Computer and World Wide Web Accessibility by Visually Disabled Patients: Problems and Solutions

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Abstract

Rapid advances in information technology have dramatically transformed the world during the past several decades. Access to computers and the World Wide Web is increasingly required for education and employment, as well as for many activities of daily living. While these changes have improved society in many respects, they present an obstacle for visually disabled patients who may have significant difficulty processing the visual cues presented by modern graphical user interfaces. This paper reviews the specific barriers to computer and Web access faced by visually disabled patients, describes clinical evaluation methods, summarizes traditional low vision methods as well as newer assistive computer technologies for universal accessibility, and discusses emerging technologies and future directions in this area.

Key words: vision disorders, visual acuity, blindness, low vision, medical informatics, biomedical technology, Internet, access to information, user-computer interface.

I. Introduction

Rapid innovations in computer and communication technology have dramatically transformed the industrialized world during the past several decades. A 2002 Harris Poll estimated that 66% of adult Americans regularly use the Internet, an increase of nearly 700% since 1995. This is significantly higher than the rate of growth of the telephone, automobile, radio, or television [Taylor H, Harris Poll #18, http://www.harrisinteractive.com/harris_poll/index.asp?PID=295, accessed 5/10/03]. The ongoing expansion of technology is providing unprecedented opportunities for people to communicate and exchange information with others around the world. But at the same time, those without the skills or resources to access information tools such as the World Wide Web will be at a severe disadvantage in educational and employment situations [Gunderson J, World Wide Web accessibility to people with disabilities: a usability perspective, http://www.staff.uiuc.edu/~jongund/access-overview.html, accessed 3/5/03]. This division has the potential to enlarge the existing economic and cultural gaps between the "haves" and "have-nots" in our society, and threatens to create major difficulties for visually disabled patients. An important challenge will be to ensure that visually disabled patients have mechanisms for universal access to these emerging technologies[1].

From another perspective, the problem of computer and Web accessibility is becoming increasingly significant because the prevalence of visual loss is rising. Patients 65 years of age and older have a greater prevalence of low vision than any other age group[38], and it is estimated that the number of Americans over the age of 65 will double between 2000 and 2040[20,32]. In 1997, the United States Census Bureau found that there were 7.7 million adults with "non-severe visual limitation," which was defined as a self-reported or proxy-reported "difficulty with seeing words and letters, even with eyeglasses." The Census Bureau similarly determined that there were 1.8 million American adults with "severe visual limitation," defined as the "inability to see words and letters, even with eyeglasses" [Bureau of the Census, Survey of income and program participation, http://www.census.gov/hhes/www/disable/dissipp.html, accessed 3/5/03]. In general, patients with even minimal visual impairment are likely to encounter problems in everyday life. For example, people with visual acuity worse than 20/40 cannot obtain an unrestricted driver's license in most states, and may require assistive devices such as magnifiers for reading[35]. In this paper, we will use the term "mild visual disability" to refer to patients who have decreased best-corrected visual acuity that causes difficulty with reading, and the term "severe visual disability" to refer to those with no useful reading vision to support computer use.

Well-known low vision aids such as hand magnifiers, stand magnifiers, loupes, closed circuit television systems, and optical character recognition systems are suitable for reading printed text[13,25]. However, these traditional devices are often less effective at helping visually disabled users adapt to the unique data input and data display requirements of modern computer user interfaces. In recent years, a number of new "assistive technologies" have emerged to facilitate computer and Web accessibility by visually impaired or blind patients. Given the increasing prevalence of visual disability, as well as the growing impact of information technology in contemporary society, eye care providers will need to become familiar with the characteristics and applications of these assistive computer technologies.

The objectives of this paper are to review the existing literature about specific difficulties faced by visually disabled patients while using computers, to summarize international commitments toward universal computer and Web accessibility, to describe clinical evaluation methods, to survey traditional low vision methods as well as newer assistive technologies for accessibility, and to discuss future directions in this area. Many assistive technologies are available, and this paper will focus on those that are most useful for modern computing applications such as graphical user interface (GUI) manipulation and World Wide Web browsing. Some of these assistive technologies are suitable for users with severe as well as mild visual disabilities, but the differing requirements of these two groups will be highlighted where appropriate.

