DOCUMENT RESUME

ED 297 545 EC 210 396

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TITLE	Accessible Computers from the Box.
INSTITUTION	Wisconsin Univ., Madison. Trace Center.
SPONS AGENCY	National Inst. on Disability and Rehabilitation Research (ED/OSERS), Washington, DC.
PUB DATE	87
GRANT	G008300045
NOTE	15p.; A product of the Trace Research and Development Center on Communication, Control, and Computer Access for Handicapped Individuals. Print in charts is small.
AVAILABLE FROM	Trace Center, University of Wisconsin-Madison, Waisman Center, 1500 Highland Ave., Madison, WI 53705-2280 ($1.25).
PUB TYPE	Speeches/Conference Papers (150) -- Guides - Non-Classroom Use (055)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Assistive Devices (for Disabled); *Computers; Computer Software; *Design Requirements; *Disabilities; *Electronic Equipment; Input Output Devices; Microcomputers; Rehabilitation

ABSTRACT

The paper briefly discusses the design of computers to allow their use by the 20% of the American population who have reduced abilities in such areas as manipulation, vision, hearing, and cognition. The role of manufacturers of standard computers in increasing computer accessibility is one of providing computers that can be used by an increasing number of individuals as well as providing the special "hooks" that special rehabilitation developers need in order to create and connect special adaptations for individuals with more severe handicaps. Specific problem areas and suggested solutions are offered for persons with movement disabilities, visual impairments, hearing impairments, and cognitive impairments. Mechanisms for making computers more accessible are grouped into five types in two categories: first, features to allow access and use of public or shared computers and second, features to facilitate use of personally owned or controlled computers. Tables provide a listing of software, operating system, and hardware modifications to improve input accessibility, output/display accessibility, and controls, media and documentation accessibility, and personal workstation modification facilitation. Modifications are listed in terms of the problem, examples, design recommendations, and design examples. (DB)

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ACCESSIBLE COMPUTERS FROM THE BOX

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DISABILITY: A CONTINUUM

Individuals who have disabilities are often seen as a separate population from the "able-bodied" population. In fact, there is no clear delineation between "disabled" and "able-bodied" people. Everyone has areas in which they are less able than others, and everyone has some activities which they have difficulty doing or some devices which they have difficulty using. Similarly, most "disabled" individuals are not really "disabled" (unable to function), but are simply hampered in their ability to do some things. Further, an individual who is impaired along one dimension of performance (e.g., walking, manipulation) may be gifted along another dimension (e.g., vision, intelligence, etc). Thus, a person's degree of disability or handicap can vary from negligible through to severe. The disability usually also only affects some of an individual's overall capabilities.

Figure 1 shows the traditional bell-shaped curve, with four vertical lines which divide the curve into five areas. The curve represents the general population. For any given device or design, there will always be people who have no trouble using the device/design, people who have little trouble, people who have some trouble, people who have a lot of trouble, and people who are totally unable to use the particular device/design. There are, of course, no clear dividing lines separating these groups; rather, it is a graded continuum. Similarly, there is no clear-cut place to draw a line where everyone falling on one side would be "disabled" and everyone falling on the other side would be "able-bodied." There simply is no clear definition of disabled individuals. At some point along this curve, individuals who are unable to use the world as it is currently designed and structured are identified as disabled in order to provide them with special assistance. Many other individuals with impairments, some of them quite severe, manage to get along without assistance, especially when the devices and systems they must use are well designed.

