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RESEARCH IN COMPUTER ACCESS ASSESSMENT AND INTERVENTION

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1 Importance of Computer Access Technology

Computer Access Technology (CAT) allows people who have trouble using a standard computer keyboard, mouse or monitor to access the computer. CAT includes relatively inexpensive devices like trackballs and small-footprint keyboards as well as sophisticated technologies like automatic speech recognition, eyegaze tracking, and brain-computer interfaces. CAT services are provided by a range of rehabilitation professionals, including rehabilitation engineers, occupational therapists, speech-language pathologists, special educators and vocational rehabilitation counselors.

CAT is critical for enhancing the educational and vocational opportunities of people with disabilities [1, 2]. In addition, CAT has been shown to contribute to improved health status by providing access to health information and interaction with clinicians and peers [3]. CAT can reduce social isolation by eliminating physical barriers, facilitating communication, and providing a forum for the exchange of information [4]. Individuals with disabilities often appreciate the anonymity of the Internet, where they can be evaluated for the strength of their contributions rather than their physical appearance or disability [5, 6]. The Internet also provides protection against self-consciousness and social anxiety, and active participation can lead to greater levels of self-acceptance and decreased feelings of isolation [7, 8].

57% (74.2 million) of working-age (between 18 and 64 years of age) computer users are likely or very likely to benefit from the use of CAT [9]:

- 17% (21.9 million) of working-age computer users have a mild visual difficulty or impairment, and 9% (11.1 million) have a severe visual difficulty or impairment [9].
- 19% (24.4 million) of working-age computer users have a mild dexterity difficulty or impairment, and 5% (6.8 million) have a severe dexterity difficulty or impairment [9].
- 18% (24.0 million) of working-age computer users have a mild hearing difficulty or impairment, and 2% (2.5 million) have a severe hearing difficulty or impairment [9].

Choosing the most appropriate CAT is a collaborative decision-making process involving the consumer, clinician(s), and third-party payers. The challenges involved in a successful computer access intervention include:

1. Evaluating and documenting client abilities and specific difficulties with the standard computer interface [10];
2. Choosing the most appropriate assistive technology to address these difficulties;
3. Configuring the technology to the user’s needs;
4. Training the user in appropriate use of their system [11-13]; and
5. Providing continuous follow-up to ensure that the interface remains well-suited to the user [14, 15, 13, 16, 17].

The consequences of failing to successfully meet any one of these challenges include wasted human and material resources spent in the intervention process, unnecessary obstacles placed in the individual’s path toward their goals, technology abandonment [18, 19] and a lack of computer use amongst individuals with disabilities [3, 20]. By all reported measures, we are largely failing to meet these challenges.

People with disabilities do not use computers at the same rate as people without disabilities. While 85% of working-age adults without disabilities use computers, computer usage is 80% among those who have mild impairments and is 63% among individuals who have severe disabilities and are very likely to benefit from the use of CAT [9].

Many people with disabilities who do own computers do not take advantage of CAT. One study found that only 24% of working-age computer users with severe disabilities use CAT [21]. A significant barrier to obtaining CAT is cost. 28% of working-age computer users with mild difficulties/impairments and 32% with severe disabilities report there is a CAT that they do not own but would purchase if it became more affordable [21].

A second obstacle is awareness. Of computer users with mild or severe disabilities, 20% were not aware that CAT existed which was appropriate for them [21]. Awareness of the free, built-in accessibility settings offered by the Windows and Mac operating systems is even lower. Of computer users with mild or severe disabilities, 36% were unaware of the available adjustments for the mouse and 35% were unaware of the available keyboard adjustment options [21].

Amongst computer users who do own and use CAT, there is ample evidence that it is not configured correctly. For example, Trewin and Pain reported target acquisition error rates of greater than 10% for 14 of 20 users with physical disabilities, and observed that 55% of the dragging tasks made by these users were unsuccessful [22]. An average of 28% of clicks in this study included a mouse movement, which is a potential source of error, and 40% of multiple click attempts were unsuccessful [22].

Worst of all, approximately a third of computer users who do receive CAT wind up abandoning it. A study of 115 individuals with disabilities who received 136 assistive technology devices over five years, including computers, communication devices and adapted software, reported a total abandonment rate of 32.4%. The abandonment rate within the study for computer access and communication devices was 30.8% [23].

