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Assistive Technology Outpacing Disease Progression: A Longitudinal Case Study

Darren Gabbert
Sr. Business Operations Associate, Division of Information Technology
University of Missouri – Columbia

Abstract

Rapid growth in dedicated assistive and accessible mainstream technologies has heightened awareness of the critical importance of appropriate assistive technology assessment and training. This importance has underscored the need for technology assessment to be a dynamic, continuous process that maintains focus on functional deliverables. This paper presents a longitudinal case study describing keys to successfully accommodating a person with a severe mobility impairment over a 27-year period. Special emphasis is given to achieving levels of productivity conducive to competitive employment within an IT customer service organization. A cyclical methodology referred to as the *Assistive Technology Optimization Process (ATOP)* is defined, described and illustrated. As demonstrated by this case study, the ATOP offers much scaffolding to track, plan, and integrate changing technology to meet changing expectations in the face of *changing capabilities*. Several trends can be observed within the course of the study where *technology benefits outpaced disease progression.* For the study subject, his employer, and the field of assistive technology that is success!

Keywords: assistive technology, assessment, mobility, muscular dystrophy, spinal muscular atrophy

Introduction

The benefits of assistive technology (AT) largely depend on the successful matching of specific user needs to specific technologies. Every AT practitioner soon realizes this matching must be done amidst changing parameters. Advancing technologies, progressive user limitations, and evolving stakeholder expectations can all pose positive and negative implications on the AT assessment process. The University of Missouri's Adaptive Computing Technology Center has established a systematic approach geared toward the variable nature of making AT system recommendations. This cyclical methodology referred to as the *Assistive Technology Optimization Process (ATOP)* is defined, described and illustrated through a longitudinal case study. This study demonstrates implementation of desktop and mobile computer technologies using the ATOP to guide the process over a 27-year period for an individual with severe and progressive mobility limitations. Special focus is placed on change over time, including: a) meeting changes in user/technology performance expectations; b) compensating for progression of mobility limitations; and c) leveraging advances in mainstream and assistive technologies.

Many assessment methods in the field of assistive technology are non-standardized, lengthy, subjective, and require substantial clinical experience of a multidisciplinary team (Jenko et al., 2010). The ATOP is designed to overcome some of these weaknesses through a practice of continuous, functional-based evaluations. ATOP's focus on functional task performance keeps the process relevant to desired outcomes, while its continuous practice reveals trends showing either positive or negative efficacy of accommodations. Ineffective assessment practices lie at the heart of statistics which suggest AT device abandonment may be as high as 30% (Federici, Meloni, & Borsci, 2016; Mumford, Lam, Wright, & Chau, 2014; Phillips & Zhao, 1993). Some assessment methods attempt to remediate this by placing heavy emphasis on *user self-determination*. The theory being that enhanced self-determination leads to more positive outcomes (Wehmeyer, 2004). While this is a fundamental part of ATOP, self-determination must be supported by expert knowledge of AT best practices. The right parameters must be provided to ensure informed decision making. One strength ATOP offers is its capacity to trend redundant access methods which lead to user discovered best practices. For example, a one-handed typist might have an adapted keyboard, as well as, speech recognition as concurrent access methods. ATOP cycles should indicate which is used most, under what circumstances, and at what level of proficiency. This practice of "discovered best practice" is demonstrated repeatedly throughout the case study.

Another noteworthy assessment approach is based on the concept of *response efficiency*. Response efficiency supports AT selection by assessing four factors that have been identified as significantly influencing efficiency: response effort, rate of reinforcement, immediacy of reinforcement, and quality of reinforcement (Mumford et al., 2014). These criteria reflect some strong similarities to the six criteria used in ATOP, however, the ATOP is strictly tied to task performance. This results in the model's ability to address redundant access methods, which is a fundamental strength of ATOP.

Target Audience and Relevance

The five-phase assessment cycle described in this paper offers an effective methodology for evaluating computer based technologies. The goal of maximizing benefits, while accommodating change in multiple factors is common to all disability types. While the degree of variability may differ from one user to another, the assessment cycle remains relevant to optimizing capabilities in all applications of AT. The ATOP offers both service providers and AT users a systematic approach to continuous improvement that can be easily documented. This approach also builds an AT user histories revealing best practices that may benefit other users with similar technologies.

Assistive Technology Optimization Process (ATOP)

Two fundamental principles guiding the ATOP are: 1) setting task specific goals; and 2) exercising client self-determination. Regarding the former, you must know what the target is before you can aim for success. Too often AT providers (and even AT users) equate *computer access* with improved quality of life and increased ability. In terms of AT success, however, gaining access to technology is more of a beginning than an ending. Regarding the latter; technology only fosters self-determination if it achieves results that are meaningful to the end user. For example, setting a goal of providing speech recognition as a primary input method falls short of defining either the need or the aim. In contrast, a task specific goal of *using speech recognition to manage and compose emails in Microsoft Outlook* provides a measureable objective for success, a defined context for training, and a functional and empowering outcome for the user.