II. Problems with computer and World Wide Web use by visually disabled patients

A. Fundamentals of the World Wide Web

In the 1960s, the Internet began as the ARPANET, a networking project started by the United States Department of Defense to allow researchers at institutions across the country to communicate with each other[30]. In addition to information sharing, a major goal of the Internet founders was network support for distributed social interactions[28]. Since that time, the Internet has evolved into a complex information network often considered synonymous with the World Wide Web. Web documents are identified by a unique Uniform Resource Locator (URL) address, and are based on the notion of "hypertext," in which certain words and phrases are annotated by "links" that connect to another location in the same or a different document. Web pages are hosted on computers known as "servers," and are accessed by users from other computers through programs known as "browsers." The Web became accessible to the general public following the 1993 release of the user-friendly graphical Mosaic browser, which led to the development of commercial applications and a user base of several million people by the next year [National Center for Supercomputer Applications, NSF initiative leads to NCSA Mosaic and e-commerce, http://www.ncsa.uiuc.edu/Divisions/PublicAffairs/MosaicHistory/impact.html, accessed 10/20/03]. In 1994, the international World Wide Web Consortium (W3C) was founded to organize and establish standards for the Web. These W3C standards allow arbitrary individuals and organizations to develop their own servers, browsers, and hypertext content independently, which will work together and be universally available. One such standard is Hypertext Markup Language (HTML), the notation which Web pages are traditionally written in, allowing programmers to specify the look and feel of a document [World Wide Web Consortium, Hypertext Markup Language homepage, http://www.w3c.org/MarkUp, accessed 10/20/03]. Overall, the Web has evolved rapidly in recent years, providing the public with access to vast stores of information. This creates two potential difficulties for visually impaired patients: (1) Hypertext Web documents are nonlinear, allowing users to link quickly to other pages that may have a completely different design and layout. This may cause confusion for those who cannot easily follow visual cues. (2) The Web now revolves around video, multimedia, real-time collaboration, and interactive documents, all of which are heavily visually-based.

B. Text-based and graphical user interfaces

The vast majority of early computer systems contained pure text-based user interfaces, because limitations in computing speed made complex graphical interfaces impractical. Patients with mild visual disabilities were often able to access these early systems using traditional low vision mechanisms such as magnifying spectacles or large-screen monitors[5]. In addition, it was relatively straightforward for users with severe visual disabilities to interact with these early machines, using keyboard input and voice output of screen contents, because the information was completely text-based and therefore easy to access in teletype mode[4]. However, because of increased computer processing power since that time, graphical user interfaces (GUIs) with "point-and-click" interactions have largely replaced the old-fashioned text interfaces. Modern Web navigation using browsers such as Internet Explorer and Netscape Navigator is heavily based on these graphical interfaces, which are intended to be intuitive, easy to remember, and relatively error-free. Basic graphical "widgets" such as icons, pushbuttons, pull-down menus, and checkboxes are recognizable even by casual computer users as convenient mechanisms for data input and output (Figure 1). This is because information is conveyed by reading textual labels, as well as by visualizing their relationship with adjacent graphical features. Although GUIs are widely regarded as a major advance in human-computer interaction, their heavy dependence on visual cues for input and output presents a significant problem for visually disabled patients[24,34]. In this respect, growth of the Internet largely occurred without consideration for the special needs of disabled users[27].

C. Previous studies involving computer use by visually disabled patients

Although a large body of ophthalmic literature has examined the overall impact of visual disability on functional status and quality of life[7,25,31], few published studies have explicitly investigated the ability of visually disabled patients to perform computer and Web-based tasks[23,32,33]. Uncorrectable visual loss may of course be manifested in several different ways, depending on the underlying etiology. Deficits in visual function parameters such as visual acuity, central visual field, peripheral visual field, contrast sensitivity, and color vision are likely to have differing effects on the ability of patients to use graphical interfaces for computer input and output. However, very little research has attempted to link the specific profile of visual impairment with computer task performance[21,22,32].

The most comprehensive and systematic evaluations to date were performed by Scott et al., who examined the ability of 18 visually disabled patients with age-related macular degeneration (AMD) to manipulate and interact with computer graphical user interface features. The findings from those studies were analyzed in two ways: (1) In terms of graphical interface features: Smaller icon size and larger icon set size were significantly associated with lower computer task accuracy, whereas smaller icon size was significantly associated with slower task completion speed[33]. (2) In terms of visual function parameters: Decreased visual acuity, decreased contrast sensitivity, and decreased color vision were significantly associated with lower computer task accuracy, whereas decreased visual acuity and decreased color vision were significantly associated with lower task completion speed[32].