2 Challenges to Computer Access Service Delivery

2.1 The Cost of CAT and Clinical Services

A significant obstacle to obtaining the most appropriate CAT is cost. CAT (for working-age adults) is often funded through vocational rehabilitation agencies which have small budgets relative to the demand for their services. Funds spent on clinician time and CAT for one client are unavailable to other clients, so maximizing each dollar spent is critical. Consumers who are retired, or not seeking employment, are equally cost sensitive as they may have to purchase their own equipment. As the population ages, an increasing number of older computer users will potentially benefit from CAT [21] but are unlikely to be candidates for vocational rehabilitation and are thus likely to be using their own funds.

2.2 The Variety Of Devices Available

Another challenge for computer access is the simple fact that there are too many options for any consumer to reasonably compare. There is a nearly limitless variety of alternatives to the traditional computer keyboard and mouse. Within each of these categories of devices there are multiple products, and each product has its own unique set of configuration options.

Given this variety of options, a consumer could spend weeks or months comparing devices, but a decision is often needed after one or two clinical sessions. In particular, consumers who need to obtain computer access technology in order to return to work or school often need to make decisions quickly to meet other deadlines. Beyond that, most consumers lack the patience or funding for multiple clinical visits. It is therefore critical to make optimal use of the time that client and clinician spend together in the clinic.

2.3 Consumer Needs Change Over Time

Even if a consumer who needs CAT receives a successful technology intervention, it is unlikely that the solution will remain effective indefinitely. Indeed, a consumer's needs can change long before he or she has the opportunity to be re-evaluated by a clinician. Regular follow-up evaluations are critically important [11-13], but often do not occur due to a variety of barriers, such as the time and travel required and a lack of funding.

In addition, a single configuration may not be appropriate for a user at all times. A user's needs may change due to changes in his or her abilities which may happen over the course of a day (e.g., fatigue) or longer (e.g., due to progression of the disability, recovery of function, or other factors). The user's needs may also change based on the user's desired tasks (e.g., some computer activities may require greater precision than others). Even if a clinician is available to recommend an initial configuration, he or she may not be available every time adjustments to the configuration are desirable. If a user is responsible for his or her own adjustments, he or she may not notice, or know how to respond to, a gradual decline in performance.

3 Potential Technology Solutions

The problems with the computer access assessment process will not be solved through technology alone. The assessment process should be based on each client's individual priorities, taking into account preferences, physical and functional needs, social environments, and related issues [24], which makes the involvement of a trained clinician crucial. A clinician will always be needed to work with the consumer and other stakeholders to choose the most appropriate technology. Similarly, a clinician or other caregiver is irreplaceable for training in many circumstances. Likewise, funding and reimbursement issues are public policy problems rather than technology problems.

In other areas, however, technology can play a prominent supporting (or even leading) role. These include computer access assessment tools that clinicians can use to evaluate and document a client's abilities, utilities to automatically configure technology for each client's individual needs, and technology to provide follow-up services through remote client-clinician interaction. Research in each of these areas is discussed below.

3.1 Assessment Tools

Many different methods are currently employed in assessments for computer access. Informal clinical observation is the oldest method and is characterized by brief trials with candidate systems in a clinic setting and qualitative judgments of client performance during these trials. The lack of an explicit, objective framework in this approach makes it likely that appropriate candidate systems may not be considered, that criteria for selecting among candidate systems may not be clearly defined, and that objective data to guide the ultimate selection may not be available, particularly when evaluations are carried out by relatively inexperienced clinicians.

The need for a systematic approach to delivering assistive technology services has long been recognized (e.g., [25, 26]). The systems and approaches developed to date are diverse and can be categorized on the following dimensions:

1. types of information gathered (qualitative vs. quantitative);
2. method of data collection and management (manual vs. computerized);
3. focus of approach (assessment of ability vs. prescription of "best" device).

Several conceptual models for the "ideal" assistive technology assessment process have been developed. These conceptual models are designed to structure the evaluation to ensure that important considerations are not overlooked. Forms and worksheets are often provided to help guide the evaluator's activities and lead to a recommendation of the most appropriate device. A weakness in this approach is that little or no support is provided for measuring specific aspects of client performance, such as speed and accuracy. The procurement and management of objective quantitative data are left to the evaluator, who may or may not perform this task in a consistent or valid way.