Determining the scope of goals to include in an AT assessment depends on self-determination factors such as the user's need for independence, their preferred methods of communication, and their education/employment performance expectations. While goals in any of these domains are influenced by numerous outside factors as well as personal

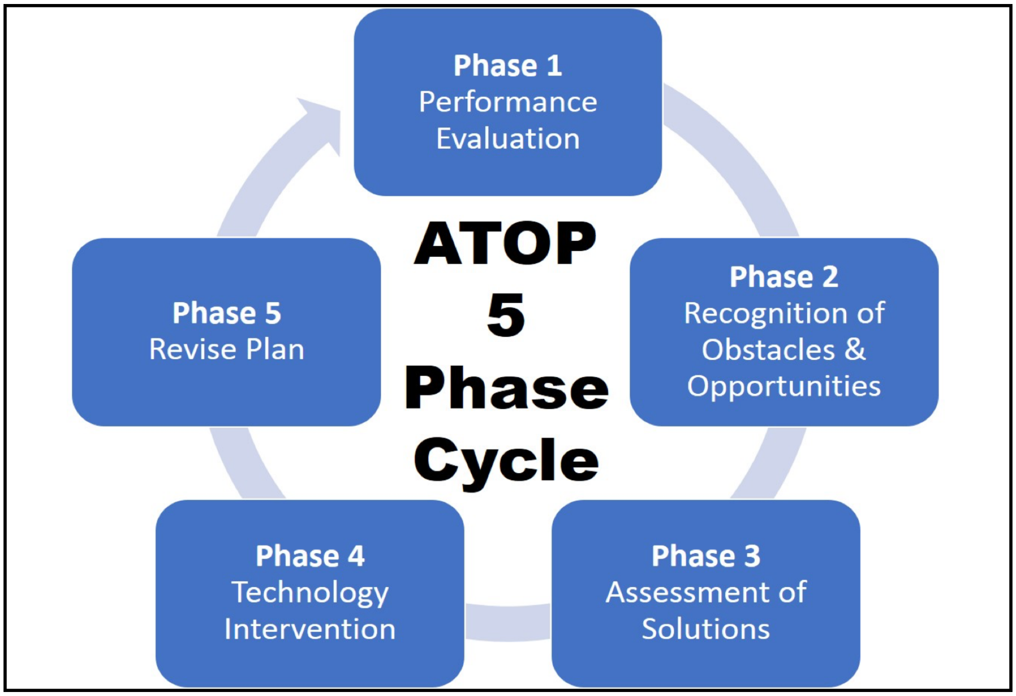

Figure 1. Assistive Technology Opportunity Process (ATOP)

factors, the centrality of self-determination is critical to both their definition and attainment (Steel, Gelderblom, & de Witte, 2012).

Using this foundation, we have constructed a five-phase, cyclical process (See Figure 1) to match and optimize AT to user goals. The first phase is the development of the initial performance plan. When this process is initiated, task specific goals are identified and defined by the AT professional and user.

Phase 1 – Performance Evaluation officially begins with a performance evaluation of the user/technology match. In reality, however, performance should be continually monitored and this phase should be invoked proactively. Undoubtedly, applying the model in a rigid, linear manner runs the risk of missed opportunities to respond to performance shortfalls outside of scheduled evaluations. Unmet user expectations in AT performance need to be recognized, communicated, and addressed in a timely manner to avoid user frustration and subsequent technology abandonment. For example, a departmental operating system upgrade would logically initiate a targeted performance evaluation of software compatibility. Changing performance expectations can likewise initiate Phase 1 of the ATOP.

Identifying measurable and meaningful evaluation criteria is a formidable challenge for individualized AT accommodations. Task-specific goals do, however, lend themselves to a fundamental measureable question: *Can the user accomplish a task?* But the ability to accomplish a task is not necessarily success. Six evaluation criteria that are particularly helpful in operationalizing successful task performance are *speed, accuracy, fatigue, load, consistency, and satisfaction*. While each of these attributes may be quantified with some precision, in many circumstances ordinal ratings such as low, medium, and high provide sufficient definition for the assessment.

Speed is the exception, however, and ratio scaling is best for tracking progress. A common example is text input rate, which is measured in words per minute; or, text-to-speech output rate for those depending on auditory reading. Speed should always be viewed alongside accuracy. An illustrative example would be high speed but low accuracy in text input. In this example the result may be a net loss of time and energy expenditure due to making corrections, thus diminishing overall efficiency and user experience.

User fatigue is another multicomponent factor, comprising both frequency and duration of the task. Load refers to the physical and/or cognitive demand associated with performing the task. Consistency relates to the user's ability to perform satisfactorily throughout the task and each time they undertake the task. And lastly, satisfaction constitutes a positive overall experience performing the task, using the technology.