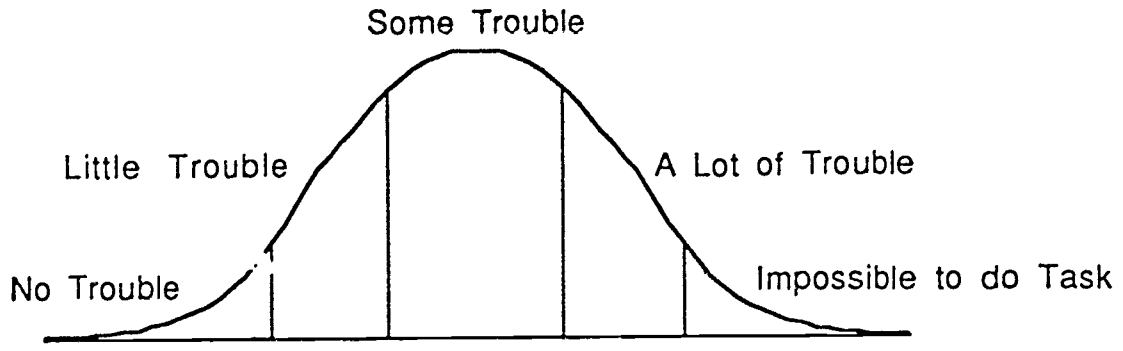

Figure 1

This paper addresses the design of computers to allow their use by individuals on the right half of the bell-shaped curve, who may have some reduced abilities along any one of a number of dimensions (e.g., manipulation, vision, hearing, cognition, etc.). This includes the approximately 20 percent of the population of the United States who have an impairment which is severe enough to cause them to be at a significant disadvantage in living and working in the world as it is currently designed.

NOT ALL NEEDS CAN BE MET THROUGH STANDARD COMPUTER DESIGN

Although there are many ways that the design of standard computers can be improved so that more people can use them, it is not possible, nor is it appropriate, to design computers in such a way that everyone can use them. For example, individuals who have severe or multiple disabilities will often require very specialized interfaces or display systems. These systems are best developed and provided by rehabilitation manufacturers who focus on the development of devices for people with particular disabilities. There are a number of reasons for this. First, building elaborate, specialized interfaces into all of the standard-manufacturer computers would not be cost-effective. Second, the design teams of standard computer manufacturers are not usually familiar enough with all of the many different disabilities to be able to effectively design interfaces for all of the different disabilities. Even the rehabilitation manufacturers tend to specialize in different areas of disability. Finally, a computer which contained every possible required interface and output display type would probably not be usable by anyone.

It is important, however, that the design of standard computers provide some mechanism for the connection of these special input and output systems. Especially as computers are becoming more and more closed at the system level (even as they are becoming more open at other levels), it is essential that these entry or connection points be provided, since it will be more difficult if not impossible for rehabilitation manufacturers to install them themselves, as has been done in the past.

Thus, the role of the manufacturers of standard computers in the area of increasing the computers' accessibility is not likely to be one of manufacturing computers that can be used by everyone, but rather one of increasing the number of individuals who can use the computers as they come from the box, as well as providing the "hooks" that special rehabilitation developers and manufacturers need to create and connect special adaptations for individuals who have multiple or more severe limitations.

MOVEMENT DISABILITIES

For individuals with movement disabilities, it is the computer input mechanisms (keyboards, mice, etc.) that present the greatest problems. Also involved, but generally of less concern, are adjustments or other controls that may be on the computer equipment. In addition to difficulties in using the computer itself, individuals with movement disabilities may have difficulty in manipulating computer-related materials such as disks and printouts.

Individuals with weakness or mild to moderate movement disorders may be unable to use standard keyboards, but are often able to use adapted or miniature keyboards. Individuals with high spinal cord injuries (no control below the neck), as well as individuals with extreme interference or weakness of their motor control systems, are often unable to use a keyboard of any kind. They are, however, able to use other special adaptive aids that could be used instead of the keyboard.

These alternate input mechanisms include sip-and-puff Morse code, voice recognition, scanning techniques requiring only the ability to activate a single switch, and eye-gaze keyboards that "type" when the individual simply looks at the "keys." These interfaces exist commercially, but there is currently no way to allow them to be used instead of the standard keyboards on unmodified computers running standard software. (Computers can be individually modified with keyboard emulating interfaces to allow their use -- see below.)

As mouse, touch screen, lightpen, and other input devices become more common, these interface problems take on new dimensions. Alternate access mechanisms need to be developed for all of these input approaches if individuals are to have access to standard educational, recreational, and productivity software.

