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Computer and cell phone access for individuals with mobility impairments: An overview and case studies

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Abstract. Computers, telephones, and assistive technology hold promise for increasing the independence, productivity, and participation of individuals with disabilities in academic, employment, recreation, and other activities. However, to reach this goal, technology must be accessible to, available to, and usable by everyone. The authors of this article share computer and telephone access challenges faced by individuals with neurological and other impairments, assistive technology solutions, issues that impact product adoption and use, needs for new technologies, and recommendations for practitioners and researchers. They highlight the stories of three individuals with neurological/mobility impairments, the technology they have found useful to them, and their recommendations for future product development.

Keywords: Technology, access, computer use

1. Introduction

An elevator or ramp provides access to spaces when a staircase is insurmountable for someone who uses a wheelchair. A curb cut allows this person to maneuver between a sidewalk and street levels. Similarly, specialized hardware and software, called assistive technology (AT), allow the operation of computers and telephones by people with disabilities for whom standard products erect barriers. Together, computers, telephones, and assistive technology have the potential to maximize independence, productivity, and participation in academic programs, employment, recreation and other activities. Specifically, AT makes it possible for a person with limited, uncontrollable, or no hand or arm movement to use all of the capabilities of a computer and cell phone and thereby successfully perform everyday tasks. In addition, for those who have the interest and aptitude, advanced technology skills open doors to high-tech career fields that were once unavailable to people with mobility impairments.

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The following examples demonstrate how computers and telephones, sometimes enhanced with AT, can be used by an individual with a neurological impairment to address functional limitations imposed by the disability and thereby contribute to her independence, productivity, and participation in school, employment, social, and other activities. Specifically, technology can help her:

- *Engage in discussions and gain and give support.* Example: Using a computer-based communication device to talk with friends, family and supervisors, and deliver presentations on the job and using online social networking systems to keep up with friends and relatives, chat with other people who have disabilities, gain support for college and career transitions from mentors, help others, and meet role models [60].
- *Achieve high levels of independent living.* Examples: Using a voice-controlled system to operate the television, turn lights on and off, open doors, and perform other tasks of daily life; commercial websites to shop for groceries, medications, clothing, and housewares; a cell phone to communicate her needs with care givers as she enjoys communi-

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ty activities; and a set of software tools to manage her calendar, grocery lists, and budget.

- *Participate in community and recreational activities.* Example: Operating the projection system used to display the words for hymns during church services.
- *Read publications.* Example: Reading journal articles, reports, and instruction manuals, even though she does not have the physical ability to turn pages of a book.
- *Enjoy physical experiences not otherwise possible.* Example: Completing a chemistry experiment through a computer simulation and observes sea life while swimming in the ocean within a virtual reality environment.
- *Engage in educational opportunities.* Examples: Using a hands-free keyboard and mouse to operate a computer to fully participate in an Internet-based or on-site course.
- *Prepare for transitions to college and careers.* Example: Using a computer to explore internship and career opportunities, take self-paced career readiness and interest tests, and research the academic programs and services for students with disabilities offered at colleges of interest.
- *Enter high-tech career fields.* Example: Completing a college degree and securing a job as a software engineer.
- *Succeed in a career.* Example: Operating a computer to edit books for a publisher. [6]

These examples shed light on the important roles computers and telephones can play as people with mobility impairments pursue postsecondary education, careers, and community life. They realize the same benefits as individuals without disabilities – they write papers, calculate budgets on spreadsheets, access Internet resources, communicate by phone and online, but also use technology as compensatory tools for doing things that are otherwise impossible because of their disabilities [65]. For example, computers combined with AT give voice to a person who cannot speak, and give a person without functional use of his hands an ability to write.

Taking full advantage of the power technology offers in supporting positive outcomes holds promise for reducing the gap in college and career success between people with disabilities and their non-disabled peers [13,42,48,49,51]. A bachelor's degree or higher is a prerequisite for many challenging careers [53]. High-tech studies and careers are particularly accessible to individuals with disabilities because of the combined effect of the increasing use of information technology in many career fields and of the advancements in AT that provide access to computers for people with disabilities.

Although the benefits of information technology (IT) may be even greater for people with disabilities than for individuals without disabilities, people with disabilities are much less likely to own computers and to use the Internet as other individuals [34]. Reported barriers to technology use include: (1) lack of knowledge of stakeholders about appropriate AT and how to use it; and (2) lack of funding to purchase AT [20,29,46]. Often educators are inadequately prepared with respect to the use of computer technology [2,30,44–46]. "Lack of adequate teacher training has an especially strong impact on students with disabilities because technology is often a critical component in planning and implementing an educational program for these students" [30, p. 188]. There is also a shortage of trained professionals to evaluate technology for people with disabilities; a sluggish bureaucracy of public programs and insurance companies to purchase products; and limited opportunities to test specific AT solutions by individuals with disabilities and other stakeholders [46]. Consequently, too often electronic resources and applications software with inaccessible features are developed and purchased. Even students who gain access to computers and AT in precollege settings are rarely allowed to take equipment and software with them after they graduate high school.

Clearly, we have not fully realized the potential of technology solutions to promote education and career success for people with disabilities. The following paragraphs describe access challenges to computer and telephone technology and current solutions to these challenges for individuals with mobility impairments. Although people with mobility impairments may also have hearing, visual, learning, or other disabilities as well, this paper focuses on issues related to mobility impairments only. A thorough analysis of specific product features and of research on the effectiveness of each product category and access approach is beyond the scope of this article; however, some references are made to publications that catalog specific products and report evaluation and research results (e.g. [1]).