Phase 2 – Recognition of Obstacles and Opportunities is a process that should be undertaken independent of possible technology solutions. Evaluation criteria for each task, changes in the user's abilities, new or modified performance expectations, and advances in mainstream or assistive technologies are all possible catalysts for AT system changes. Obstacles and opportunities from Phase 2 dovetail with *Phase 3 – Assessment of Solutions*, where solution and optimization options are studied. This assessment phase of the process includes: 1) Identifying recognized obstacles/opportunities that can be readily addressed; 2) researching solutions for unsolved issues; and 3) determining timing and feasibility for implementing researched solutions. When possible, multiple technology solutions should be introduced as redundant systems, thus permitting the degree and rate of technology adoption to follow inherent benefits. For example, someone with progressive mobility limitations may have a workstation with both speech recognition and eyegaze capabilities. Which, where and when each is used will be discovered by the user and optimized in future ATOP iterations. *Phase 4 – Technology Intervention* is the actual implementation of the technology solutions with appropriate testing, training, and adapting. And *Phase 5 – Revise Plan* brings the process back to the performance plan; documenting revisions and targeting a future date of the next evaluation.

Case Study

Subject Background

The subject in this case study is a 51-year-old male with an advanced form of Muscular Dystrophy called Type 2 – Spinal Muscular Atrophy. This genetic condition affects the nerves that control muscle movement. Type 2 of this disease is characterized by moderate onset and progressive weakness in arms, legs, lower torso, and respiratory muscles. The subject has used a power wheelchair for mobility since adolescence. Navigation was initially via a joystick controlled by his right hand. By 2005, disease progression had reached complete paralysis, with wheelchair navigation accomplished through electromyography (EMG) switch scanning. The subject has been ventilator dependent since 2013. The subject has a 4-year degree in Computer Science, and was hired into a full-time position with an IT organization in 1989. Subject continues to work within the same organization in a 50% full-time equivalent capacity.

ATOP Iterations: 1989 – 2016

Listed here are six iterations of the Assistive Technology Optimization Process that were conducted with the study subject between 1989 and 2016. Each iteration presents highlights of all five phases of the process: Performance Evaluating, Recognition of Obstacles and Opportunities, Assessment of Solutions, Technology Intervention, and Revise Plan. Performance goals are listed as column headings within each iteration's Functional Goals Matrix. It should be noted that the subject's technical skills and aptitude from the onset of the study significantly contributed to continuous optimization. This is most clearly seen in the subject's comfort level with technology change. The responsibility to initiate ATOP iterations would fall more to the AT practitioner in instances where the

Table 1
1989 Functional Goals Matrix for Keyboard and Mouse Modifications

Functional Goals		1. Place and receive calls	2. Manage and compose email on a mainframe system;	3. Compose written text and graphics for user support documentation;	4. Access Apple and Windows operating systems (mouse)
Evaluation Criteria	**(Sp)eed**		One-handed typing, 20 wpm	One-handed typing, 20 wpm	
	(A)ccuracy		High	High	Low **(High)**
	(F)atigue	High **(Low)**	Medium	Medium	High **(Low)**
	(L)oad	High **(Medium)**	Medium **(Low)**	Medium **(Low)**	High **(Low)**
	(C)onsistency	Low **(High)**	High	High	Low **(High)**
	(S)atisfaction	Low **(High)**	High	High	Low **(High)**

AT user possesses less computing skills.

Accommodation (1989): Keyboard and Mouse Modifications

Phase 1 – Performance evaluation. The subject seemed satisfied with one-handed typing on a standard keyboard, and demonstrated an input rate of approximately 20 words per minute (Sp) with high accuracy (A). Moderate drop in efficiency associated with fatigue was observed (F). Standard mouse was unusable due to restricted range of motion. Subject could dial standard push button phone, but could not lift handset.

Phase 2 – Recognition of obstacles and opportunities. Subject experienced significant difficulty answering and hanging up phone. Access to both Apple and Windows operating systems was hampered by subject's inability to manipulate the computer mouse. Opportunity existed to reduce keyboarding load by accommodating one-handed key combinations associated with modifier keys (e.g. shift, ctrl, alt).

Phase 3 – Assessment of solutions. The following issues were addressed:

- Work environment was not conducive to speaker phone conversation. Gooseneck arm with phone handset cradle could allow subject to drive wheelchair to position handset to ear/mouth. Needed to fabricate aluminum lever to allow user to easily open/close the phone line.
- Trackball could replace computer mouse, requiring significantly less range of motion. Because the subject had excellent fine motor movement, mouse pointer navigation could be further enhanced by trackball sensitivity settings (i.e. reduce the ball-to-pointer movement ratio).
- Installed Sticky Keys software utilities on both Apple and Windows workstations which allowed subject to press key combinations sequentially.