VISUAL IMPAIRMENTS

Visual impairments vary in cause, characteristics and degree. As a result, the impact and problems presented in computer use also varies between individuals.

People with visual acuity impairments have difficulty seeing even when focusing properly. These individuals have difficulty with displays. The small lettering on some keyboards also poses a problem for individuals with limited visual acuity. With the aging of the population who use computers, problems in visual access will be of increasing concern. Availability of optional large-screen displays helps somewhat with personally-owned systems, but does little for the larger problem of access to computers in public, educational, and employment settings.

Visual perception problems are the problems faced by individuals whose eyes focus well, but who have visual processing difficulties that make it difficult or impossible to handle printed information or complex displays. This is more of a software design issue than a hardware or system access issue. Simpler, larger displays may help on systems to be used by the public, as would some of the solution strategies for totally blind individuals.

Color blindness will pose increasing problems as color displays are more commonly used. This, too, is largely a software question, although alternate display options could be of benefit. The problem is best addressed by careful selection of colors which appear different in shade to color blind individuals, or through redundant cues.

Blindness, of course, presents severe problems for using standard software, due to the high reliance of the software on the visual display of information Although full-screen tactile displays are under development, it is doubtful that these will ever be effective enough for on-line mouse and windowing operations. Alternate display approaches (voice and Braille, most notably) exist, but usually cannot be used to access the screen images produced by standard software without modifying the operating system or the computer itself. Manuals and information on how to use these systems and software are usually not available in a form that is usable by blind individuals (e.g., in Braille or on disk).

For people with visual impairments who can currently manage printed information through some technique or aid, and are gainfully employed, the advent of computers and displayed information can be traumatic, and force relocation (Knutsson, 1986). If effective techniques can be identified which can make the displayed information available in a form which enhances reading comprehension, this new barrier could be turned to an asset.

HEARING IMPAIRMENTS

Individuals with hearing impairments are not currently at a great disadvantage when trying to use standard software packages. Warnings that appear only as sounds or tones are a problem. Warnings that are both visual and auditory generally are not a problem -- especially if the visual warning is difficult to miss. Some newer programs that use speech to guide or assist the user or as output do pose a significant barrier when the information is not also provided in visual form (e.g., on the screen).

COGNITIVE IMPAIRMENTS

Specific learning disabilities, memory problems, and retardation are examples of cognitive disabilities. Each of these disability areas, however, is very distinct from the others, and poses different constraints. Public access systems in particular may want to consider the complexity of keyboards and visual displays, memory requirements (on the part of the user), and the cognitive demands of their programs and systems. Clear, simple, step-by-step directions and documentation are important, as is the lack of clutter on screens. All of these measures also increase the ease of use of systems by the elderly and by the general public.

MECHANISMS FOR MAKING COMPUTERS MORE ACCESSIBLE

Features which would make computers more accessible can basically be broken down into two groups:

a) features which allow persons with disabilities to access and use computer that are not owned by or assigned to them (public or shared computers);

   Type 1) features that allow individuals with mild impairments to use the computers directly as they come from the box;

   Type 2) features that facilitate the connection of specialized interfaces and accessories for individuals with more severe disabilities.

b) features which facilitate the use of computers which are personally owned or controlled by the disabled individual;

   Type 3) features that facilitate customization of a personal computer to allow access to standard software;

   Type 4) features that make computer use easier but are not required for access;

   Type 5) features that facilitate special applications for computers.

Table 1 provides a listing of some features from each of these categories. Many of these modifications can be implemented in software, often as relatively minor modifications or extensions to the operating system of the computer. As such, they do not increase the manufacturing cost of the computer. Even hardware design modifications, which would be very expensive on a retrofit basis, can usually be implemented in manufacturing cost on future systems. In Table 1, those items which could be implemented through software modifications are marked with a dagger. Note that most of the modifications would increase the flexibility or ease of use of the computers for the non-disabled "mass market" as well.