D. Statistics

The American Foundation for the Blind, in collaboration with the United States Bureau of the Census, has collected extensive statistics regarding Internet access and regular computer use by visually disabled patients[2]. Based on these data, there are four notable trends[16]. First, people with visual limitations are much less likely to use a computer regularly, or to have regular access to the Internet, compared to people those without visual disabilities (Table 1). Second, individuals with severe visual disability have lower rates of Internet access than those with mild visual disability (13% compared to 23%). Similarly, individuals with severe visual disability have lower rates of regular computer use than those with mild disability (7% compared to 15%). Third, many patients with visual disabilities are elderly people who suffer from additional impairments such as hearing loss or physical limitations. As shown in Table 2, adults whose only disability is visual loss have higher rates of Internet access than those with visual disability accompanied by one or more other impairments (53% compared to 28%). Fourth, the rates of Internet access and regular computer use may be affected not only by visual disability, but also by the factor of employment. Among employed people aged 25-49, 64% of those with no disabilities had Internet access, compared to a similar number (54%) of those with visual disabilities.

Taken together, these statistics certainly suggest the existence of significant disparities in computer and Internet access among patients with visual disability. At the same time, the statistics about computer use by those with isolated visual disability, and by those who are employed, suggest that computer accessibility is feasible by patients with visual impairments. However, it is difficult to draw definitive conclusions because the above associations are not normalized for variables such as education and income status[16].

E. Accessibility legislation in the United States

The Americans with Disabilities Act (ADA) of 1990 includes several provisions that required employers to provide "reasonable accommodation" and mechanisms for "effective communication" to workers with disabilities [United States Department of Justice, Americans with Disabilities Act home page, http://www.usdoj.gov/crt/ada/adahom1.htm, accessed 3/5/03]. This law is applicable to the entire nation, not only to entities that receive federal funds, and was originally focused on areas such as employment, public accommodations, and telecommunication services. However, the subsequent growth of the Internet for communication in educational and work settings has now broadened the ADA's scope to require "electronic curb cuts and ramps" that allow disabled users to access computers and the World Wide Web[3,17,29].

Two other significant pieces of legislation pertaining to the accessibility of electronic and information technology are Sections 508 and 504 of the Federal Rehabilitation Act of 1973. Section 508 requires that all electronic and information technology that is developed, procured, or used by federal agencies must be accessible to people with disabilities [United States General Services Administration, Section 508, http://www.section508.gov, accessed 2/27/03]. Because this law is based on the U.S. Access Board's Electronic and Information Technology Accessibility Standards, which are in turn based on the World Wide Web Consortium's Web Content Accessibility Guidelines (see Section VI), it has become an important legal reference for Web accessibility[36]. Although Section 508 applies only to direct purchases by the federal government and not to purchases made by entities receiving federal funding, it may have an important impact on the design of computer systems for universal accessibility because of the buying power of the United States government[26]. In contrast, Section 504 has a more general scope, requiring that all educational programs receiving federal funds must be accessible to all students with disabilities [United States Department of Labor, Section 504, http://www.dol.gov/oasam/regs/statutes/sec504.htm, accessed 3/7/03]. Together, these laws represent a large-scale, national commitment to include people with sensory, physical, or cognitive disabilities in all facets of life[17,39].

III. Traditional low vision solutions

A. General factors regarding accessibility

The goal of most traditional low vision approaches toward computer accessibility is to provide *sight-enhancement rehabilitation mechanisms* that maximize the useful remaining vision.

This includes three main components: standard refractive care, specialized care for patients with reduced vision, and specific advice on the use of computers.

Standard refractive care places the best-focused image on the retina. Specialized care for patients with reduced vision includes the determination and compensation for magnification and lighting needs. Traditional hand-held magnifying devices are generally not optimal for computer use because of the unique data display and entry requirements of graphical user interfaces. However, many visually disabled patients will require magnification, which may be provided by high reading adds with concomitant closer working distance, as discussed below ("Low vision approaches based on characteristics of visual loss"). Lens design is an important factor, with either full-field computer lenses or bifocal segments large enough to see most of the screen. Increased convergence demands caused by reduced working distance may require base-in prism to preserve binocular vision. Font enlargement and screen magnification software programs are often very useful, as discussed below (Section IV). Lighting should be sufficient; at the same time, lights that cause glare reflecting from the computer screen should be moved.

Specific advice on the use of computers involves ergonomic factors and screen enhancement capabilities that the patient already has access to. Several recommendations may be given to visually disabled patients: (1) Computer monitors should be positioned directly in front, and slightly lower than, eye level. (2) If typing from a page, a stand should be used to support the page to one side of the monitor, at the same distance as the monitor. (3) If a bifocal segment is used, it should be positioned so that unusual head position or neck flexion is not required. (4) Text font size may be increased in software applications for easier readability. Similarly, reduction of screen resolution will increase the size of material on the computer screen, although this may require additional scrolling to see the entire page.