Phase 4 – Technology intervention. The following solutions were implemented:

- Introduce Gooseneck/lever phone accommodation.
- Introduce 2 Trackballs (Apple and Windows compatible) with sensitivity adjustment capability.
- Implemented Sticky Keys on both platforms.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses in Table 1.

Table 2
1993 Functional Goals Matrix for Transition to Discrete Speech Recognition

Functional Goals		1. Place and receive phone calls	2. Manage and compose email on Microsoft Outlook Client;	3. Compose written text and graphics for user support documentation;	4. Access Apple and Windows operating systems (mouse)
Evaluation Criteria	**(Sp)eed**		One-handed typing, 9 wpm (Discrete speech, pending)	One-handed typing, 9 wpm (Discrete speech, pending)	
	(A)ccuracy		Medium	Medium	High
	(F)atigue	Medium	High **(Low)**	High **(Low)**	High **(Medium)**
	(L)oad	Medium	High **(Medium)**	High **(Medium)**	Medium
	(C)onsistency	High	Medium **(High)**	Medium **(High)**	Medium
	(S)atisfaction	Medium	Low **(High)**	Low **(High)**	Medium

Accommodation (1993): Transition to Discrete Speech Recognition

Phase 1 – Performance evaluation. Progression of subject's neurological disease was seen in increased fatigue for all functional goals, which is inversely correlated with satisfaction. All criteria (Sp, A, F, L, C, S) supported an immediate intervention to address text entry (2, 3). Mouse control (4) was following same downward trend (F, L, C, S), though indicators showed continued viability (A, C, S). Telephone accommodation (1) was likewise losing ground (F, S), but continued to be effective.

Phase 2 – Recognition of obstacles and opportunities. Disease progression was causing weakness and shrinking range of motion. Advances in speech recognition offered a keyboard alternative on the Windows platform. Mouse control via speech recognition would be awkward. Availability of speech recognition on the Apple platform was very limited.

Phase 3 – Assessment of solutions. The following issues were addressed:

- Speech recognition technology was available for Windows platform, and would have strong potential to increase speed while decreasing fatigue. Subject's private office offered optimum speech recognition environment. Windows system was targeted for composing text (speech recognition offered awkward mouse control).
- Robust speech recognition technology was not available for Apple platform. Voice Navigator system did offer speaker-dependent, discrete speech system with a 1,000-word capability. This technology could supplement existing trackball capability with voice macros for repetitive keystrokes. Apple system was targeted for graphic design and internet browsing.
- Telephone accommodation was left unchanged with eye on future opportunity to integrate into Windows workstation after speech recognition transition.

Phase 4 – Technology intervention. The following solutions were implemented:

- Dragon Dictate for Windows (speaker-dependent, discrete speech) introduced as a hands-free access method.
- Voice Navigator added to Apple system for graphic design and internet browsing.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses on Table 2.

Accommodation (1999): Redefining Performance Expectations

Phase 1 – Performance evaluation. As a result of disease progression and other health related issues the subject's performance expectations were reduced to coincide with a 50% full-time equivalent appointment. Telephone accommodation (1) had continued to show diminished efficacy (L, C, S). Composing text (2) via discrete speech recognition was approximately 18 words-per-minute (Sp). Redefined functional goals were aligned with applications supported the by Windows platform, thus removing the Apple technology from his performance plan. Because worksite location would be flexed between home and work, the need for mobile computing access was added to functional goals (3) and would be addressed in this cycle.

Phase 2 – Recognition of obstacles and opportunities. Integrating new telephone accommodation into the speech recognition system appeared to be the best fit. A wireless headset microphone could facilitate independent access to the home workstation. Access to a physical switch for toggling the microphone on/off would be needed to facilitate using one headset for both computer and telephone. Laptop with docking station could seamlessly allow the same system to satisfy both functional goals 2 and 3. Opportunity explored to increase speech recognition accuracy because of advances in this technology.

Phase 3 – Assessment of solutions. The following issues were addressed:

- Because of the subject's limited pulmonary function, upgrading from discrete to continuous speech recognition was not feasible. Accuracy for continuous speech recognition is heavily dependent on word context, thus requiring users to speak long phrases within single utterances. Trials showed poor recognition accuracy because the subject's breath capacity could produce only two or three words per utterance.
- A laptop with expanded RAM was identified to meet speech recognition system

Table 3
1999 Functional Goals Matrix for Redefining Performance Expectations

Functional Goals		1. Place and receive phone calls	2. Compose written text and manage information via Microsoft Office software;	3. Manage information and email beyond home workstation
Evaluation Criteria	**(Sp)eed**		Discrete speech, 18 wpm	
	(A)ccuracy		Medium	**(Medium)**
	(F)atigue	Medium **(Low)**	Low	**(Low)**
	(L)oad	High **(Low)**	Medium	**(Medium)**
	(C)onsistency	Low **(High)**	High	**(High)**
	(S)atisfaction	Low **(High)**	High	**(High)**

requirements and allow portability.