2. Computer and telephone access challenges for people with mobility impairments

The National Science Foundation defines *access* as "the ability to find, manipulate and use information in an efficient and comprehensive manner" [38, p. 1]. The design of most computer and telephone software and hardware erects barriers for some individuals with disabilities [50,59,69]. In other words, these individuals do not have *access* to all of the benefits the products deliver to their counterparts who do not have disabilities.

Sometimes a person cannot operate computer or telephone technology due to inappropriate positioning of the devices. For example, some wheelchairs do not fit under standard height computer tables. Some computer users do not have enough strength or functional use of their hands and arms to operate a standard keyboard or mouse. For example, an individual with poor dexterity or hand control may have difficulty pressing a desired key on a computer or telephone keyboard without inadvertently pressing other keys. Even when access to mouse functions is provided through alternate keyboard commands, not all applications, both standalone and web-based, allow mouse functionality through keyboard commands, thus erecting an additional barrier for the user.

The design of most cell phones requires that they be held in one hand and operated with the other. This makes accurate use of these devices difficult or impossible for some individuals with mobility limitations. A specific manufacturer may have multiple operating systems for their line of telephone products, further confusing potential buyers. For cell phones with a touch screen interface, small icons (targets) may be challenging or impossible to activate for some users with mobility impairments. Proprietary connection ports on some phones also limit options for attaching alternate input devices that otherwise could offer access options for individuals with mobility impairments.

3. Computer and telephone access solutions

Assistive technology is defined as "any item, piece of equipment, or system, whether acquired commercially, modified, or customized, that is commonly used to increase, maintain, or improve functional capabilities of individuals with disabilities" [64]. Assistive technology enables people with disabilities to accomplish daily living tasks and assists them in communication. It allows greater access to education, employment, and recreation as it maximizes physical functions and minimizes the impact of a disability. Examples of assistive technology include wheelchairs, scooters, environmental control units, alternative automobile controls, prostheses, hearing aids, and alternative input devices for computers and cell phones. An *assistive technology service* is defined as "any service that directly assists an individual with a disability in selection, acquisition or use of an assistive technology device" (Technology-Related Assistance Act).

The mobility impairments of some individuals who use AT are obvious to the observer; however many are less apparent. For example, an individual with a repetitive stress injury (RSI) may have no visible impairment yet require significant AT in order to use a computer without experiencing pain. However, a person who uses a wheelchair may require no special technology to access a computer. AT specialists often find it more useful to focus on abilities and functional limitations rather than a medical diagnosis such as muscular dystrophy, cerebral palsy, spinal cord injury, multiple sclerosis, or RSI because people with the same medical condition may have different abilities that lead to different technology solutions. In the following paragraphs, examples of tools and approaches to computer access that have been effectively used by individuals with mobility impairments are described. They include solutions related to furniture and mounting, keyboards, mice, and software support.

3.1. Furniture and mounting issues

Proper seating and positioning is important for anyone using a computer or cell phone, perhaps even more so for a person with a mobility impairment. People with mobility impairments are not a homogenous group when it comes to height, weight, and other physical characteristics. For proper positioning, a person with a mobility impairment should consult a specialist in seating and positioning to ensure that correct posture and successful control of devices can be achieved and maintained. Often this person is trained as an occupational therapist.

Flexibility in the positioning of tabletops, keyboards, mice, screens, and documentation is a key concern. Connecting computer components into power outlet strips with accessible on and off switches makes it possible for some individuals to turn equipment on and off independently. An adjustable table can be cranked higher or lower, either manually or with a power unit, to put the keyboard and monitor at a proper height. Adjustable trays can move keyboards up and down and tilt them for maximum typing efficiency. Mounting keyboards perpendicular to tables or wheelchair trays at head-height can assist individuals with limited mobility who use pointing devices to press keys. Simple approaches to furniture access should not be ignored. For example, wood blocks can raise the height of a table and a cardboard box can be used to raise the height of a keyboard on a table. Repositioning a device may provide a simple access solution. For example, a reasonable accommodation for use of a pointer by someone who can't use his hands but can move his feet is to place a standard mouse or trackball on the floor. Locating a cell phone or computer screen in a position that is comfortably visible to the user is also important, as well as sizing the text and icons on the screen to maximize readability.

3.2. Keyboard and mouse alternatives

Individuals who lack the dexterity or range of motion necessary to operate a standard keyboard or mouse have a wide range of alternatives from which to choose.

3.2.1. Solutions found in the operating system

Someone who has use of one finger, a mouth- or head-stick, or some other pointing device and can press the keys on a standard keyboard with the pointing device is, essentially, a "one finger typist." Some access solutions adapt the traditional keyboard to address specific needs. The accessibility features that are included with modern operating systems should be considered before purchasing a separate keyboard option. The Accessibility Options control panel in current versions of Microsoft Windows or Universal Access in Macintosh OS X, for example, contains a variety of settings that can make a standard keyboard easier to use. For a one finger typist, software utilities can create "sticky keys" that electronically latch the SHIFT, CONTROL, and other keys to allow sequential keystrokes to input commands that normally require two or more keys to be pressed simultaneously. FilterKeys can eliminate unwanted keystrokes for a person who has difficulty accurately targeting a key. Similarly, the key repeat function can be disabled for those who cannot release a key quickly enough to avoid multiple selections. Macintosh operating systems have similar keyboard accessibility features in the Universal Access control panel.