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prepared by the Design Considerations Task Force
of the Industry-Government Cooperative Initiative
on Computer Accessibility
July, 1987

Input Accessibility

Physical Disabilities Input Access

Individuals cannot physically use some standard input devices.

Problem	Examples
Some individuals who can use only one hand, or who use a mouthstick, cannot activate multiple buttons or keys at the same time.	Individuals with one arm, or those who use a mouthstick, cannot use shift/control keys on standard keyboards... ...or operate a mouse in conjunction with shift/control/option keys... ...or operate a multi-button mouse.
Some individuals do not have enough fine movement control to use some newer input methods.	Individuals with motor coordination problems or paralysis cannot accurately use a mouse or touchpad.
Some individuals have slower or irregular reaction times, making time-dependent input unreliable.	Individuals with a slower reaction time can get undesired characters if the key repeat rate is too fast.
Individuals with more severe physical disabilities who must use special input systems have no way to connect them to the standard computers they encounter in the workplace, school, etc.	Individuals who require an eyegaze or sip&puff controlled input cannot connect their device in place of the normal input devices (keyboard, mouse, touchscreen) on the various computers at work/school. When computer systems are changed/upgraded or a person wants to change jobs (or gets a promotion) his/her special input systems don't work on the new computer/model.

Design Recommendations	Design Examples
To allow more individuals with mild/moderate physical disabilities to be able to use the standard input devices:	
* IPM-1 Input devices that require multiple simultaneous activations should have an optional (sequential) mode of operation. This mode should be available at any time and should eliminate the need for simultaneous actions.	† Addition of an invokable 1-finger "sticky key" feature to the operating system which allows sequential use of shift/alt/option etc keys † Optional multiple mouse button control from keyboard (see next)
* IPM-2 Systems having mice or other pointing systems should have a method for carrying out all the same functions from the keyboard.	† User invokable option which uses part of the keyboard to control mouse cursor & buttons or to create simulated touchscreen input.
* IPM-3 Systems requiring responses in less than 5 seconds or release time less than 2 seconds, should have provision for the user to adjust the time, or have a non-time-dependent alternative method.	† User adjustable key repeat rate and delay. † A response delay is programmed to be longer than 5 seconds.
To allow individuals with more severe disabilities to connect their special input devices:	
* IPS-1 All systems should have an externally accessible connection point (standard or special port) to which alternate input devices can be connected. This connection should be an industry or company standard. All input through the connection should be treated identically to input from standard input devices by the system and application software.	† Operating system can accept data from serial port in a standard protocol which is treated by the system and application programs as input from standard input devices. - Standard input bus for all input devices.

Visual Disabilities Input Access

Individuals cannot visually use some standard input devices.

Problem	Examples
Some visually impaired individuals have difficulty finding or identifying keys or buttons on input devices.	Individuals with low vision have difficulty reading the legends on keys and controls.
	Individuals with severe visual impairments have difficulty locating the home keys and selected peripheral keys on a keyboard.
	Individuals with severe visual impairments cannot find keys on perfectly flat membrane keyboards or keypads.
Individuals with severe visual impairments cannot use input devices which require constant visual feedback.	Blind individuals cannot use a mouse because they cannot monitor the mouse cursor's continually changing position in relation to the image on the screen. Blind individuals cannot use input systems which have dynamically defined keys with only visual feedback as to current key value.

Design Recommendations	Design Examples
To allow individuals with mild/moderate visual disabilities to use standard input devices:	
IVM-1 Legends and lettering on keys should be easily readable.	- Larger lettering on keys and around controls. - High contrast lettering.
To allow individuals with severe visual disabilities to use standard input devices:	
* IVS-1 There should be tactilely distinct landmarks on home keys on a keyboard	- Nibs on center or front edge of home keys on keyboard and keypad.
* IVS-2 The edges of keys or buttons should be tactilely discernable. Keys or buttons should not be activated by a hand lightly feeling them.	- Small raised ridge outlining keys on flat membrane keyboards.
IVS-3 If a computer has a standard input system which requires continual visual feedback to operate, the computer would preferably have an alternate means or mode for achieving as many of the functions as possible. This alternate means or mode should be available at any time and should not require continual visual feedback.	† Keyboard equivalents for as many mouse operations as possible. † Optional mode which can be invoked by blind users which eliminates need for continual feedback features (where possible). - (Some functions like freehand sketching may not be possible.)