- Home workstation needed to permit the subject to come and go freely without requiring assistance to engage the system (e.g. subject cannot be tethered to workstation with wired headset microphone).
- Nanopac CINTEX4 system identified to provide hands-free control of the telephone via the same wireless headset used for speech recognition.
- A foot switch could be mounted underneath workstation desk and actuated by the subject elevating his wheelchair's power leg rests. Switch would toggle the speech recognition's microphone on/off. Speaking while the microphone is in a sleep state frequently causes the microphone to inadvertently wake up, an issue that would be exacerbated by the microphone's shared function between the computer and the telephone.
- A wired headset microphone with noise reduction capabilities could be used when laptop is undocked and mounted on the wheelchair's lap tray.

Phase 4 – Technology intervention. The following solutions were implemented:

- Primary workstation configured with a laptop and docking station, external monitor for increased desktop workspace, scanner for paperless workflow, and wireless headset microphone (rechargeable with 8-hour life);
- Nanopac's CINTEX4 hands-free telephone system integrated with speech recognition;
- Additional wired headset microphone with noise cancellation supplied for use when laptop is undocked and mounted on wheelchair lap tray.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses on Table 3.

Accommodation (2005): Transition to Continuous Speech Recognition

Phase 1 – Performance evaluation. In light of the discrete speech recognition software no longer being supported, and growing concern over the likelihood of compatibility beyond Windows XP, continuous speech recognition was revisited. Advances in continuous speech recognition could offer improvements in both speed and accuracy (Sp, A), in addition to the numerous benefits associated with using a supported, feature-rich technology. Subject's mobile solution continued to show functional efficacy (Sp, A, F, L, C), but satisfaction was low due to bulkiness of the laptop and the prohibitive background noise associated with public settings. Alternative mobile solutions were studied. Telephone setup continued to be effective and satisfactory against all evaluation criteria.

Phase 2 – Recognition of obstacles and opportunities. An advanced feature within the Dragon NaturallySpeaking software allowed a pause between spoken words, which could facilitate access despite limited breath. Pocket PC/Smartphones were quickly becoming ubiquitous technologies, though largely unexplored for alternate access methods. Software developed in Switzerland existed that offered some degree of switch scanning access.

Phase 3 – Assessment of solutions. The following issues were addressed:

- Trials with the pause between spoken words set to nearly 1 second permitted the subject to inhale between pairs of words, thus simulating continuous speech recognition. Subject could dictate entire sentences that Dragon NaturallySpeaking would process as a single utterance with percent of recognition accuracy in the upper-nineties.
- NoHandCom software showed strong potential for effective switch access to Windows Mobile platform. Developer was willing to add functionality that would move toward all device features being switch

Table 4
2005 Functional Goals Matrix for Transition to Continuous Speech Recognition

Functional Goals		1. Place and receive phone calls;	2. Compose written text and manage information via Microsoft Office software;	3. Manage information and email beyond home workstation
Evaluation Criteria	**(Sp)eed**		Discrete speech, 18 wpm **(Continuous Speech, pending)**	Discrete speech, 18 wpm **(Single switch scanning, pending)**
	(A)ccuracy		Medium **(High)**	Medium **(High)**
	(F)atigue	Low	Low	Low **(Medium)**
	(L)oad	Low	Medium	Medium
	(C)onsistency	High	High	High
	(S)atisfaction	High	High	Low **(Medium)**

accessible. Mobile device could be accessed by the second switch output from the Tinkertron EMG switch. Triggering of this switch occurs when muscle activity is detected by a single electrode on the surface of the skin, and a trigger sustained for more than 2 seconds causes the switch to toggle between two outputs. In this case, switch output #1 being used for power wheelchair navigation and switch output #2 controlling smartphone single-switch scanning.

P*hase 4 – Technology intervention.* The following solutions were implemented:

- Transitioned speech recognition system to Dragon NaturallySpeaking, setup custom speech commands for telephone control, and expanded global commands to support complete hands-free computing.
- Introduced NoHandCom app on an HP iPAQ device running Windows Mobile.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses on Table 4.