Generalized qualitative assessment models (applying to all aspects of assistive technology) include:

- **The Student, Environment, Tasks, Tools (SETT) model** [27]. A general framework (rather than an actual protocol) for evaluating a person, environment and goals to identify the most appropriate assistive technology.
- **Matching Persons with Technology (MPT)** [28, 13, 29, 30]. A validated measure that evaluates how individuals judge their own functional and health status. The MPT measures quality of life and predisposition towards AT use, and has been shown to successfully predict satisfaction with AT one month after discharge [29].
- **Considering Assistive Technology** [31]. A flowchart to guide professionals through consideration of assistive technology by asking a series of questions.
- **Assessing Students' Needs for Assistive Technology** [32]. A protocol for evaluating a child's assistive technology needs in the context of an Individual Education Plan (IEP).
- **Education Tech Points** [33]. Assessment forms and a manual documenting the components of effective AT service delivery.

As shown in Table 1, several assessment tools have been developed specifically for computer access. Qualitative assessment methods designed specifically for computer access include:

- **Alternative Computer Access: A Guide to Selection** [34]. A decision tree which guides clinicians through the assessment process. Decision points prompt the clinician to evaluate the client's motor, sensory and cognitive skills. The "leaves" of the tree are suggestions of appropriate types of computer access devices.
- **Control of Computer-Based Technology for People with Physical Disabilities: An Assessment Manual** [35]. A manual with data collection instruments, procedures for client observations, testing procedures for various computer access methods, and guidelines for matching client needs and device characteristics.

- **Assessment of Computer Task Performance** [36]. A series of tests and measurement criteria for assessing computer skills. No software is provided to support testing. Instead, the tests are administered using icons present on the computer desktop and standard word processing software. A series of transparencies are provided which can be placed on the computer monitor to support the tests (e.g., indicating a path which the client should follow with the cursor).
- **Lifespace Access Profile** [37]. A team-based assessment tool that uses worksheets to measure physical, perceptual, cognitive and emotional skills, support resources, and environmental considerations. The worksheets are computerized, but data consists of subjective ratings from each team member.
- **EvaluWare**. A software package that presents evaluation exercises for a range of computer access skills. Despite the use of computerized tests, EvaluWare does not automatically record performance data.

Several computerized systems attempt to support the evaluator through all stages of the assessment process, producing a recommendation for the most appropriate assistive device. Examples of these systems include:

- **Computer Access Selector** [38]. Uses device criteria chosen from a series of prompts by a clinician to identify the most appropriate device from a list of known devices.
- **Assistive Technology Expert System** [39, 40]. Presents a series of questions to the clinician based on rules in an expert system. Answers to each question determine subsequent questions, until a device is identified.

Systems with a primary focus on device prescription generally use assessment data only as a means to that end, which tends to limit the main use for these systems to "one-time" major evaluations lasting several hours or more. They are not easily applicable to assessments that take place in a single therapy session and are not designed to track performance across multiple assessments. Furthermore, the systems developed to date are limited to recommending a single device at a time, and are unable to coordinate a multi-faceted approach to computer access.

Tool	Recommends Assessment Protocol	Computerized Skill Evaluation	Automatic Report Generation	Recommends Devices	Skills Evaluated
Compass	N	Y	Y	N	Use of text entry pointing devices; sensory abilities; cognitive abilities
REACH Interface Author	N	Y	Y	N	Use of text entry and pointing devices; switch skills
Alternative Computer Access: A Guide to Selection	Y	N	N	N	Use of text entry and pointing devices; sensory abilities; cognitive abilities
Control of Computer-Based Technology for People with Disabilities	Y	N	N	N	Background; environment; text entry, pointing and switch skills
Lifespace	Y	N	Y	N	Physical, cognitive, emotional, support resources and environmental characteristics
Assessment of Computer Task Performance	Y	N	N	N	Text entry and pointing skills
EvaluWare	N	Y	Y	N	Looking, listening, pointing, switch, some text entry skills
VOCAselect	Y	N	Y	Y	Criteria for an appropriate AAC device
Computer Access Selector	Y	N	Y	Y	Criteria for an appropriate computer access device

Table 1. Computer access assessment models and products

What most models, protocols, guidelines and tools uniformly lack is a means of collecting detailed quantitative performance data for use in decision making. As a result, computer access assessments primarily consist of brief trials with candidate systems resulting in qualitative judgments of client performance. Some clinicians collect quantitative data with a stopwatch, typing test software, or video games, but these approaches do not necessarily produce valid comparisons between devices.