B. Low vision approaches based on characteristics of visual loss

Clinical evaluation of visual function parameters will guide the decision as to the most appropriate mechanisms for supporting computer accessibility. Best-corrected visual acuity is used to predict the magnification required for reading. This will determine the required reading add, or the appropriate combination of screen magnification and higher add. As a general rule, visual acuity of approximately 20/50 will allow patients to read a standard computer screen, although this can vary depending on the screen size and resolution setting. Based on that rule, a patient with 20/200 visual acuity would need a magnification of 4x (200/50). This magnification may be provided by moving the monitor to a distance 4x closer, and then by prescribing an appropriate reading add for that distance. The reading add may quickly be determined by taking the product of the required magnification and the standard add of +2.50 D (e.g. (4X)(+2.50 D) = +10.00 D). Alternatively, this may be accomplished by combining screen magnification with a reading add. For example, enlarging the letters 2x and using a 2x magnification add (i.e. +5.00 D) will give the same results as using a +10.00 D add alone. Increased convergence demands caused by shortened working distance may require base-in prism in lenses to preserve binocular vision.

Visual fields may be plotted with perimetry or Amsler Grid. This will provide guidance to patients regarding compensatory approaches. For example, patients with left homonymous hemianopia should be instructed how to return back to the beginning of each line of text, whereas those with right homonymous hemianopia must be instructed to go to the end of each line. Interestingly, patients with decreased peripheral visual field may benefit from reduction in screen size, rather than magnification, assuming that their visual acuity is adequate. With reduced contrast sensitivity, magnification alone may not be sufficient to support accessibility. In that situation, procedures to enhance screen contrast may be beneficial. Many computer operating systems have built-in screen enhancement capabilities that may be used to enlarge the screen, and to enhance the contrast of the material being viewed (Figure 2).

Overall, the optimal low vision strategy will depend on the type and severity of visual disability. A classification system based on the type of visual field loss has been developed by Faye to categorize sight-impaired patients[13]. Although all patients should fit into one or more of these categories, management decisions can of course be made only after assessment and evaluation of an individual's specific needs and capacities. These general guidelines regarding visual performance are[13]: (1) Patients with overall blur, glare, or loss of contrast, but without central scotoma, should initially try magnification, appropriate lighting, and contrast enhancement. (2) Patients with central scotoma should try magnification, as well as contrast enhancement. (3) Patients with constricted peripheral visual field, but with relatively preserved visual acuity, may try reducing computer screen size. Alternatively, they may need to become good at scanning the computer screen.

IV. Assistive technology solutions

A. Goals and challenges for assistive technology

The overall goal of visual assistive technology is to provide equivalent, *sight-enhancement or sight-substitution rehabilitation mechanisms* for computer and Web access that are appropriate for the level of disability. For patients with severe visual disability, this requires non-visual alternatives for traditionally visual tasks such as reading text, selecting from menus, responding to system prompts, analyzing tables, and navigating between different parts of Web sites. In general, this is accomplished by translating the visual screen display into auditory output (e.g. screen reading software with speech synthesizers), tactile output (e.g. Braille display that echoes the screen display), or a combination of the two modalities[6]. For users with mild visual disability, more conservative adaptations such as screen magnification may also be appropriate.

As discussed above, the problem of Web access for visually disabled patients is particularly difficult because the Web navigation paradigm is dependent on graphical interfaces with visual cues. Special challenges for assistive technology devices include translation of complex mathematical and scientific notation into computer-readable formats; interpretation and display of images and digital videos; efficient navigation and interpretation of Web-based tables; and entry of data using Web-based text boxes and forms[29]. Successful solutions to these problems will require not only that assistive technologies are well-designed, but also that website content and layout are organized to promote accessibility (see Section VI).

B. Screen magnifiers

A straightforward adaptive strategy for many partially sighted patients is simply to enlarge the computer screen. In the past, this was often done using large-screen monitors. Recently, "screen magnifier" software applications have become more popular. Screen magnifiers run as background tasks, and are ideally compatible with all other commercial software products such as word processors, spreadsheets, and Web browsers. Typical screen magnifiers provide the capability of enlarging both text and graphics over a wide range of levels. The user generally determines whether the full screen is magnified, or whether only the portion of the screen that tracks the cursor or menu bar activity is magnified (Figure 3). Most of these products use image-smoothing algorithms to produce clear graphics and text even at large magnifications, and some products include special functionalities such as the ability to automatically scan and review an entire screen. Popular commercial screen magnifiers are currently manufactured by Ai Squared (ZoomText®; Manchester, Vermont) and Tieman UK (Lunar®; Nottingham, UK). While screen magnifiers are popular among users with mild visual disability, they provide little benefit for those with severe visual disability.