Accommodation (2013): Transition to Single Switch Scanning

Phase 1 – Performance evaluation. In January of 2013 the subject experienced a serious health event which resulted in a permanent tracheotomy. This, combined with the advanced level of his neuromuscular disease, eliminated his entire ability to speak. Another computer access method was needed to replace functional goals previously accomplished through speech recognition. Advances in mobile technology switch access had increased the subject's mobile capabilities to fully accessing all features of an Android smartphone. This ClickToPhone system (developed in Ireland) was unaffected by the subject's health event, and became the centerpiece of a radically changed performance plan. Because of the extent of quadriplegia, potential muscle sites for switch access were limited to up/down movement of eyebrows (moving together), strong twitch action of left pectoral muscle, strong twitch action of left cheek, and faint movement of right thumb. The left pectoral muscle was already dedicated to controlling the smartphone and navigating his power wheelchair via a dual output EMG switch. And the eyebrows

Table 5
2013 Functional Goals Matrix for Single Switch Scanning

Functional Goals		1. Place and receive phone calls (Remove)	2. Compose written text and manage information via Microsoft Office software;	3. Manage information **(and communicate beyond home workstation)**
Evaluation Criteria	**(Sp)eed**		Continuous Speech, 35 wpm **(Single switch scanning, pending)**	Single switch scanning, 5.7 wpm
	(A)ccuracy		High	Hig
	(F)atigue	Low	Low	Medium
	(L)oad	Low	Medium	Low
	(C)onsistency	High	High	High
	(S)atisfaction	High	High	High

were committed to the operation of the power wheelchair's emergency kill switch. This left the subject's left cheek as the most likely candidate for engaging another technology access method. A telephone/Skype accommodation was explored, in addition to smartphone communication options.

Phase 2 – Recognition of obstacles and opportunities. Subject could clearly benefit from several feature enhancements to the ClickToPhone system, chief among which was increasing scanning rate beyond 333ms. Smartphone could initially be primary augmentative and alternative communication device. Eyegaze technology and single switch scanning were the two most likely candidates for replacing speech recognition.

Phase 3 – Assessment of solutions. The following issues were addressed:

- Needed text-based Android App for augmentative and alternative communication. Alexicom app had capacity to support large, complex phrase collections with multi-platform compatibility.
- Smartphone SMS capabilities seemed to provide satisfactory communication and standard phone accommodation could be dropped from performance plan.
- Subject's comfort level with single switch scanning became the driving factor in choosing it over eyegaze technology as the subject's primary workstation access method. Though it had not seen a software update in years, Words+ EZ Keys was still the most efficient and customizable product available for single switch scanning. Compatibility with Windows 7 was confirmed.
- AbleNet's SCATIR switch was chosen for EZ Keys menu selections. Mounting scheme included placing the infrared sensor on an extended microphone gooseneck, allowing it to be positioned about 1 cm from the subject's left cheek. Optimum switch placement was aimed at maximum sensitivity for rapid triggering with minimum fatigue.
- Switch under workstation desk for toggling the speech recognition microphone was retrofitted to toggle SCATIR switch on/off

with wheelchair's power leg rests.

Phase 4 – Technology intervention. The following solutions were implemented:

- Alexicom AAC app installed on Android mobile device with cloud backup of custom phrase categories.
- Introduced Words+ EZ Keys with AbleNet's SCATIR switch and gooseneck mount as primary workstation access method.
- Adapted switch setup for wheelchair leg rests to toggle SCATIR switch on/off.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses on Table 5.

Accommodation (2016): Combined Single Switch Scanning and Eyegaze

Phase 1 – Performance evaluation. Evaluation criteria showed strong efficacy for both desktop and mobile accommodations (1, 2). While 12.9 words-per-minute is an outstanding text entry rate for single-switch scanning, it was still a productivity limitation in view of the subject's high demand for written documentation. Eyegaze with switch selection could enable faster text entry. Likewise, any system enhancements for improving text entry rate on the mobile device was also considered. The growing demand for creating and delivering multimedia presentations should be added to performance goals (3).

Phase 2 – Recognition of obstacles and opportunities. Two disadvantages of eyegaze technology are 1) not integrating well with mainstream computing applications; and 2) fatigue associated with eye strain. Implementing eyegaze as a redundant, complementary input method alongside the single switch scanning mitigated these limitations. System configuration needed to allow the subject to easily, and independently, switch between the two access methods. Clearest opportunity for improving input rate on mobile device was to work with the ClickToPhone developer to increase the maximum scanning rate. Software solutions needed identified for meeting new performance expectation of creating and delivering presentations.

Table 6
2016 Functional Goals Matrix for Combined Single Switch Scanning and Eyegaze

Functional Goals		1. Compose written text and manage information via Microsoft Office software;	2. Manage information and communicate on the go	3. Create and deliver multimedia presentations
Evaluation Criteria	**(Sp)eed**	Single switch scanning, 12.9 wpm (+eyegaze, pending)	Single switch scanning, 5.7 wpm	
	(A)ccuracy	High	High	**(High)**
	(F)atigue	Low	Medium	**(Low)**
	(L)oad	Medium	Low	**(Low)**
	(C)onsistency	High	High	**(High)**
	(S)atisfaction	High	High	**(High)**

Phase 3 – Assessment of solutions. The following issues were addressed:

- Subject's workstation consisted of a Microsoft Surface Pro 3 and docking station with two 19-inch displays attached. Displays mounted vertically to accommodate subject's inability to turn his head side to side. Eyegaze control was targeted on the top display to accommodate subject's supine resting position.
- Optimum eyegaze calibration statistics were sought through adjusting position of camera, tilt of display, and angle of subject's eyeglasses.
- Determined optimum text entry rate would be reached through switch selecting eyegaze targets.
- ClickToPhone developer agreed to increase mobile device scanning rate from 200ms to 100ms. Soft start feature would also be added to enable better selection of first menu item in each row.
- In addition to Microsoft PowerPoint, Camtasia software was identified for creating multimedia presentations. Camtasia recording mode is compatible with Words+ EZ Keys control. All In One Remote Server (Windows) and All In One (AOI) Remote app (Android) were selected to allow subject to control PowerPoint presentations on the Surface Pro 3 remotely from his Android smartphone when away from docked workstation.

Phase 4 – Technology intervention. The following solutions were implemented:

- Introduced EyeTech TM5 eyegaze system. Mounted camera on top of lower display, with eyegaze control aimed at top display.
- Implemented trial with ClickToPhone scanning speed at 100ms and softstart feature at 125ms.
- Introduced Camtasia for multimedia development, and All In One Remote and Server for independently conducting presentations.

Phase 5 – Revise plan. Changes resulting from this technology accommodation are indicated within parentheses on Table 6.

Discussion

The six ATOP cycles outlined in this paper clearly show evolving obstacles and opportunities resulting from changes in technologies, user abilities, and user expectations. It is interesting to note how many accommodations requiring an AT solution 20 years ago now have the needed functionality built into mainstream technology. The fundamental assessment process remains the same, but today many tools are immediately available and bundled in standard operating systems. For example, adjustable keyboarding delays and sequencing; mouse speed, sensitivity, pointer size and shape; screen magnification and text-to-speech; speech recognition and universal switch access are among the standard features of most mainstream technologies.

It is important to appreciate that the focus of each technology intervention is to maximize productivity. The evaluation cycle therefore would be beneficial to any computing technology user, with or without a disability, wishing to maximize their productivity. For example, enormous productivity gains can be realized through combined keyboard/speech recognition input. How this is implemented, however, depends on the functional goals and abilities of the user. The overarching principal should be to maximize the user's strengths and minimize their weaknesses, and to focus productivity on intentional goals.

To illustrate this principle, one can look at the initial (1989) Functional Goals Matrix (shown in Table 1). The subject's initial performance plan included four functional goals associated with his employment expectations. The subject's text input rate is arguably the most significant measure and we have extracted these data points to create Table 7. In

Table 7
Text Entry Rates, 1989 – 2016

Intervention		**Rate (wpm)**	**Fatigue**	**Input Type**
1989	Pre	20	Medium	One-handed typing
	Post	20	Medium	One-handed typing
1993	Pre	9	High	One-handed typing
	Post	18	Low	Discrete speech recognition
1999	Pre	18	Low	Discrete speech recognition
	Post	18	Low	Discrete speech recognition
2005	Pre	18	Low	Discrete speech recognition
	Post	35	Low	Continuous speech recognition
2013	Pre	35	Low	Continuous speech recognition
	Post	12.9	Low	Single switch scanning
2016	Pre	12.9	Low	Single switch scanning
	Post	*Pending*	Low	Scanning / Eyegaze

Table 7, changes in text entry rate can be seen; a result of buffering disease progression with AT. Major technology interventions occur in 1993 and again in 2013, both of which were necessitated by significant losses in the subject's physical abilities. Between these two turning points we can observe 20 years of increased productivity marked by negligible fatigue associated with text entry.

With speech recognition technology, the subject was able to realize steady increases in his text entry rate, culminating at 35 words-per-minute via continuous speech recognition. In other words, the net result was improved because technology gains steadily outpaced the subject's disease progression. Mainstream technology and AT advance in tandem, but always at different rates of change. How this impacts decision making about technology interventions is most evident in the subject's 1999 and 2005 accommodations (see Tables 3 & 4). While discrete speech recognition continued to show strong efficacy and high satisfaction for the subject, it was becoming an obsolete technology. By 1998, Dragon Dictate for Windows was no longer actively supported by the developer. Advances in the Windows operating system posed a significant compatibility threat to this discrete speech recognition software that was no longer receiving upgrades. Furthermore, it would not be until 2005 that continuous speech recognition could offer the recognition accuracy and advanced customization features needed to accommodate the subject's compromised pulmonary condition.

The subject's text entry rate peaked in 2013 at 35 wpm. As noted previously, it was at this juncture that the subject experienced a catastrophic health event resulting in loss of speech due to a tracheotomy. Fortunately, the text entry method already being exercised with the subject's mobile devices offered a smooth transition to workstation access via single switch scanning. Though the subject was able to use single switch scanning with good efficacy, its maximum rate of input after two years only reached 12.9 wpm - a 63% drop from that reached with continuous speech recognition. Despite this setback to text production, the single switch scanning implementation offered low fatigue and eventually high satisfaction.