The Compass software system [41-44], which measures users' skills in various kinds of computer interaction, is designed to help clinical and educational professionals perform computer access evaluations with their clients by providing them with a clear picture of a client's strengths and limitations. Compass tests the skill families of text entry, pointing and switch use through a hierarchy of tests which tap into successively more complex aspects of each skill. A hierarchy of complexity helps accommodate differing client abilities. For example, matching single letters of the alphabet may be a more appropriate assessment of keyboarding skill in a young student than transcription of full sentences. The hierarchy also provides a way to isolate the physical component of the test from its perceptual and cognitive aspects. As one moves up the hierarchy, tests incorporate more perceptual and cognitive skills. Performance on higher level tests may be compared to performance at the lower level of the hierarchy to reveal how perceptual and cognitive issues affect keyboarding and pointing for a particular client.

3.2 Automatically Adapting Device Configuration

The behavior of most computer input devices, such as keyboards and mice, is adjustable. Because each person's disability is unique, tuning these devices to a user's strengths and limitations is critical for success in many cases. Ideally, configuration is performed in consultation with a clinician who has expertise in computer access for people with disabilities. However, a trained clinician may not be available, and even when one is, proper tuning of a device to the needs of a particular user can be a difficult and time- consuming task. The challenge is magnified by the fact that user needs and abilities may change over time, whether in the short term due to factors such as fatigue or in the long term due to factors such as changes in the individual's underlying impairment. For these reasons, input devices are often not appropriately configured to meet users' needs, with consequent negative effects on user productivity and comfort.

A user's system is typically configured in one or more of three ways. The first, and perhaps most common, is to use the default values for the device. Moderately inappropriate values may result in multiple keyboarding errors and/or difficulty selecting targets with the mouse, decreasing user performance and satisfaction. In a more extreme case, the system may be virtually unusable under the default values.

A second scenario is when the user makes his or her own adjustments. This requires that the user knows what parameters are available and how to adjust them. This is a complex task. Performing all possible adjustments for keyboard and mouse within Windows XP requires accessing three separate Control Panel applications with 12 tabbed panels, while making objects larger for easier selection would require accessing a number of additional Control Panel applications. Terminology can be ambiguous; for example, to invoke BounceKeys, the user chooses to "ignore repeated keystrokes," while to adjust the repeat settings, the user must select "ignore quick keystrokes." Another potential source of confusion is that the repeat settings can be adjusted in two different control panels, with the accessibility settings overriding the keyboard control panel settings. Even if the user can successfully navigate the options, knowing the most appropriate values for all applicable settings may be even more difficult. Users may not understand how the parameter settings relate to the interface problems they are having, or if they do, the best choice of specific values may be unclear. Recent versions of the Windows operating system include an accessory program called the Accessibility Wizard, which does provide some help in reducing the complexity of configuration for keyboards, pointers, and the visual display. However, it does not include all available settings (e.g., the key repeat settings are not available), nor does it give specific suggestions about how to appropriately set parameter values based on user performance.

A third scenario occurs when a clinician or teacher is available to assist with the configuration process, using clinical observations and knowledge of the possible accommodations as a guide. However, most users with physical disabilities do not have a qualified clinician available to them. Trewin and Pain [45] found that only 35% of 30 computer users with physical disabilities had a "computer teacher." Further, not all clinicians have the skills to effectively assist. Even when a clinician or other advisor with relevant expertise is available, input device configuration often requires considerable trial and error.

Under each of these three approaches, it may be difficult to define appropriate settings for a user's initial configuration. It is equally difficult, if not more so, to address changes in the user's abilities over time, which may happen over the course of a day, a month, or a year, depending on the nature of the user's disability. Current methods may lead to appropriate input device configurations in some cases, but it does take special knowledge, additional time, and continued maintenance to do it right [34]. As a result, input devices are often not appropriately configured to meet users' needs, with consequent negative effects on user productivity and comfort.