3.2.2. Keyguards

A keyguard can support keyboard use by a person who has difficulty pressing one key at a time on a standard or specialized keyboard. Keyguards limit excessive or inaccurate key presses with a standard keyboard or filter key input using settings in common operating systems. Typically, a keyguard is a plastic shield that fits over the keyboard; holes above the keys that are drilled through the guard help an individual press a desired key without inadvertently pressing other keys. Unfortunately input filters such as keyguards are typically not available for handheld devices such as PDAs and smart phones.

3.2.3. Alternative keyboards

Replacing a standard computer keyboard with an alternative keyboard may be appropriate for a person who cannot effectively operate the standard keyboard by adjusting operating system settings or installing a keyguard. A mini-keyboard may be the best solution for a person with limited range of motion, but good fine motor skills. For someone with adequate range of motion but poor dexterity, a keyboard with extra large keys may be appropriate. Some alternative keyboards offer alternate layouts to the traditional "QWERTY" design. For individuals who need to operate a computer with one hand, left- and right-handed keyboards provide more efficient key arrangements for use with one hand. Some keyboards have recessed keys or nonstandard arrangements to help prevent or relieve the effects of conditions such as tendonitis or a RSI.

3.2.4. Switches

Using a switch in combination with other AT described in the paragraphs that follow may be an important part of a computer access solution. There is an almost countless array of switch choices that can be activated with nearly any body part – e.g., with the kick of a foot, swipe of a hand, sip or puff, move of the head, blink of an eye. Even physical closeness can activate a proximity switch. Switches work in concert with software that sends commands for the keyboard or mouse to the computer. For example, activation of a switch may bring up a main menu of options on the screen. Additional switch activations allow a drilling down of menu items to the desired keystroke, mouse, or menu action.

3.2.5. Virtual keyboard

A virtual keyboard presents an image of a keyboard on the computer screen and a person uses a mouse, trackball, or other pointing device to select the keys on the screen image, including function keys and modifier keys such as Ctrl and Alt. In scanning input, lights or cursors scan letters and symbols displayed on computer screens or external devices. Individuals use switches to make selections. Some virtual keyboards incorporate word prediction (as described in section 3.3) to increase entry speed and may include alternate layouts in addition to the traditional "QWERTY" layout found on standard keyboards.

3.2.6. Morse code input

Morse code keyboard emulation is another alternative for someone who cannot operate a standard keyboard. In this case, special switches make use of at least one muscle over which the individual has voluntary control (e.g., head, finger, foot) and the individual enters standard Morse code and additional codes for modifier and function keys by activating switches (e.g., a sip-and-puff switch registers dot with a sip and dash with a puff). Special hardware and software then translate the Morse code into a form that the computer understands, thus offering access to all of the capabilities of a standard keyboard. Many computer users quickly adapt to using Morse code and can achieve high entry speeds with practice.

3.2.7. Mouse alternatives

There are many alternatives for individuals who lack the physical skills necessary to operate a standard mouse [18]. Trackballs are good mouse alternatives for people who find its control surface easier to manipulate. One valuable feature is that the buttons can be activated without affecting the pointer position. In addition, some trackballs offer buttons for double-clicking, click and hold, and other enhanced functionality, and can be programmed to a person's specific needs. Alternative pointers can be found in many mainstream computer stores and supply catalogs. They include external touchpads, similar to those built into many notebook computers; handheld pointing devices with a small control surface area; and joysticks, which are especially attractive to someone who already uses a joystick to drive a wheelchair. New technologies and design approaches have made eye gaze pointing systems, once very unreliable and difficult to use, a more reasonable alternative for individuals with disabilities [41].

Combining an eye or head pointing system with an on-screen keyboard may allow full computer control to a person who has good eye or head control but cannot control a mouse, keyboard or alternative devices. Someone who cannot reliably control a limb may use a head-controlled pointing system that uses infrared or ultrasound detection and a transmitter or reflector that is worn on the user's head and translates head movements into mouse pointer movement on the computer screen. One of the many available switch alternatives can provide an alternative to the mouse button.

3.2.8. Speech input

Speech input provides another computer interface option for individuals with mobility impairments. Speech recognition systems allow users to control computers by speaking words and letters. A particular system is trained to recognize specific voices. Speech recognition software converts words spoken into a microphone into machine-readable format. The user speaks into the microphone in a normal talking manner. In these continuous speech systems, corrections can be made if there are recognition errors. Speech recognition technology requires that the user have moderately good reading comprehension in order to correct the program's text output. Voice and breath stamina should also be a consideration when evaluating speech recognition as an input option. While speech input has been promoted as a promising computer input option for many years, end-user experiences and adoption rates have been disappointing in part because of the level of errors current products make in recognizing an individual's speech and the cumbersome process in correcting them [19].

3.3. Computer input software support

Features common in popular word processors can be used to ease text entry for a person with a mobility impairment. For example, the AutoCorrect feature of Microsoft Word allows sentences or blocks of text, such as an address, to be represented by unique and brief letter sequences. For example, entering "myaddr" could be set to automatically display one's address in proper format. Long words can be abbreviated and entered into the AutoCorrect settings to increase typing speed and accuracy.

Special software can also make computer applications more usable by those with mobility/neurological impairments. Abbreviation expansion (macro) and word prediction software can reduce input demands for commonly used text and keyboard commands. Word prediction software anticipates entire words after several keystrokes and increases input speed. It prompts the user with a list of likely word choices based on letters and words previously typed. Some word prediction software automatically collects new words as they are used and considers a person's common vocabulary when predicting words in the future. Although designed to increase typing speed and accuracy, in some cases word prediction can actually decrease typing speed particularly when short words are involved.

