as the user enters numbers to be added, but once the user has a column of numbers, the cursor moves right to left as he or she enters the sum. Special symbols (e.g., Greek letters) and the use of superscripts and subscripts are also required for algebra. AAC device characteristics that are required for drawing include cursor movement in all four directions; choice of colors, line widths, and other features; and the ability to save a drawing for later editing.

AAC systems may be thought of as having three major components: (1) user interface, (2) processor, and (3) output. The user interface was described earlier in this chapter. It includes the user control interface, selection method and selection set, and an optional user display to provide feedback for self-correction. AAC devices often use special symbols in the selection set. These include miniatures of objects, color or black and white pictures, line drawings, pictographic symbols, text characters, and multiple meaning icons* (Beukelman and Mirenda, 1998). For AAC systems, the processor has several specific functions: (1) selection technique, (2) rate enhancement and vocabulary expansion, (3) vocabulary storage, and (4) output control. The output is conversational and/or graphic communication. Communication takes place in many different settings.

In order to maximize the production of output, AAC devices use techniques to increase the rate of entry by the user. Any approach that results in the number of characters generated being greater than the number of selections that the individual makes will increase rate. Rate-enhancement techniques can be grouped into two broad categories: (1) encoding techniques and (2) prediction techniques. There are several types of codes that are currently used in AAC devices. Numerical codes can be related to words or complete phrases or sentences. When the user enters one or more numbers, the device outputs the complete stored vocabulary item. Abbreviation expansion is a technique in which a shortened form of a word or phrase (the abbreviation) stands for the entire word or phrase (the expansion). When an abbreviation is entered, it is automatically expanded by the device into the desired word or phrase. Vanderheiden and Kelso (1987) discuss the major features of abbreviation-expansion systems and the strategies for developing stored vocabulary using this approach. An alternative approach that is based on coding of words, sentences, and phrases on the basis of their meaning is called semantic encoding (Baker, 1982). In this approach, pictorial representations, called icons, are used in place of numerical or letter codes. For example, using a picture of an apple for “food” and a sun rising for “morning” and then selecting “apple” and “sunrise” as a code for “What’s for breakfast” is easier to remember than an arbitrary numerical or letter code for the same phrase. The apple can also represent the color red, eating, fruit, etc.

It is also possible to realize significant increases in rate by using word-prediction or word-completion techniques with any selection method (Swiffin et al., 1987). Devices that use these techniques typically have a list on the screen that displays the most likely words based on the letters that have previously been entered. The user selects the desired word, if it is listed, by entering a number listed next to the word. If the desired word is not displayed, the user continues to enter letters, and the listed words change to correspond to the entered letters. In adaptive word completion, the ranking of the presented list is changed based on the user’s frequency of use.

A selection set for AAC consists of a maximum of 128 selections on most devices, and many have far fewer available at any one time. However, even a child has a vocabulary of thousands of words. Thus it is necessary to have methods to allow easy access to vocabulary items that are not displayed. The rate-enhancement techniques are one way to do this, but they all require memory and cognitive skills such as sequencing. One approach is to present the selection sets on a dynamic display accessed through a touch screen. The displayed information is changed based on previous entries. For example, a general selection set might consist of categories such as work, home, food, clothing,
greetings, or similar classifications. If one of these is chosen, either by touching the display surface directly or by using scanning, then a new selection set is displayed. For example, a variety of food-related items and activities (eat, drink, ice cream, pasta, etc.) would follow the choice of “foods” from the general selection set. Thus the user does not have to remember what is on each level. Cook and Hussey (2002) describe typical approaches used in AAC system design.

### 30.7 AIDS FOR MANIPULATION

Many individuals who have limited function of their arms and hands experience difficulty in manipulating objects, controlling appliances (e.g., television, telephone, etc.), reading a book, feeding themselves, or doing self-care. Assistive technologies that aid manipulation may be simple mechanical aids (e.g., reachers or enlarged-handle eating utensils), special-purpose electromechanical devices (e.g., page turners or feeders), or general-purpose devices (e.g., electronic aids to daily living and robotics). In this section I will discuss only electronic aids to daily living (EADLs). The others are described in Cook and Hussey (2002).