An automated agent on the user's computer could help ensure that input devices are properly configured for the individual, and reconfigured as the user's needs change. Such an agent would need a means to observe the user's performance and predict appropriate input device configuration settings based on that performance. Several groups have been working toward configuration agents that would support this process [46-51]. A configuration agent models a user's strengths and limitations, and based on the model, helps configure the user's input devices appropriately.

3.2.1 Automatically Configuring Keyboards

Tuning a keyboard to a user's strengths and limitations may yield significant performance and comfort benefits. Conversely, the potential consequences of inappropriate settings are many [1]. For example, for someone who types with a mouthstick, not having StickyKeys active makes it cumbersome to type capital letters and impossible to use other key combinations such as Ctrl-C.

Trewin and colleagues have been developing a configuration agent for keyboard settings [52-57, 22]. The agent creates a user model based on free typing and determines settings for a range of parameters such as StickyKeys, Repeat Delay, and BounceKeys (see Table 1). The agent's recommendations were evaluated with 20 keyboard users who have physical disabilities. For StickyKeys, the agent's recommendation correlated significantly with users' opinions on how useful StickyKeys would be for them. However, the discrimination of the agent was imperfect, as 9 users felt that StickyKeys was useful for them, even though the agent did not recommend it for them. For repeat delay, use of the agent-recommended settings significantly reduced key repeat errors (from 2610 to 151 errors) [58]. The agent accurately recommended use of BounceKeys for 5 of 7 subjects who made bounce errors. Effects on productivity measures, such as typing speed, were not measured.

One of the challenges in Trewin's approach is that it makes inferences based on unconstrained typing tasks. The difficulty of this approach is shown in the fact that the agent accurately detected only 55% of inadvertent keypress errors [45] The use of unconstrained typing tasks allows for continuous monitoring, which is less obtrusive to the user, but may compromise the success of the agent's suggestions.

Koester, LoPresti and Simpson are developing a software system called IDA (Input Device Agent), whose goal is to optimally configure input devices for people with physical impairments [59]. In a study of twelve typists with physical impairments, IDA recommended three keyboard parameters in response to measurements of typing performance: repeat rate, repeat delay, and use of StickyKeys. For two participants with significant problems with inadvertent key repeats, use of the IDA-recommended repeat settings reduced the number of repeated characters by 96% and significantly improved text entry rate and typing accuracy. IDA recommended StickyKeys for six participants, which eliminated their modifier-related errors and significantly improved their typing speed. IDA did not recommend StickyKeys for the six participants who demonstrated no need for it.

Parameter	Description
Repeat Delay	How long a key must be held down before it begins to repeat.
Repeat Rate	Once the keyboard begins to repeat a character, the rate at which it repeats.
SlowKeys	How long a key must be held down before it is accepted.
BounceKeys	Tells the operating system to ignore keystrokes that are depressed within x seconds of the previous key release.
StickyKeys	When StickyKeys are activated, the typist can enter key combinations (e.g., Shift-A to type a capital A) by pressing the modifier key (e.g., Shift) and other keys (e.g., "A") in series, rather than holding down multiple keys simultaneously.

ToggleKeys	Gives an auditory signal when locking keys, such as Caps Lock, are depressed.

Table 1. Keyboard configuration parameters.

3.2.2 Automatically Configuring Pointing Devices

Pointing devices include the standard mouse as well as trackballs, laptop trackpads, head-controlled pointers, and many other devices. Typical parameters for pointing device configuration include those shown in Table 2. Other settings may be available, depending on the specific device and device driver being used. For example, Logitech trackballs (Logitech, Fremont, CA) allow the user to program the buttons to perform different functions. The trackpads common on laptop computers include settings related to cursor speed and whether the user can click by pressing on the trackpad or whether he or she must use the buttons.

Proper adjustment of these settings can be critical to efficient use of the pointing device for people with disabilities [1]. For someone with impaired motor control, the default pointer speed on the pointing device may cause the cursor to move much too quickly, making it difficult or impossible to select small targets such as toolbar buttons. Other difficult tasks include dragging the pointer with the mouse button depressed and clicking and double-clicking the mouse button while keeping the pointer still.