3.4. Cell phone access

People who cannot open a flip phone, or activate a very small button to unlock a phone should select a telephone that provides alternate means to open and start the phone. Those who do not have the dexterity required to operate a touch screen with their fingertips may require an alternate control method, perhaps by using a pointing device, changing the phone controls, or attaching another piece of hardware such as full size keyboard via a cable or Bluetooth. These external devices, however, do not always fully integrate with a specific phone and its operating system.

Like computers, cell phones use operating systems to read user input and control device features. Unlike common desktop operating systems, most telephone operating systems lack the variety of features that benefit people with a wide range of abilities. Phones based on Microsoft and Apple operating systems tend to be more likely to provide enhanced accessibility options for individuals with mobility impairments. It is important that developers who create applications for these platforms use the appropriate Application Programming Interface (API) in order to provide access to these capabilities.

Most modern telephones provide a means to dial contacts using speech input commands. Although this feature reduces the need for physical access to the phone, successful use of voice dialing is impacted by speech legibility, ambient noise, and microphone quality for a built-in, wired, or Bluetooth connection to the device. Used in combination with speaker phone features, many telephones can be used by those who cannot physically hold them. However it may be necessary to change default phone features and settings to provide independent access to these features, including setting the speaker phone to always-on, not automatically locking the phone after a pre-set time, and placing the most-used icons for applications on the main screen.

3.5. Universal design and built-in standard accessibility features

The process of creating products that are accessible to people with a wide range in usage plans and of abilities, disabilities, and other characteristics is called *universal design* (UD), or *design for all*. Universal design is defined by the National Center for Universal Design at North Carolina State University as "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" [9]. At this Center, a team of architects, product designers, engineers, and environmental design researchers established a set of principles of universal design to provide guidance in the design of environments, communications, and products. General UD principles are: the design accommodates a wide range of individual preferences and abilities; the design communicates necessary information effectively, regardless of ambient conditions or the user's sensory abilities; the design can be used efficiently and comfortably, and with a minimum of fatigue; and appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility.

The concept of UD has been applied to many products and environments that include instruction, student services, physical environments, and technology [5,7, 8]. In particular, when universal design principles are applied as technology is created, the resulting products are more usable by everyone, including people with disabilities. UD in this context is "the conscious and systematic effort to proactively apply principles, methods and tools, in order to develop IT&T products and services which are accessible and usable by *all* citizens, thus avoiding the need for a posteriori adaptations, or specialised design." [63, p. 3]. The UD approach minimizes the need for assistive technology [63,67]. UD technology is also compatible with commonly used assistive hardware and software [67]. Although relatively few products have built-in UD features, the field is rapidly progressing world-wide toward a higher level of maturity [62]. To expand its influence, the field needs to continue to evolve to address access challenges created by new technologies, develop stronger linkages between research and industry, and incorporate UD issues into the professional training of future scientists, IT designers, educators, and other stakeholders [62].

In the next sections, individuals with neurological impairments share their experiences in using computers and telephones, examples of AT they have found useful, and recommendations for future development.

4. Three cases studies: Experiences with computer and cell phone access of individuals with mobility impairments

4.1. Dr. Sang-Mook Lee, University Geophysics Professor

My name is Sang-Mook Lee and I am a professor and geophysicist at Seoul National University in Korea.

A spinal cord injury resulting from an automobile accident during a geological field trip in California in 2006 left me completely paralyzed below my neck. I was 44 at the time of the accident. Despite my paralysis, I'm able to teach and conduct research at the top university in Korea with the aid of various assistive devices.

I use two computer input devices: (1) the sip-and-puff system Integramouse, and (2) the head-motion controlled mouse HeadMouse Extreme. I can use the latter device because I have a large range of head movement. Once you are able to simulate the movement of a computer mouse on the computer screen, a new world opens up in front of you. With the help of these devices, I can send emails, read electronic books, conduct searches online, make and receive phone calls using applications such as Skype, and watch television and flip channels by myself. I often say that the computer is a gift from God to disabled people like myself.

Writing long letters or documents can be a challenge even with a good computer input device. A simple way to write is to click letter by letter on an onscreen keyboard, a feature that can be found on many operating systems today. Onscreen keyboards are useful for typing short sentences or several words but are painfully slow and tiring. A solution for me is to use speech recognition software. Initially I used Dragon NaturallySpeaking on the Windows XP operating system. However, since early 2007, I have used the speech recognition feature built into the Windows Vista operating system. I have found both products to be good. Unfortunately, there is no usable Korean speech recognition software on the market. As a result, creating long documents in Korean is a big challenge for me. In this case, I usually dictate the text for someone else to enter.

Another obstacle that I had to overcome was making and receiving phone calls. Many computers have faxes and modems and so initially I did not expect a problem in this area. However, faxes and modems send content one direction at a time, which is different from how we use a mobile telephone where we can listen and speak simultaneously. I found a solution in Korea. A company named HasoIntech makes a USB-based module called EZ Caller, which accepts a normal telephone line; using a desktop application I can actually dial and receive telephone calls from the screen. I find this software, which was not specifically made for the disabled community, to be quite useful. One modification that I made is to convert the headset into an external speaker and microphone so that I do not need to wear the headset all day long.