C. Braille displays

Electronic Braille displays are typically connected to a keyboard and produce refreshable, line-by-line displays of text output (Figure 4). These devices consist of numerous arrays of movable pins that are connected to solenoids or piezoelectric outputs. Depending on the specific electrical signal received from the source computer system, the pins are raised or lowered to generate Braille characters. Computer data input may be performed using standard keyboards, although special Braille keyboards are also available to complement Braille displays. In general, Braille output displays have been useful for allowing patients with severe visual disability to perform accurate proofreading and review of computer screen layouts[41]. Of course, these are purely text-based and therefore less helpful when used alone for Web-based and other graphical interfaces. Their widespread application has been further limited because of the relatively small number of completely blind patients who regularly use Braille. According to recent statistics from the American Foundation for the Blind, there were 55,200 legally blind children in the United States in 1998-1999, of whom only 5,500 used Braille as their primary reading medium[2].

D. Screen readers

The purpose of screen reading programs is to translate text and graphical displays into auditory output. This is performed using software synthesizer programs to drive sound cards that are built-in to most computer systems, or using external hardware speech synthesizers. As in the case of screen magnifiers, screen readers are background software applications that operate transparently to word processors, spreadsheets, Web browsers, and other commercial software packages.

Screen readers have become a popular technology among patients with severe or complete visual loss, who may navigate the screen using keystrokes while the assistive software announces the word or line at the cursor location[41]. Most commercially-available screen readers will automatically announce menu bars and pop-up windows, and will use standard protocols and voices to identify icons, radio buttons, text boxes, and other common graphical user interface widgets. When used with Web browsers, screen readers will generally announce text and graphic content, and will note the presence of hyperlinks. In addition, they include specific features to orient Web users by reading information about navigation bar contents, table column and row headings, and other page layout and navigation details.

Popular screen reading programs are published by Freedom Scientific (JAWS®; St. Petersburg, Florida), ALVA Access Group (outSPOKEN®; Oakland, California), and Dolphin Computer Access (Hal®; San Mateo, California). Although most screen readers work well with Web browsers, several software packages that have been exclusively designed to provide speech access for Web navigation and electronic mail purposes (e.g. IBM Home Page Reader®; White Plains, New York) are also available. A simple screen reading program, known as Narrator®, is available with the Microsoft XP operating system (Microsoft Corporation; Redmond, Washington). While screen readers may be effective as an isolated technology to support data display and entry, they are frequently used in combination with other devices such as Braille displays or screen magnifiers[6,41].

V. Emerging technologies and future directions

A. Motivation

Because computer-based technologies are evolving rapidly, assistive technologies and other tools to improve computer and Web accessibility are also advancing quickly to keep pace[6,29,36]. For those reasons, physicians and others who care for visually impaired patients should become aware of these new tools as they emerge.

B. Design guidelines for universal Web accessibility

Legislative requirements, low vision solutions, and assistive technologies are not sufficient to allow World Wide Web accessibility by visually disabled patients. Ultimately, these adaptations are only useful for reading Web content to the extent that websites are developed with the special requirements and needs of disabled users in mind. For this reason, the World Wide Web Consortium (W3C) has undertaken a broad initiative to ensure that Web programs are written to be maximally accessible by disabled patients. The W3C publishes a series of Web Content Accessibility Guidelines, which have become an international standard for creating universally accessible Web-based products[10]. For example, one design guideline states that "alternative text equivalents" must be available for all non-text elements such as images or video animations (Figure 5). These text equivalents should describe the content that the image was intended to convey, so that screen readers may output the auditory information. However, text equivalents are often omitted by Web authors, making information inaccessible to visually disabled users[9,37].

Similarly, W3C has begun to create standardized guidelines for the speech rendering of Web documents [World Wide Web Consortium, CSS3 Speech Module, http://www.w3.org/TR/2003/WD-css3-speech-20030514/, accessed May 30, 2003]. This will allow Web designers to specify parameters such as the volume, inflection, and rate of speech, such that auditory information may be conveyed optimally to visually disabled patients using screen readers.

Although these design guidelines were originally directed toward disabled users, they are likely to benefit a much larger population of users, such as those with slower Internet connection speeds or non-traditional Web browsers (e.g. mobile computing devices)[36,40].

C. Improved computer interaction devices for accessibility

A hallmark of the graphical user interfaces (GUIs) used by most modern operating systems, software packages, and Web-based applications is that they rely on a mouse or a similar pointing device. Although patients with mild visual disability may still find that using a pointing device is more efficient than attempting to navigate graphical interfaces using keystrokes with a screen reader, problems such as decreased visual acuity and restricted visual field present major challenges for pointing devices[15]. Examples of these experimental devices include a "target mouse" that provides auditory assistive feedback when the pointer enters or exits a target region, high-contrast "roll-over" buttons that make the target entrance more obvious by using redundant visual cues, and color adjustments to improve the visibility of the pointer[15,24].