These recommendations are intended as suggestions for improving the accessibility of standard desktop and portable computers. They are not intended as a list of required features for accessibility, but rather as an aid in designing computers which are more accessible.
- If used as source material for design or procurement guidelines only a subset should be thought of as required; the rest should be left as recommendations. Those design recommendations which appear to be most important at this time in order to provide reasonable access to current and near future systems are marked with an asterisk. Examples which can usually be implemented in software are marked with a †.
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Output/Display Accessibility

	Problem	Examples	Design Recommendations	Design Examples
Visual Disabilities Output Access	Some visually impaired individuals have difficulty in discerning the images on the screen.	Individuals with low vision have difficulty reading the screen because the characters are too small.	To allow more individuals with mild/moderate visual disabilities to use standard displays:	
			OVM-1 A means for zoom-enlarging the image on the display would preferably be provided; this feature should be able to enlarge any area of the screen and provide magnification up to 16 times in at least 8 steps.	† Modification to basic graphic interface allows user to zoom in on any area of the screen. Zoom follows mouse or cursor movements.
		Color blind individuals cannot see text presented in some text - background color combinations.	OVM-2 Color used on displays would preferably be user selectable for color blind individuals.	† Color of text and background adjustable by user.
		Individuals with low vision have difficulty seeing the screen due to glare or distance.	OVM-3 Displays would preferably be repositionable.	- Display separate from CPU and keyboard on computers with a large CPU unit.
Individuals cannot use some standard visual output devices.	Individuals with severe visual impairments have special alternate displays but do not have a means to use them with the computer.	Blind individuals could use a portable voice output access device in place of the computer's standard screen display except where these devices cannot get access to the contents of the computer's display screen.	To allow individuals who are blind or have more severe visual impairments to connect their special display devices:	
			* OVS-1 Screen display information should be provided on request or continuously at an external connector in a company or industry standard format in the first of the following forms that is available to the operating system: - screen description - character listing (for character based screen displays) - bit image.	† Special request from external device causes information on current console display to be sent to external bus or standard port or connector. † Special mode is invoked after which all information sent to screen processor (software or hardware) is also sent to external bus or port connector.
Hearing Impairments Output Access	Individuals with hearing impairments have difficulty hearing audible feedback from computers.	Individuals who are hard of hearing have difficulty hearing beeps that indicate errors when typing or issuing commands.	To allow individuals with mild/moderate hearing impairments to be able to hear auditory output:	
		Individuals with hearing impairments are unable to turn the volume up sufficiently in some environments (e.g. library or noisy environment).	OHM-1 The output volume would preferably be controllable and have a wide range (this is less important if all auditory feedback is available redundantly in an appropriate visual form, or it there is an external speaker jack).	- Larger range on volume control.
			OHM-2 Devices would preferably have an audio jack or have speaker near edge for amplification.	- Could be special jack or dedicated pin on another connector if standard across machines.
Individuals cannot use standard auditory output.	Individuals who are deaf or have severe hearing impairments do not receive any information presented in an auditory form.	Deaf individuals cannot hear beeps that indicate errors when typing or issuing commands.	To allow individuals who are deaf or have more severe hearing impairments to receive feedback:	
			* OHS-1 All information presented in an auditory form which is required for system operation and error detection should also be provided or available redundantly in an appropriate visual form. (Training materials would not normally be considered as required for operation but would preferably also be available in captioned form.)	† Beeps accompanied by a flash on part of the screen. - Small LED which flashes in parallel with beeps. †All auditory/spoken messages also displayed. † Invokable feature causes spoken text to be displayed at top or bottom of screen.