My next experiment was to find a way to use a cell phone. Many cell phones today are smart phones with touch screen features. Because I cannot use my hands at all touch screen features are a barrier. Unlike computers, cell phones and other handheld commercial electronic products such as Kindle do not have a USB port. Therefore, the input devices that I use for other purposes cannot be used in many mobile devices. I found a partial solution for smart phones. For Windows Mobile users, the freeware program MyMobiler emulates the cell phone touch screen and allows me to communicate with the smart phone. So as long as my computer is turned on and I have my cell phone connected to the computer, I can operate the cell phone independently. I have found Bluetooth products that allow me to communicate between computer and cell phone to be less reliable.

With the advent of wireless communication and ubiquitous computing, I expect a bright future for people with disabilities. However, in order to take advantage of the new opportunities continued efforts in developing assistive technology must be made.

4.2. Anthony Arnold, assistive technology specialist

I'm Anthony Arnold from Grand Forks North Dakota. I have cerebral palsy, which requires me to use a power wheelchair for mobility and a communication device with speech output for speaking. In addition to my cerebral palsy, I have some learning disabilities that affect my abilities in reading and spelling.

There may be no perfect time to have a disability of any kind, but I feel if I had to have a disability, I picked the perfect time. I was born on May 22, 1977, so when I reached school age, teachers were introducing inclusion in classrooms, and, at the same time, computers and other assistive technology devices were also getting introduced. It may have been like the blind leading the blind at times, but I feel my parents and educational/rehabilitation specialists were excited to explore new avenues, something I'm thankful for.

During my early elementary school years, I was introduced to the Apple IIe computer. The computer at school was equipped with a keyguard to help me type with my pointer finger; educational software for reading, spelling and math; and word processing software that I used to complete most of my school assignments. My parents saw the progress I was making with the Apple IIe computer at school, so they decided to purchase one for home use. After obtaining a home computer that I could use effectively, I would spend hours on it, which helped me educationally and was also great hand therapy. At home, the expectations of me were the same as what I had at school – to use the computer for homework assignments as well as educational games.

During second grade, I experienced my first augmentative and alternative communication system, the Touch Talker with a synthesized voice. In its day, the Touch Talker was a powerful device. Back then, the Touch Talker did not come with a preprogrammed vocabulary. It required total customization. Once we began customizing, the Touch Talker played an important role in my education. Having vocabulary I could access independently allowed my teachers to teach me more effectively. The Touch Talker also supported computer access, allowing me to type using my programmed vocabulary, which was helpful for typing homework assignments and other documents.

Thanks to my computers and Touch Talker, I was included more in school. In both elementary and secondary school, I usually only went down to the resource room to focus on reading and spelling. During my eighth grade year, I attained my Liberator, an upgrade for the Touch Talker. The Liberator had more features such as a calculator, math scratch pad, notebooks, and a built-in printer. With the Liberator, I was able to be a more effective and independent student.

During my high school years, I also obtained computer software and a scanner to scan textbooks and worksheets so that they could be read aloud to me. This capability continues to be helpful. Because of my learning disability, it is easier for me to learn things when text is read aloud.

I graduated high school in 1996, and then enrolled for a couple of semesters at the University of North Dakota. College seemed overwhelming for me at the time so I applied for a job at Prentke Romich Company, the company behind my communication devices. I was hired as a remote troubleshooter for their technical service department. Along with technical service, I engaged in research and development activities, which I've learned are some of my strengths. I have done some testing on 95% of the current Prentke Romich product line. One of the biggest projects I have been involved in is the integration of our communication devices with Bluetooth cell phones.

Even with access to my cell phone, I'm limited by what cell phone companies and their towers will allow. With my cell phone using Bluetooth, I can only accept voice calls and check voicemail. In other parts of the country (e.g., larger cities like Minneapolis), text messages can be exchanged via Bluetooth as well. I think that assistive and mainstream technology companies need to work together in order for people with disabilities to get better results with their products.

The future of augmentative and alternative communication looks bright as we learn from parents, therapists, teachers, and people with disabilities. The majority of today's systems are dynamic displays. Dynamic displays are nice when first learning a system and its vocabulary since the icon changes, the word gets displayed underneath the icon, or both happen. However, a drawback is that the screen isn't visible outside in sunlight, thus limiting communication options for the user. Augmentative and alternative communicators such as myself have brought this issue to the attention of manufactures; hopefully, they will come up with better screens. At least one manufacturer of the augmentative and alternative communicators is considering the development of a screen that automatically adjusts itself under certain lights.

I would also like to have the ability to control more of my environment (e.g., raise and lower blinds) through my communication device or computer. Currently, I operate the television, stereo system, and other entertainment systems with these devices, but, ideally, I would like to control things like thermostats, indoor lighting, and door openers using my communication device to reach a higher level of independence.

Another thing I know is in the works but years away is a brain interface between an augmentative and alternative communicator and a communication/computer system. Once it is fully developed, the person would only need to be in range of the computer system; with this enhancement, a system could be mounted behind my wheelchair, and I would still have full access.

A lot of these things are going to come one day, but we need to continue to prepare future developers on accessibility issues. One thing I hope we learned from Christopher Reeve is that a disability can happen to anyone; it is good to be able to offer those with new disabilities a wide variety of computer and cell phone options.