Parameter	Description
Button-handedness	Controls the functions assigned to the left and right mouse buttons.
Click method	Whether the user performs a single or double click to select icons.
Double-click speed	Controls the allowable time between two clicks in a double-click.
Pointer speed (Gain)	How quickly the cursor moves across the screen in response to mouse movements.
Enhanced pointer precision	The Enhance Pointer Precision (EPP) setting enables a complex algorithm controlling the velocity and acceleration of the mouse cursor.
Snap-to-default	If this option is active, when a dialog box appears on the screen, the cursor will immediately move to the default button (e.g., “OK”).
Object Size	It is possible to change the size (in pixels) of icons, menu bars, and

	other objects in the user interface. Increasing the size of these objects may make them easier to select, at the cost of reduced space on the screen. There may be many separate settings which could be adjusted to make different classes of objects larger.

Table 2. Typical configuration options for pointing devices.

If a relationship can be found between an individual's movement patterns and his or her optimal configuration settings, a software agent could customize the settings in response to the user's needs. This concept has been explored with a force-sensing joystick which adapted to hand tremor using measurements of the user's tracking ability and tremor [48]. A preliminary study with three subjects who had Friedrich's ataxia indicated that the adaptive joystick provided some improvement in performance for tracking tasks.

Tracey and Winters developed a system to configure mouse settings in the Windows operating system based on subject performance on computer tracking exercises as well as direct questions directed toward an assistive technology clinician who had observed the user [12]. The principle limitation of this system is its assumption of the presence of an assistive technology expert when, in some cases, users may need or want to configure their systems independently

LoPresti developed and evaluated a system that automatically adjusted the gain for users of head-controlled pointing devices [17]. For 16 subjects with physical disabilities, the system was able to select settings that were appropriate for most subjects and provided a modest but significant improvement in performance ($p < 0.05$). IDA recommends a setting for the computer's control-display gain based on observations of a user's performance in a target selection task [60]. In a study involving 12 participants who have motor impairments, the IDA-selected gain was not associated with significant improvements in selection time or error-free performance compared with the operating system's default gain. However, two participants did have notable and consistent improvement in selection time and error-free performance using the IDA-selected gain [60].

3.2.3 Switches

Individuals who cannot use adapted keyboards or pointing devices may use switch-based input techniques. One example is single-switch scanning, in which the system presents choices sequentially to the user. A common implementation of single-switch scanning requires three switch hits to make one selection from a row-column matrix of letters, numbers, symbols, words, or phrases. The first switch hit initiates a scan through the rows of the matrix. Each row of the matrix is highlighted in turn until a second switch hit is made to select a row. Each column of the row is then highlighted in turn until the target is highlighted, when the third switch hit is made to select the target. Depending on the scanning system used, there may be three or more adjustable parameters (see Table 3), with the scan rate being most important. Switch-based parameters are incorporated into the switch system used and are not a feature of the operating system. The scan rate and other configuration parameters determine the minimum letter selection time which is possible for a user. If the scan rate in single-switch scanning is too fast, the user will make a lot of errors or may be unable to use the system. A scan rate which is too slow will unnecessarily slow down performance in a process that is already inherently very slow [1].

Parameter	Description
Scan period	The amount of time an item remains highlighted for the user to make a selection
Initial Scan Delay	Additional delay applied to the first row or column
Column Scans	Maximum number of times the columns within a row are scanned
Layout	Arrangement of targets within the scanning matrix

Table 3. Typical configuration options for single-switch scanning.

One-switch row-column scanning can be tiring to use and is generally a relatively slow method of communication. An able-bodied individual using an optimally-designed matrix of 26 letters and a space can produce between 6 and 8 words/minute using this method [61, 62]. Despite its limitations, however, row-column scanning fills an important niche within access techniques by providing an affordable and reliable option for many individuals with limited movement and limited vocal abilities. Hence, despite increasing interest in speech recognition, eye-tracking, and direct-brain interfaces for accessing assistive technology, there remain valid reasons for seeking to enhance performance using row-column scanning.