D. Content extraction from Web pages

Web documents are often cluttered with features such as pop-up advertisements, banners, and superfluous links that may distract users from the actual content of the page. These cluttering features may be particularly disorienting for low vision patients, particularly because assistive technologies such as screen readers are generally unable to automatically remove these extraneous materials and are therefore forced to simply read them out. Gupta et al. have developed a software tool for "content extraction" from Web pages[18]. Documents that have been filtered by this tool may be input to screen readers or other assistive technologies, potentially allowing visually disabled users to understand the essential content of Web pages more efficiently[18]. Although methodologies for effective content extraction are still developing, this concept may play an important role for supporting accessibility in the future[8,14].

E. Voice recognition

Automated voice recognition technology continues to improve, and is being used in diverse applications such as automated dictation, telephone systems, voice email, and mobile computing devices. Emerging voice-based Web browsing systems offer the potential for voice-driven navigation and telephone-based Web access, and provide opportunities for improved data *input* by visually disabled patients[11] [World Wide Web Consortium, W3C home page, http://www.w3c.org, accessed 2/15/03]. Well-known existing products are manufactured by Speech Technology (Dragon NaturallySpeaking®; Wellington, Florida) and IBM (ViaVoice®; White Plains, New York). When used for medical applications, commercially-available voice recognition programs have been found to have transcription error rates between 7% and 15%[12].

These programs have been shown to be cost-effective in limited medical transcription studies by pathologists and emergency room physicians[19,42].

VI. Summary

The recent information technology revolution has produced rapid social changes. Access to computers and the Internet is increasingly required for education and employment, as well as for many activities of daily living, and these factors are threatening to widen the existing "digital divide" in our society. In many ways, the rapid growth of the Internet did not account for the specific needs of low vision patients. Fortunately, legislative requirements and assistive technologies have recently emerged in support of accessibility. Physicians will need to understand the etiologies of these existing barriers to computer and Web access by their patients, the significance of this problem, the potential solutions offered by a new family of assistive technologies, and the limitations of these technologies.

Existing assistive devices are being used successfully by some visually disabled patients, and are continuing to improve[5,6]. However, important gaps in knowledge remain. The unique assistive needs of patients with differing patterns of visual loss are not known[21,22]. Systematic usability evaluations of existing assistive technologies in visually disabled patients have not been performed. Furthermore, the cognitive strategies used by blind and partially sighted patients to organize and process information during computer and Web navigation are not well-understood. The successful planning and execution of this research will require collaboration among physicians, computer scientists, medical informaticians, cognitive scientists, and policy makers.

VII. Method of literature search

The Medline database and the Association for Computing Machinery (ACM) digital library were queried, without any date limitations. The following search terms were used: *vision disorders, blindness, low vision, visual impairment, visual disability, medical informatics, Internet, World Wide Web, access to information, accessibility, assistive technology, user interface, and voice recognition*. Criteria for inclusion were the relevance, clinical importance, and scientific importance of articles to the subject of this paper. Articles cited in the reference lists of other articles were reviewed and included when considered appropriate. All articles with English abstracts were reviewed, but only English-language articles were used for this paper. Additional sources included relevant websites, as well as reference materials provided by The Jewish Guild for the Blind, Lighthouse International, and the American Foundation for the Blind.

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Outline

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Figure 1. Common computer interface "widgets" contain graphical cues that are easily recognizable by sighted users, but which may cause significant accessibility problems for sight-impaired patients. This is because information is conveyed not only by reading textual labels, but also by visualizing their relationship with adjacent graphical features. Tabbed folders (1) are used to graphically organize and display information output. Checkboxes (2), slider bars (3), and buttons (4) are used for data entry. Menu bars (5) are used for data organization, input, and output. Icons (6) are a symbolic representation of information for data input and output, and rely on users' ability to identify images. Navigation bars (7) and hypertext (8) are used to organize data display on Web pages. In each case, users must be able to recognize text and images, interpret proper mechanism for human-computer interaction, and use data input tool such as mouse or keyboard.