4.3. Kayla Brown, a community college student

My name is Kayla Brown. I am a 22-year-old college student at Bellevue College in Washington State. I have muscular dystrophy. I use a power wheelchair to get around school and work, as well as anywhere else I go. I plan to transfer to the University of Washington where I hope to study psychology or sociology. I have participated in several DO-IT projects and am employed by DO-IT as a student worker. DO-IT – which stands for Disabilities, Opportunities, Internetworking, and Technology – is an outreach program at the University of Washington in Seattle that helps students with disabilities succeed in college and careers. As a result of time spent with DO-IT, I have decided that in the future I would love to work with individuals with disabilities and promote disability advocacy and empowerment. Being a mentor in the DO-IT program made it clear that this type of interaction is important. I would love to do it on a larger scale.

Technology has played a major role in helping me reach a high level of independence, particularly when I purchased my first smart phone (iPhone). It was amazing to have so much information available to me at all times. It also became easy to call and text using a cell phone because of its touch screen. Because of my weak hand strength, it is hard to press down multiple times, so this was a great improvement. I almost never get lost anymore, and I can easily look up local bus information. I also use a laptop computer multiple times a day (a Dell and Macbook), for school, work, and entertainment. In terms of assistive technology, I use a smaller-sized mouse and speech recognition software. Technology improvements that would benefit me include more precise voice recognition software. What I have available to me is accurate some of the time, but not always. I also would suggest a better design for the devices, such as a non-slip surface that makes the phone easier to grasp and exterior buttons that aren't so difficult to push.

5. Outcomes research and reported benefits of computer and cell phone access for individuals with mobility impairments

Computer and telephone access hold promise for reducing the impact of limitations resulting from a mobility impairment, increasing participation in employment and, overall, enhancing quality of life. AT outcomes can be defined in terms of changes that result from the incorporation of AT in a person's life, including less dependence on other individuals to complete daily tasks [23]. However, researchers have reported high abandonment rates of AT by people with disabilities [52,54]. Many researchers and practitioners have supported the idea that outcomes of AT result from the interaction among characteristics of the device, its user, and the environment and some have proposed a framework for facilitating the development of device-specific causal models and measures [16,23]. Key issues addressed in current AT outcomes research are discussed in the paragraphs below.

5.1. Fatures of AT

Many articles in the literature describe and compare the features of specific AT. Some explore why individuals choose one device over another. For example, Bates and Istance [3] explored the preference of head-based pointing devices over eye-based pointing devices as a mouse alternate. The eye-gaze systems may initially perform poorly, be uncomfortable to the use, and require greater training and workload from the user in order to perform as well as the head mouse [41]. It should be recognized that the preferences regarding AT features are not always the same for all stakeholders. For example, caregivers highly value simplicity of set-up and programming, while users desire customization features [36,37]. It is also desirable that devices be durable.

5.2. Abandonment of AT

Studies have reported high rates of AT non-use and abandonment [70]. Galvin and Scherer [25] report AT abandonment rates between 8% and 75%, with an average of one third of all AT being abandoned by users. Several researchers have explored reasons for abandonment of AT generally, but few have specifically addressed abandonment of AT used for computer access [27]. Factors that result in non-use of AT include those related to personal issues, to the AT device, to the user's environment, and to the intervention. Strategies recommended to reduce non-use of AT have included those that relate to improving the communication skills of the practitioner, helping the individual adapt to changes that result from use of the AT, dealing with personal preferences and cognitive skill of the user; fitting of the AT into a person's daily routine and adapting the individual's social circle of support to incorporate the AT, and improving the products and services of device providers, and [70].

5.3. Overall factors influencing integration of AT

Researchers have undertaken studies to better understand factors that influence successful integration of AT [43]. Issues include ability of the AT to enhance functional abilities for the individual, ease of use, device transparency, cost, system constraints, meanings a person associates with the AT, the person's expectations regarding the AT, anticipated social costs of using the AT, and accepting and adapting to a disability as a significant, but not defining characteristic of themselves [35,40,57]. The Person-Environment-Occupation (PEO) model emphasizes that individual measures as well as the relationships between the person, the environment, and the occupation/activity should all be considered when evaluating AT [31]. The importance of personal and psychosocial factors in predicting AT use has been well documented in the literature. Scherer, Sax, Vanbiervliet, Cushman, and Scherer [58] validated an AT baseline and outcomes measure and quantified the measure's value in determining the best match of consumer and AT considering consumer ratings of their subjective quality of life, mood, support from others, motivation for AT use, program/therapist reliance, and self-determination/self-esteem.

5.4. *Psychological factors*

Quality of life has been described as "life satisfaction, subjective well-being and a positive general affect." In addition to these global constructs, it is associated with "satisfaction in specific areas of life such as work, social relationships, and being able to go where one wishes beyond the mere physical capability to do so" [56]. Although quality of life has been measured by subjective reports from individuals as well as objective indicators such as socioeconomic status and success in pursuing a career, it is a common view that the perspectives of the individuals with disabilities regarding their quality of life is more relevant than objective measures, since individuals respond quite differently to similar disabling conditions [22].

Whether AT will be successfully integrated into a person's daily life is related to his overall process of adapting to a disability plays a major role in determining [40], his subjective measure of quality of life, his outlook for future functioning, expectations of others, and financial and environmental support for the use of technology [57]. Progressive conditions present distinct challenges as functional abilities decrease as use of AT increases as a disease progresses. Personal meanings people attach to AT have been found to be both negative (e.g., a reminder of functions lost) and positive (a tool that enhances independence) [40]. Galvin and Sherer [25], through interviews with people with disabilities and therapists, found that people with congenital disabilities more often welcomed AT than those with acquired disabilities, perhaps because they more readily perceive the enhancement AT brings to their abilities. Coping strategies, problem solving skills, hope, and motivation promote disability acceptance whereas emotion-focused and cognitive disengagement associated with lack of acceptance of disability [40].