Three research groups have worked on methods of automatically adapting the scan period of a single-switch row-column scanning system. Cronk and Schubert [63] developed an expert system for the adaptation of scan period, but it was never integrated into any commercial systems. Lesher et al. [64, 65] developed a rule-based method of scan period adjustment based on user errors and the time required for the user to make a selection relative to the available time. Their primary goal was to provide a means of scan period adjustment for empirical studies comparing different scanning displays, and their system performed well enough to meet this goal with able-bodied subjects [65].

Simpson and Koester [66] developed and evaluated a single switch scanning system that used a Bayesian network to adjust the user's scan period in real time. Two studies, involving a total of 16 subjects without disabilities, demonstrated that the system could make reasonable adaptation decisions, with no human intervention, for a system with a single scan delay. Subjects' text entry performance and subjective opinion was no different with the automatic system as compared to a manual adjustment protocol, in which able-bodied subjects could change the scan period at will with a single keypress. A major limitation is that the work was not validated with users with disabilities.

IDA's ability to make recommendations for scan period in a row-column scanning system was evaluate with two groups of individuals (8 people who were either able-bodied or had spinal cord injuries and 6 individuals with severe physical disability secondary to cerebral palsy) [67]. Participants' speed, accuracy, and subjective ratings when using the IDA-recommended scan rate suggest that IDA can recommend an appropriate scan rate. Participants' performance was at least as good for the IDA-selected scan period as for the self-selected scan period [67].

3.3 MONITORING AND TELEREHABILITATION

The Institute of Medicine defines *telemedicine* as "the use of electronic information and communications technologies to provide and support health care when distance separates the participants [68]." The Shepherd Center has further defined *telerehabilitation* as "the use of telecommunications technology to provide rehabilitation and long-term support to people with disabilities [69]." Telerehabilitation technology can either be used *interactively* or in a *store-and-forward* mode. Interactive telerehabilitation sessions involve both the client and clinician participating in the session at the same time, typically using audio- and video-conferencing technology. Store-and-forward telerehabilitation sessions, on the other hand, allow the clinician to collect data from the client without the need for simultaneous interaction.

Telerehabilitation technology can allow a clinician to collect performance data during a "loan period" to evaluate how well a potential computer access solution meets the consumer's needs. Quite often, the sole measurable outcome of a loan period is the consumer's subjective impression of the AT. While the consumer's impression is important, there is typically no record of how often the device was used during the loan period, how well the consumer performed when using the device, or how the device was configured - all of which is important for making informed comparisons between multiple potential solutions. More importantly, self-reports can be unreliable. Studies [70-72] have shown that "estimates of concordance of client self-reports and proxy-reports with performance-based measures range from a low of 63% to a high of 94% depending on the specific daily living task [73]."

Telerehabilitation can also be a cost-effective solution to providing follow-up to consumers after a device has been purchased. Receiving a device is no guarantee that the device will be installed and configured correctly, particularly if funding for an in-person visit from a clinician is not available. Telerehabilitation may reduce the cost of a clinician's involvement in the installation and configuration process to the point where this service can be provided with each piece of equipment received. Follow-up assistance may take several forms, including:

- interactive desktop sharing, video conferencing or text messaging to allow the clinician to guide (or control) the installation/configuration process;
- interactive or store-and-forward use of skill tests, which allow the clinician to compare performance obtained in the clinic with results on the consumer's home or work computer.

Several clinical teams have documented the use of telerehabilitation to enhance the provision of computer access and augmentative communication services, although these publications have thus far been limited to case studies with little or no statistical analysis. In the United States, the Shepherd Center of Georgia has perhaps the most experience using telerehabilitation technology for computer access. They have described one instance in which a videophone was used to evaluate how well a computer access system was configured for a client [69], and have also described using telerehabilitation technology for training a client to use speech-recognition software for computer access [74].

Another American researcher, Elliot Cole, has described a computer-based cognitive rehabilitation intervention that made use of telecommunications technology [75]. Cole developed computer software that assisted a client with communication and information storage and retrieval. The client was trained to use the software using videoconferencing technology and desktop sharing software. Perhaps more importantly, this is the only reported instance we could identify in which telerehabilitation was used as a means of conducting follow-up evaluations. Specifically, Cole modified the system based on data automatically collected by the system during regular use.