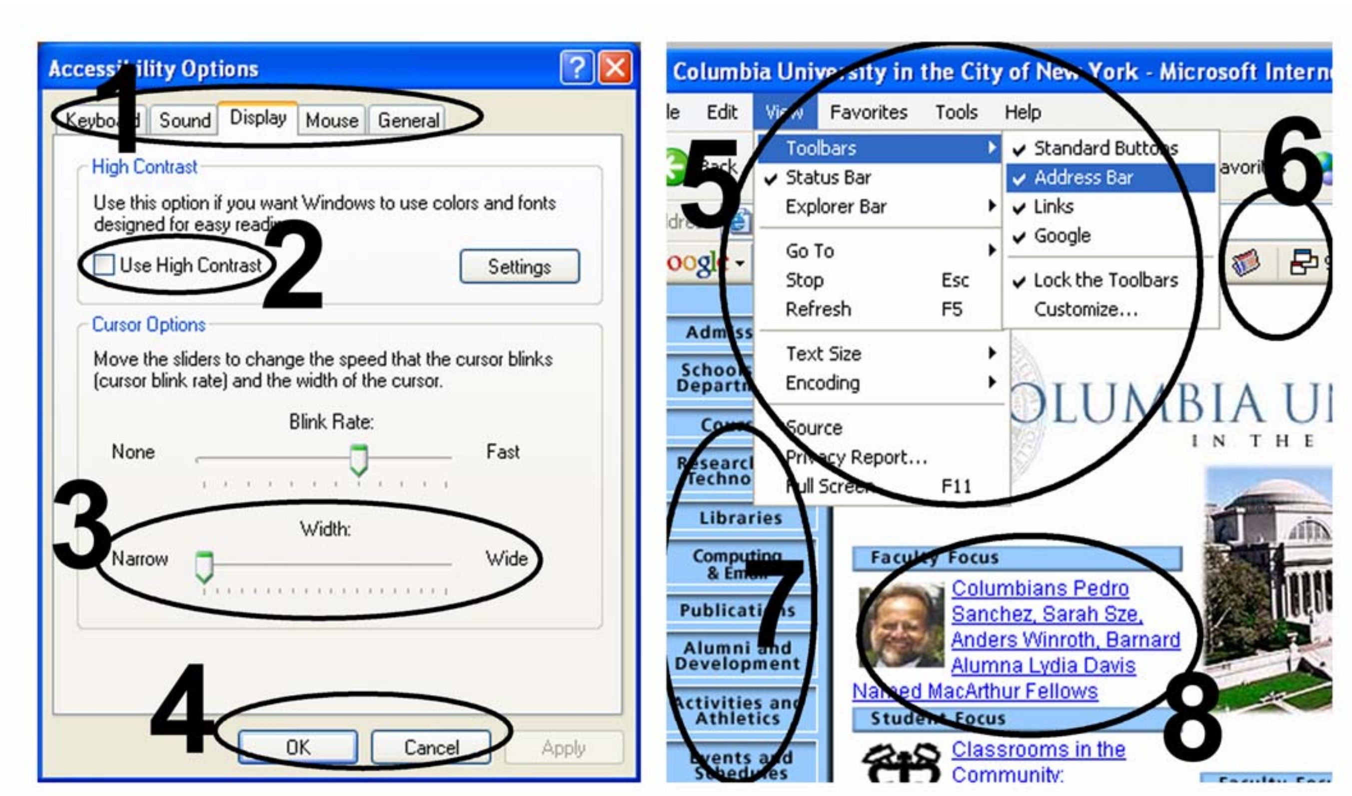

Table 1. Rates of Internet access and regular computer use among visually impaired and non-visually impaired users, aged 15 and older*.

Visual impairment**		No visual impairment	
Internet access	Regular computer use	Internet access	Regular computer use
21%	13%	57%	51%
Total number: 7,326,000		Total number: 166,108,000	

*American Foundation for the Blind. Statistics and sources for professionals. New York: American Foundation for the Blind, 2000.

**Visual impairment defined as "difficulty with seeing words and letters, even with eyeglasses."

Table 2. Rates of Internet access and regular computer use among patients with isolated visual impairment and multiple physical impairments, aged 15-64. Note that total number of patients is different from Table 1 because of different age range[*].

Only visual impairment[**]		**Multiple impairments**	
Internet access	Regular computer use	Internet access	Regular computer use
53%	42%	28%	18%
Total number: 919,000		Total number: 2,680,000	

[*]American Foundation for the Blind. Statistics and sources for professionals. New York: American Foundation for the Blind, 2000.

[**]Visual impairment defined as "difficulty with seeing words and letters, even with eyeglasses."

Figure 2. Screen views to demonstrate output produced by built-in "accessibility options," which are available with many modern computer operating systems such as Microsoft Windows®. Image (A) is normal screen view. Image (B) is the same screen viewed with "high contrast" and "enlarged text" options, to facilitate accessibility by some visually disabled patients.