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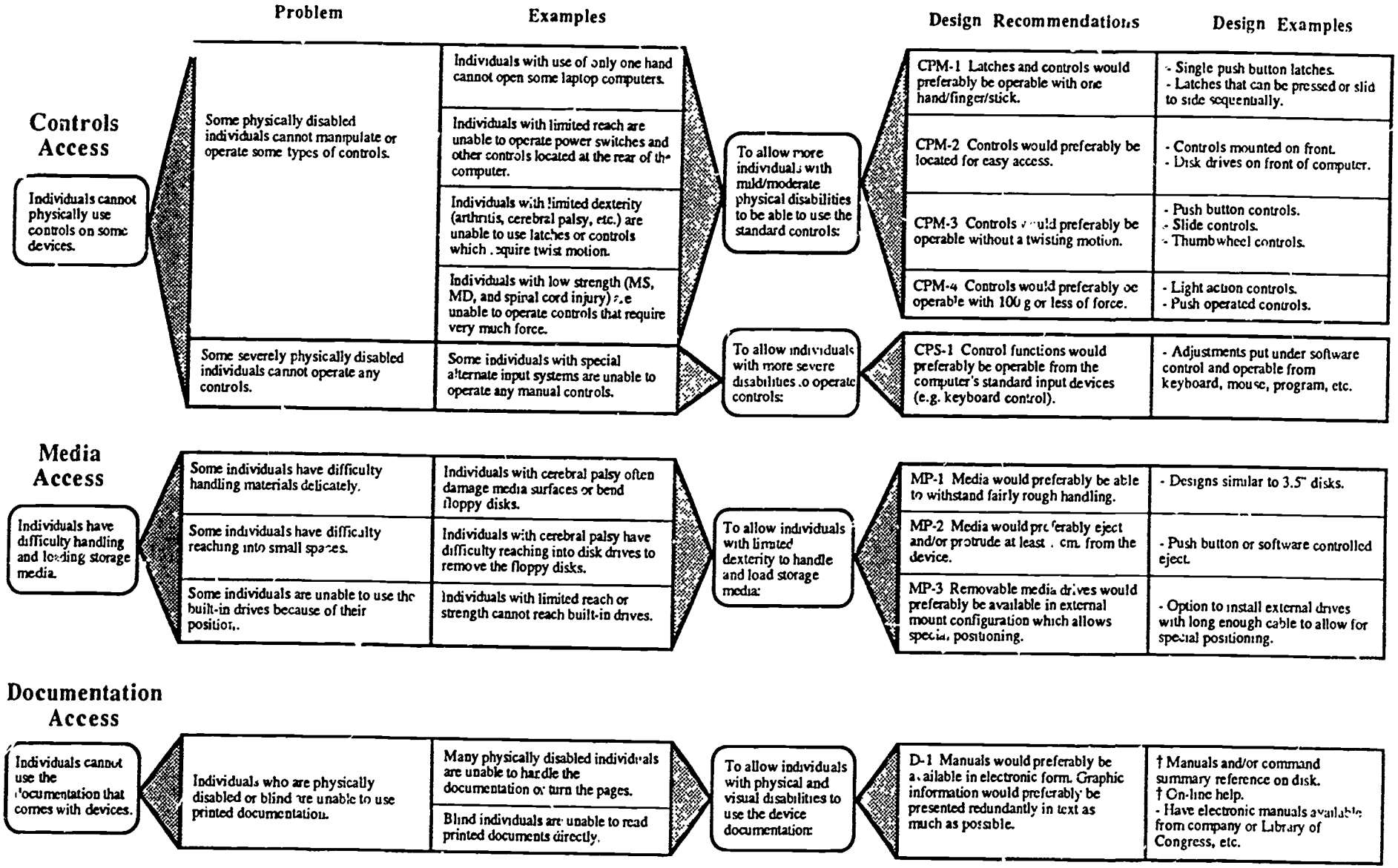
Controls, Media and Documentation Accessibility



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Personal Workstation Modification Facilitation

Input Modifications

Individuals have difficulty installing special input access programs or modifications in their personally owned or assigned computers.