Many objects that need to be manipulated are electrically powered devices such as appliances (e.g., television, room lights, fans, and kitchen appliances such as blenders or food processors), which use standard house wiring (110 volts ac in North America). EADLs are designed to allow people with limited upper extremity function to control these appliances. They were formerly known as environmental control units (ECUs). A typical EADL for turning appliances on and off is shown in Fig. 30.1. The user control interface may be a keypad, as shown, or a single switch with an indirect selection method. The appliances are plugged into modules that are controlled by the EADL. The most common type of on/off module is the X-10.* Three types of wireless transmission are used in EADL design. The most common is infrared (IR) transmission like that used in most TV remote units. A second method, also sometimes used for TV control, is ultrasound transmission. The third method, often used in garage door openers, is radiofrequency (rf) transmission. IR and ultrasound require line-of-sight transmission. RF transmission does not have this requirement.

The system in Fig. 30.1 may be modified to include remote control over TV or VCR functions such as volume control, channel selection, play, fast forward, and reverse. In this case, the level (for volume) or number (for channel) is under the control of the human user. Often these functions are incorporated into EADLs by modifying standard TV or VCR remote controls. This may be done merely by adding a single switch to the remote control or by more elaborate adaptations that allow indirect selection. Sometimes universal remote controls that can “learn” the signal for a particular TV or VCR are used. This allows several appliances to be controlled from the same EADL. Cook and Hussey (2002) describe several commercial approaches to this type of EADL.

Persons with physical disabilities of the upper extremities often have difficulty in carrying out the tasks associated with telephone use. These include lifting the handset, dialing, holding the handset while talking, and replacing the handset in its cradle. There are several options for accomplishing these tasks. Nonelectronic methods such as mouth sticks or head pointers can be used to press a button to open a line on a speakerphone, dial, and hang up. EADLs perform these same telephone tasks electronically. For persons who require single-switch access to the system, the control interface is connected to a control unit that also interfaces with a display and with standard telephone electronics. A typical approach is for the device to present numbers sequentially on the display, and the user presses a switch when the desired number to be dialed is on the display. By repeating this process any phone number can be entered and then sent through the standard telephone electronics for automatic dialing. Since many persons with disabilities respond slowly, all practical systems use stored numbers and automatic dialing. Another unique feature is the inclusion of a Help or Emergency phone number that can be dialed quickly. Most systems have a capacity of 50 to 100 stored numbers. Some telephones are IR-controlled, and they can be included with EADLs that learn device codes.

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* X-10 Powerhouse System, Northvale, N.J.
The editors of *PC Magazine* identified 10 trends that are likely to have a profound impact on assistive technology design and application over the first 10 years of the twenty-first century (Miller et al.,...
One prediction is that computers will have more human attributes such as reacting to spoken words (using ASR) or hand-written instructions. In general, the emphasis is on making the user interface more “friendly.” Telephone access to the Internet via ASR is already available. ASR will continue to improve, but a major challenge will continue to exist for people who have unintelligible (dysarthric) speech. Current ASR systems do not provide good results for this population, and this is clearly an area in which assistive technologies must be developed to allow persons with speech disabilities to access the new user interfaces. Similar problems could occur for individuals who have poor fine motor control if user interfaces require recognition of handwriting.

The chatbot, a virtual character that responds to questions using voice synthesis, is another feature designed to make the user interface more human-like. With this user interface, the user asks questions in a particular subject area using ASR. Successful use of these interfaces depends on expected questions and answers in a given subject area. This is how the interface appears “smart.” However, the chatbot cannot reason or solve problems. A natural-language interface of this type has great appeal for use by people who have intellectual abilities. The question is how forgiving these interfaces will be if the user becomes confused or uses nonstandard forms of language and speech. Rehabilitation engineers can ensure that these general-purpose technologies are inclusive of all individuals by employing universal design principles and by adapting the user interface so that it is accessible to individuals with motor, sensory, and cognitive limitations.