The final evaluation to date occurred in 2016, and reflects a return to ATOP's proactive intervention approach. At this point, a combined scanning/eyegaze access method was introduced. A key component to this system was the user being able to readily and independently switch between the two modes of input. Text entry speeds for eyegaze are typically constrained by dwell time (i.e. the time required to gaze at a target before it is selected). For example, a 1 second dwell time would result in an upper limit typing speed of 12 wpm (Majaranta, MacKenzie, Aula, & Räihä, 2006). Thus, because the subject had the option to trigger eyegaze selections with his switch of choice, it was hypothesized that the reduced selection time (between 100ms and 200ms per letter) would lead to a typing speed over 20 wpm. It was further hypothesized that the shared load with single-switch scanning would also mitigate issues associated with eye strain and eyegaze inefficiencies with mainstream technologies.

Outcomes and Benefits

When we consider the outcomes and benefits of continuous and rigorous technology interventions that are aimed at maximizing productivity, we must understand the benefits of discovered best practice. Best practice discovery is a user-centered process that involves a technology configuration that is able to adapt to the user while the user is also adapting to the system. The aim is productivity. The means are many and varied. For example, the subject of our study began with access to both Windows and Apple workstations. Keyboard accommodations were made alongside integration of speech recognition. And later, single-switch scanning was combined with eyegaze control. These redundancies illustrate the benefit of allowing best practices to be discovered by the user, instead of being a hypothesis of the AT practitioner. Note, in addition to discovery of best practices, having redundancies built into the system offers off-loading in response to fatigue and increased system reliability. Specifically, the study subject's use of EMG switch technology is a good example (see Tinkertron Dual EMG switch description, included in the section on 2005 accommodations). The subject developed skill sets for both primary and secondary placements of the EMG electrode. Primary placement was above the left pectoral muscle, which offered high accuracy

Table 8
Task / Load & Electrode Placement

Task	**EMG Electrode placements**	
	Primary	**Secondary**
Power wheelchair navigation	*Heavy*	*Light*
Smartphone text entry	*Light*	*Heavy*

(trigger timing) and moderate fatigue (repetitive triggering). Secondary placement was on the left cheek, which offered less accuracy due to inadvertent triggering. Virtually no fatigue was associated with cheek-muscle triggering. Using these modes, the discovered best practice for EMG control was gradually established and is conveyed in Table 8. While the primary placement is ideal for heavy navigational use, the secondary placement still provides a backup in cases of muscle strain or injury. When the subject was away from his computer workstation, increased reliance of mobile device text entry could be accommodated through the secondary placement. This built-in redundancy results in healthier and more reliable use of the technology.

Ideally, when there are multiple access methods, there should be customization options that the user can modify independently. An example of this is single switch scanning parameters (e.g. keyboard layouts, scanning and pause rates, scanning patterns, etc.). Within this philosophy, user training includes or even begins with accessing the system's customization features.

Timely, user-driven adjustments can lead to outcomes that promote technology adoption. In our case study, keyboard and trackball use supplemented speech recognition. As a result of disease progression, however, speech recognition gradually replaced both for text entry and mouse control. But this happened naturally, with the user's abilities and preferences driving the change. Results are pending with regard to the subject's combined scanning/eyegaze technology accommodation, but the expected outcome should reveal when and for what purposes each method is most efficient for the subject.

User self-determination is an underlying principal of this cyclical evaluation process. This is not only true philosophically, but pragmatically: the efforts to provide redundant access methods create a mechanism that facilitates self-determination. Thus, it is reasonable to expect more positive outcomes to be derived from the enhanced self-determination being exercised (Wehmeyer, 2004).

Efficacy of the ATOP model should also be considered in terms of the culminating outcomes of the cycle over time. In the case study presented, these long-term benefits included:

1. A user mindset of continuous improvement;
2. A habit of proactive change; and
3. A continuum of optimal productivity.

Conclusion

Assistive technology can be life-changing technology. The case study presented represents one of the most challenging scenarios in the practice of AT assessment and intervention. Severe and progressing limitations coupled with high performance expectations require the most AT can give. Change, both positive and negative, is a parameter that touches every aspect of life.

Through this case study, the Assistive Technology Optimization Process showed itself to be the needed scaffolding to track, plan, and integrate changing technology to meet changing expectations in the face of changing capabilities. As noted in the Discussion section, several trends can be observed within the course of the study where technology benefits outpaced disease progression. For the study subject, his employer, and the field of assistive technology that is success!

Declarations

The content is solely the responsibility of the author and does not necessarily represent the official views of ATIA. No financial disclosures and no non-financial disclosures were reported by the author of this paper.

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