In Europe, the Oxford Aiding Communication in Education (ACE) Center has made extensive use of telerehabilitation technology to support computer access and augmentative communication interventions. The Telenet [76] and CATCHNET [16] projects evaluated the effectiveness of low-cost videoconferencing and online software sharing in providing computer access assessment, training and support. Both projects used an ISDN line to connect clinicians at the ACE Center with clinicians and clients in remote clinical sites, and reported general client and clinician satisfaction with the approach.

The Telesupport for Loan Equipment project [10] compared in-person support for computer access teams with remote support. The ACE runs a technology loan library and has observed a need for “good quality, on-going training while a piece of equipment is borrowed [10].” Results indicated that telerehabilitation interventions provided the following benefits to users and aides [10]:

- clients could interact in real-time with clinicians;

- trained clinicians could configure devices remotely;
- training and support via videoconferencing technology was perceived to be of higher quality than more conventional communication methods (e.g., phone, email).

Also in Europe, the Remote Service of Rehabilitation Technology (RESORT) project [77-79] developed telerehabilitation technology that allows a clinician to establish a communication channel with a client for transmitting audio and visual data and for desktop sharing[1]. A clinician can use RESORT to interact with a client, monitor (but not collect data on) the client's computer use, and adjust the configuration of the software. The RESORT team also developed an application programming interface (API) that allows an application on the client's computer to be synchronized with the clinician's computer. This API is different from other application sharing technologies (e.g., Microsoft NetMeeting) in that it supports real-time synchronization.

4 Discussion

Quantitative evaluation tools such as Compass provide the means for clinicians to collect evidence in a rigorous manner. The underlying technology, however, can be advanced in several directions. One opportunity for potential improvement is the integration of additional performance measures, many of which were developed by the human-computer interaction (HCI) community. For example, MacKenzie and colleagues [80] have developed error measures that compare the cursor's actual path of travel to the "ideal" path of travel. Keates and Hwang [81-85] extended this work by developing error measures that incorporated the "instantaneous" optimal cursor path, referred to as the Instantaneous Task Axis (ITA). These measures can provide the client and clinician with a great deal of additional information, but it is likely that a distinct subset of measures will be of greatest interest for each client, device and task. Hence, a means of flexibly integrating user- and device-specific errors would also be useful.

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[1] *Desktop sharing* refers to the ability of one computer user to remotely operate another computer while seeing the windows and icons on the remote computer's "desktop"

Clinical assessment tools can also benefit by adopting protocols originally developed for HCI research. For example, investigators within the field of human factors have recently begun employing "unconstrained" text entry protocols [86-90] in which the user is allowed to make errors and to decide whether or not to correct the errors that occur. The primary advantage of this approach is that it allows users to enter text under more natural, realistic conditions [86-90]. This approach also allows investigators to analyze the entire input stream, including errors and error corrections [90], thus providing a more detailed picture of text entry.

Wobbrock has recently demonstrated how the text input stream can be decomposed into [90]:

- Non-errors. Correct keystrokes (i.e., the correct key pressed at the correct time).
- Substitutions. Incorrect keystrokes in which one character is entered instead of another.
- Insertions. Incorrect keystrokes in which additional characters are entered.
- Omissions. Errors in which a character that should appear in the input stream does not.
- Fixes. Keystrokes used to remove characters or reposition the cursor (e.g., backspace, delete, arrow keys)

The algorithms developed by Wobbrock, however, make certain assumptions that are not necessarily valid for individuals with disabilities or for text entry methods like word completion and abbreviation expansion where a single input can generate multiple characters [90]. Additional work is needed to determine how Wobbrock's work can be extended to cover these situations.

Software like IDA may one day assist clinicians in configuring CAT, and may also be used by clients to adjust the configuration of their technology over time. IDA is limited, however, in that the client must complete performance tests in order for IDA to collect enough data to make configuration recommendations. A more desirable approach would be for IDA to make its recommendations based on the client's performance on unconstrained real-world tasks in the normal course of computer use. Hurst and colleagues have used machine learning techniques to automatically categorize user performance on pointing tasks based on whether or not assistance with clicking on targets was likely to improve performance [91].

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