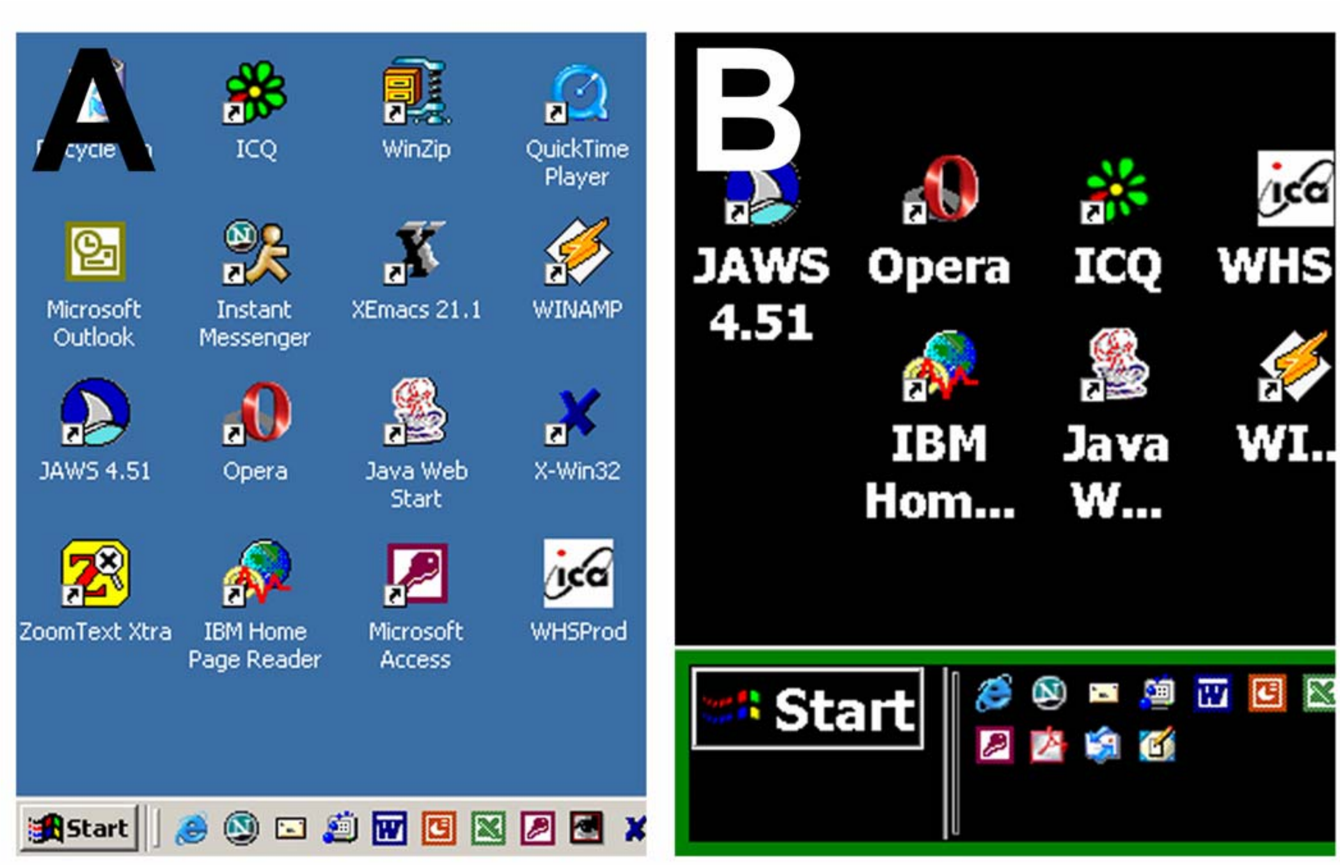

Figure 3. Simulated screen view produced by screen magnifier used in "vertical split mode." Left side of computer screen is normal size, and orients visually disabled patient to overall screen layout and organization. Right side of screen is enlarged, in the area where patient is working (note position of cursor). Amount of magnification may be variably adjusted, allowing some visually disabled patients to read details on screen.

Figure 4. Electronic Braille display for reading text output. Movable pins are raised or lowered based on electrical signals to generate characters on Braille display. Data input may be performed using standard keyboard or special Braille keyboard.

Figure 5. Equivalent alternatives to visual content on Web pages. (A) and (B) show the same Web document with embedded text equivalents to describe image contents, making it accessible to visually disabled users through auditory screen reading software. (C) shows a simulated view of the same Web image without text equivalents, making it completely inaccessible to visually disabled users. Image courtesy of National Eye Institute, National Institutes of Health.