5.5. *Socio-cultural norms*

Socio-cultural norms influence AT selection and use [40]. Some non-use of AT can arise from the social stigma attached to the AT. When AT fits within the value system of the society and a specific family as well as within the expectations of a person's role within these units, it is more likely to be adopted and effectively used.

5.6. *AT support regarding selection and training*

Differences in decision making approaches of practitioners have been reported in the literature [37]. Kintsch and DePaula [37] propose a framework for facilitating the adoption of AT. It identifies participants in the adoption process to be users, caregivers, designers, and AT specialists and describes attributes to the process each should bring in order that appropriate AT be designed, selected, personalized, learned, and integrated. The framework identifies common features of abandoned technology and suggests how to avoid AT abandonment derived from a review of empirical studies and direct observations. The needs of the various stakeholders vary. The phases are development, selection process, learning, and integration. Consideration of all stakeholders is crucial. In one study, fourteen college students with disabilities were given AT training and identified factors that influenced them to adopt or reject AT for computer use recommended to them. Their reports support the need for training to improve adoption of computer access AT. Personal characteristics of the students, the presence or lack of environmental support were also identified as important factors.

6. Promising directions for future product development

As summarized by Vanderheiden, "designing a more accessible and usable world will require:

(1) Designing products so that they are directly usable by people with as wide a range of abilities as is commercially practical and
(2) Building in as much compatibility with assistive technologies as is commercially practical" (1998, p. 33).

Technological advances and future directions hold promise with respect to future products that will enhance the lives of individuals with neurological/mobility impairments. These include research and development related to interoperability between equipment, increased customization options, more network-based resources, enhancements to speech recognition technology to more accurately work for individuals with speech impairments, direct brain control, movement-smoothing strategies for those with tremors and/or spasticity, virtual reality applications, pluggable user interfaces, and wearable and clothing-based systems [28,61,66].

Continued development of third party Bluetooth products will improve options for people who have difficulty manipulating a mobile phone. For elderly users who have difficulty with overly complex features, hard to see controls and keys, and limited hearing, there are a few phones available to address their needs. Adaptive interfaces that learn from user's common needs may address the accessibility needs of some users [24]. As noted previously, Apple offers built-in features in their phones that provide text-to-speech capability that provides some accessibility for users with visual impairments. At least one developer (Code Factory, n.d.) offers commercial software that will work on Windows Mobile and Symbian devices to provide cell phone access to blind users.

7. Recommendations for rehabilitation professionals and other practitioners

The best choice for AT often requires customization for the individual. While it can be helpful to recognize the specific limitations of a person's disability, it is more important to focus on the tasks to be completed and how her abilities, perhaps assisted with technology, can be used to accomplish the tasks. The person with a mobility impairment should play a key role in determining her goals and in selecting AT. Once basic tools and strategies are initially selected, she can test drive, adapt, and refine. Promising practices to be considered in order to maximize the access to and benefits of computers and telephones for individuals with mobility impairments include those that follow [6].

7.1. Purchase

Administrators should establish policies and procedures at all academic, employment, and transition levels to ensure that accessibility is considered when IT is procured and that AT tailored to individual needs is purchased in a timely manner. Besides consideration of the overall costs, it is important to decide who (e.g., school, government agency, insurance, family, employer) should pay for computers, cell phones, and AT under specific circumstances and who owns the technology as a person transitions between various levels of education and employment. Funding issues related to technology upgrades and adjustments as functional abilities change should also be addressed. Agencies should collaborate on planning, funding, selecting, and supporting AT to ensure continuous technology access and support as individuals with disabilities transition through academic levels and to employment.

7.2. Selection

Decisions need to be made at all academic and career levels about who will be involved in the selection of appropriate technology and provide ongoing support for individuals with disabilities at various levels of education and employment. Specialized knowledge and skills regarding legislation, policies, and technology applications and products are required by those in decision-making and support positions, including special education teachers, occupational therapists, other service providers, individuals with disabilities, and families [4,46]. The importance of including consumers in all decision-making with respect to the selection and use of computer and telephone technology cannot be over-emphasized [10,65].

7.3. Training

Individuals with disabilities, parents, educators, librarians, computer support staff, and other stakeholders should have access to training regarding the availability and potential uses of computers, telephones, and AT [4, 46]. Stakeholders need to be more aware of the capabilities and needs of people with disabilities and use technology to help them fully participate in academic and employment offerings.

7.4. Use

Individuals with disabilities should be taught to use technology in ways that (1) maximize their independence, productivity, and participation in all academic and employment activities; (2) facilitate successful transitions between all academic and employment levels; and (3) lead to successful, self-determined adult lives. Technology should be used to support mentoring relationships. They should be encouraged to use technology to self-advocate, perform daily tasks independently, and move toward self-determined lives. Student transition plans should include self-advocacy objectives in the technology area so that students are able to articulate their technology needs to others (e.g., teachers, professors, employers) and access training and support throughout their lives [4].

7.5. Evaluation

Practitioners should use existing tools to select appropriate AT and measure the AT outcomes [12,14,58]. They can also provide input to researchers to further validate and improve these instruments.