Another example of a human-like user interface is the inclusion of emotion (Miller et al., 1999). Current work in this area includes cameras that monitor facial expressions and sensors that detect physiological changes. These signals provide the information necessary for an affective tutor to adjust a program to react to emotions. For example, if the tutor detects confusion, an alternative explanation could be offered. Researchers are also working on user interfaces that express emotion to the user as well. These are based on animated characters that change facial expressions to react to input questions. These advances could be of benefit to individuals who have intellectual disabilities and require more concrete interactions.

Changes in the nature of networks will occur over the next few years. These changes have the potential to benefit those who have disabilities. Existing networks will be expanded into the home, work, and community environments to provide the capability for unique and powerful connections. For example, automobile networks will be connected to toll booths and automated fuel pumps. They will also make assisted driving possible, with a potential benefit to persons with disabilities. Because networks will become wireless in the future, connectivity will be a function of local resources, not existing hard-wired communications providers. This offers the opportunity for people with disabilities to use their assistive technologies to connect to the network. If this is to be realized, then rehabilitation engineers must design assistive technologies that keep pace with constant changes in the design of network configurations. A second major trend affecting networks is an increase in the “intelligence” of the Internet. Web browsers will be able to track sites by the characteristics the user typically looks for. These might include styles, colors, and sizes of clothing and particular items of interest. Software will also determine a profile for the user based on these preferences and then compare the profiles with those of other users who have similar tastes and interests. The intelligent agent can then recommend products and services matching the profile. These changes require XML (for Extensible Markup Language), an enhanced programming language. Accessibility guidelines for XML are being developed by the World Wide Web Consortium Web Access Initiative (www.w3.org/WAI).

In the future, appliances from watches to dishwashers will have embedded microcomputers, making it possible to network them within a home and to control them remotely. For example, a meal can be started from work by turning on the stove remotely. Some appliances such as cellular phones will also include access to the Internet and other computing functions. One of the keys to these applications is the use of hardware and software that allows digitally controlled appliances to self-organize into a community without a server to manage the network. This type of interconnectivity and remote control are ideal for individuals who have EADLs or who cannot see appliance controls. To ensure accessibility to persons with disabilities, the software and networking capabilities in these appliances must meet the accessibility guidelines described earlier. They must also be compatible with assistive devices (e.g., desktop computers, personal digital assistants, control interfaces, AAC devices) used for input or output from the network. There will also be major changes in e-mail and chat
rooms. They will proceed beyond pure text to text-linked and three-dimensional graphics. The Internet (e-mail and chat rooms) has the advantage of anonymity, and this can be a major benefit to individuals who have disabilities (Blackstone, 1996). Some of these advantages are

1. Composition at a slower speed since the partner reads it at a later time.
2. User can communicate with another person without someone else being present.
3. Because the person’s disability is not immediately visible, people with disabilities report that they enjoy establishing relationships with people who experience them first as a person and then learn of their disability.

As the ability of the Internet to connect people grows, the benefits to people who have disabilities will also increase. The engineering to make this a reality is that these individuals must continue to have access to both input to and output from the Internet as this growth progresses.

Other trends, cited by Miller et al. (1999), include smarter and more powerful software with faster computing hardware, expanded memory and functionality, and decreasing or stable cost. This means that the size of information-processing electronics will continue to shrink, with greater and greater capability in smaller and smaller packages. This will have implications for assistive technologies that depend on large amounts of signal processing with severe size and weight limitations such as hearing aids and AAC devices.

**30.9 SUMMARY**

Electronic assistive devices provide expanded opportunities for people who have disabilities. Those discussed in this chapter include access to computers for both input and output functions, Internet access, electronic aids for manipulation, and communication devices (AAC). As advances are made in electronics, computing, and network applications, there is a constant challenge to ensure that these systems remain accessible to persons who have disabilities. Rapidly changing communication technologies may result in the need to redesign accessible interfaces. Developments that broaden the scope, applicability, and usability of the user interface will be driven, at least in part, by the needs of people who have disabilities. Engineers who focus their efforts on rehabilitation applications can have a significant influence on these developments and on the lives of people who have disabilities.

**REFERENCES**