Problem	Examples	Design Recommendations	Design Examples
Some operating systems do not allow simulation of input device activity (keystrokes, mouse pointing) by programs running in background (or under multitasking). This prevents the use of low cost software solutions for providing alternate input systems for those who can use this approach.	Scanning and other special input programs do not have a means to inject simulated keystrokes, touchscreen or mouse activity into the computer for use by the operating system and application programs.	WP-1 Operating systems which support background programs or multitasking would preferably have a means for simulation of keyboard and other input devices by a program running in the computer. This simulated input should be treated identically to input from the standard input devices by the system and application software. This input simulation capability should extend to all input devices required for operation of the computer.	† Operating system has an "inject only" vector or address to which simulated input can be sent. This input point is in front of the first access (read or filter) point available to the system functions or application programs. In multitasking environments, the program is able to inject keyboard input even if keyboard is being read by another application, but for security, the application program has to be invoked by the same user.
Some operating systems do not provide a mechanism for programs running in the background (or under multitasking) to provide continual visual information to the user. This prevents the use of low cost software-based alternate input systems which require a continuous visual selection or feedback display.	Special access programs such as those which put a keyboard image on screen and use a head movement operated "mouse" won't work on computers where the window containing the keyboard image does not stay visible when other programs (windows) are active.	WP-2 Windowing environments would preferably have the ability to open and maintain special windows which can always remain fully visible (for use by special input routines).	† Window environment modification.
Most computers have no provision for connecting any external switches, making special, more expensive, adapters necessary to connect special switches needed by some access programs.	An eye-blink operated scanning program needs a way to connect the eye-blink switch to the computer. A sip-puff Morse code input program needs 2 switches.	WP-3 Computers would preferably have a way of connecting special momentary contact (SPST) input switches.	- Special jack or dedicated pin(s) on a standard connector.
Some software programs discard some keystrokes that show up in type-ahead buffers - interfering with the use of special "macro" based acceleration programs.	Multiple backspaces or arrow keys are often discarded by software programs, causing problems for abbreviation expansion based acceleration programs.	WP-4 Operating systems would preferably allow macro-generated input to be marked so that it can be treated differently from standard input by system and application software.	† Operating system modification.

To facilitate the installation of special input access modifications in personally owned or assigned computers:

Output Modifications

Individuals have difficulty installing special output access programs or modifications in their personally owned or assigned computers.

Visually impaired persons can often take advantage of commercially available large screen monitors to provide larger images .... but some computers with built-in monitors have no provision for external display connection.	Computers with special technology built-in displays may not make provision for external display connection.	WV-1 Computers would preferably allow connection of larger image displays.	- Built in or standard add-on connector for larger displays (display can be 3rd party).
More powerful, multitasking computers create the potential for having sophisticated screen reading and interpretation software running in a computer along with standard application programs. This would allow lower cost solutions for some people. However, the total screen content is not necessarily available to these programs preventing this approach.	A screen reading program running in the background could provide a blind person with voice output description of the contents of the screen (where standard application programs are displayed) if screen contents were available to it from the operating system on request.	WV-2 Computers which support background programs or multitasking would preferably provide screen display information on request or continuously in a company or industry standard format to a special program running in the computer. This information would preferably be provided in the the first of the following forms that is available to the operating system: - screen description language - character listing (for character based displays) - bit image.	† Special system routine which provides applications or background program with a description of the console display. † Invokable option in operating system which continually feeds output display information to a background or multitasking program as it is being fed to the display processor (hardware or software).

To allow individuals with visual impairments to make special modifications to their personally owned or assigned computers:

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Partial funding for this work was provided under Grant #G008300045 from the National Institute of Disability and Rehabilitation Research, United States Department of Education.