7.6. Universal design

All stakeholders should promote the universal design of technology. Encouraging the use of technology standards established by government and other bodies can help society move closer to this goal [47,61]. A universal design approach can promote compatibility of equipment and software in education and workplace settings; reduce stigma, cultural, and attitudinal barriers for individuals with disabilities; and make it easier for practitioners to respond to the changing technology needs of individuals with disabilities. In addition, UD can solve situation-related access issues for individuals who do not have disabilities. For example, features that make technology accessible to individuals with neurological conditions that affect manual dexterity can benefit scientists in space suits and those people in bouncing vehicles [68]. A breakthrough of particular importance is the recent creation of international standards for pluggable user interfaces which, when applied, increases the ability of developers to design products that can be used by people with a broad range of characteristics and environmental constraints.

7.7. Policies

Policy makers and advocates should also explore ways to clarify existing legislation and use consistent terminology and standards. Differences that occur as students transition between academic levels and academic and career environments should be addressed. They should reduce inconsistencies and gaps in legislation and policies regarding the selection, funding, and support of AT [46].

8. Recommendations for researchers

How can we promote research that will improve our understanding of issues related to technology access for people with disabilities and its impact on academic, career, and independent living outcomes? Mainstream computer and telephone technology as well as assistive technology is in a constant state of rapid development. We cannot assume that what was impossible yesterday for people with disabilities is not possible today. The National Science Foundation, the Department of Defense, the U.S. Department of Education, and other national and private funding agencies should be encouraged to support basic research and promising practices that employ technology to improve the postsecondary education and career outcomes for individuals with disabilities. The current conditions, legal issues, potential applications, and challenges regarding the use of technology by individuals with disabilities discussed in this article thus far lead to the implications for practice listed in the next section.

AT outcomes research has the potential to improve delivery of AT practices, but this field of research is still evolving [21,33]. Gelderblom and de Witte [26] recommend that "(a) existing instruments must be further developed to improve quality and applicability, (b) instrument application must be standardized, and (c) international collaboration should be strengthened to improve both development and application of instruments" (p. 91).

A review conducted by Ivanoff et al. [31] revealed a need for more AT outcomes research, improved research methodologies, and conceptual and theoretical development with respect to this research area. Scherer et al. [58] summarized the evaluation of 82 AT outcome studies published between 1980 and 2001. They provide several suggestions to guide future development of AT outcome measures in the domains of usability, quality of life, and social role performance and provide seven recommendations to outcomes researchers, policy makers, journal editors, and reviewers in order to improve the reporting of AT outcomes research. Three yet unmet challenges in AT outcomes research were identified by Fuhrer as "(1) operationalizing a multiple-stakeholder approach to outcomes research; (2) formulating adequate treatment theories; and (3) creating shared databases" (2001, p. 528).

Besides taking immediate steps to ensure that technology is accessible and appropriately used by individuals with disabilities, there is a need for ongoing research to inform future practice. Recommendations for research areas to be addressed include those proposed by Vanderheiden and Zimmerman of the Trace Research and Development Center. They include:

- Better understanding of the factors for technology-adversity
- Strategies to help novices better understand the use of technology to improve the quality of their lives
- Adoption rate studies
- Natural language interface development
- Relative effectiveness of natural language vs. structured language vs. direct manipulation interfaces (2002, p. 26)

Further research is needed to identify best practices that ensure that all individuals with disabilities (a) have access to technology that promotes positive academic and career outcomes; (b) learn to use technology in ways that contribute to positive outcomes; and (c) experience a seamless transition of availability of technology as they move through educational and career environments [6]. It is recommended that future research:

- Study the extent to which the application of universal design principles to IT reduces the need to provide assistive technology to individuals with mobility impairments in academic and employment settings [67].
- Explore the relationship between degree of choice and effective use of technology for people with disabilities.
- Determine the long-range effectiveness of technology in helping students gain access to the general education curriculum [15,16].
- Explore how IT can best be integrated into instruction and transition planning for students with mobility impairments to achieve positive postsecondary school and employment outcomes.
- Study effective approaches for developing IT knowledge and self-advocacy skills on the part of individuals with mobility impairments.
- Produce baseline data on the present knowledge and skills of key stakeholders in order to effectively plan technology training for individuals with disabilities, parents, teachers, educational support staff, service providers, librarians, and employers.
- Evaluate and develop AT outcome measures [39].

9. Conclusion

The rapidly developing technology innovation in today's world will likely continue to impact the availability of computers and telephones and of assistive technologies for individuals with disabilities, including those with neurological impairments. IT is ubiquitous – in education, employment, community involvement, and personal services. Although access to computer technologies and mobile devices has the potential to promote positive postsecondary and career outcomes for individuals with neurological impairments, this potential will not be realized unless stakeholders secure funding; are knowledgeable about technology; and develop and apply policies, standards, and procedures that maximize the independence, participation, and productivity of people with disabilities throughout their lives. Ensuring that technology-based opportunities are accessible to everyone will contribute to the creation of a level playing field in education, employment, and daily living. The contribution of people with disabilities to the workplace and society enriches life for all.

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Resources

Useful information about products that can assist an individual with a mobility impairment can be found at the following websites.

AbleData
http://abledata.com/
Assistive Technology Industry Association (ATIA)
http://atia.org/
Closing the Gap
http://closingthegap.com/
CSUN Technology and Persons with Disabilities Conference
http://csun.edu/cod/conf/
DO-IT Technology and Universal Design
http://uw.edu/doit/Resources/technology.html
EmpTech
http://emptech.info/
RESNA
http://resna.org/
Trace Center
http://trace.wisc.edu/

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