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Preface

The Center on Disabilities at California State University, Northridge is proud to welcome you to the second issue of the Journal on Technology and Persons with Disabilities. These published proceedings from the Annual International Technology and Persons with Disabilities Conference, represents submissions from the Science/Research Track presented at the 29th event held March 17-22, 2014.

The Center on Disabilities at CSUN has been recognized for sponsoring an event that for almost three decades highlights the possibilities and realities which facilitate the full inclusion of individuals with disabilities. Over the years it has truly become a major global platform for meeting and exchanging ideas, now attracting more than 4,000 participants annually.

We were once again pleased that the second Call for Papers for the Science/Research Track in 2014 drew a large response of more than 75 leading researchers and academics. A panel of more than 30 highly-qualified peers from around the world formed the program committee and was chaired by Dr. Klaus Miesenberger. The expertise of the program committee ensured that each contribution was expertly and equitably reviewed and only those submissions of the highest caliber were accepted for presentation and publication.

Demonstrating a clear focus on scientific excellence, this second Journal and the Science/Research Track at the conference, show how CSUN is committed to involve scientific researchers from all over the world to fulfill its mission as a platform of exchange with full cooperation and support of all stakeholders.

We would like to thank the authors, the Science/Research Track review panel, the Center on Disabilities team at CSUN, and the editorial staff for their professional support. As always, we are grateful for and appreciate the many participants and partners who have contributed to the Annual International Technology and Persons with Disabilities Conference throughout the years.

Welcome once again to our second publication of "The Journal on Technology and Persons with Disabilities." We hope you will continue to enjoy our endeavors and with your continued support of the Center on Disabilities at CSUN and the annual conference we can all work together in our mission of "changing the world for people with disabilities."

Sandy Plotin
Managing Director, Center on Disabilities

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A Research Agenda for Assistive Technology Used by Students with Visual Impairments

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Abstract

Assistive technology for individuals with visual impairments has long provided the equalizing effect for which it was intended. Due to federal mandates for the use of scientifically-based interventions for students with disabilities, the question of whether specific assistive technologies are effective in learning has surfaced. The purpose of this research synthesis was to determine the status of scientifically-based interventions related to assistive technology for students with visual impairments. Using a rigorous methodology to locate and analyze the research literature, the synthesis found 397 articles between 1965 and May 2013 that focused on assistive technology within the educational framework. These articles were organized into nine distinct categories. Three categories focus on "research" considered rigorous by the What Works Clearinghouse and the CEC Division for Research standards. Further analysis found that 98 articles fell into these three categories with the majority being descriptive, correlational, and quasi-experimental (N=66, 67%). A subset of articles included single-subject (N=4) and qualitative studies (N=24, 25%). Four articles that met the "golden standard" of experimental research as determined by the What Works Clearinghouse standards. There was evidence that the literature on AT for students with visual impairments is growing with many of these newer articles using stronger methodologies.

Keywords

Assistive technology, visual impairments, blindness, research

Introduction

Technology has always had great potential to have a positive impact. For students with disabilities, the use of specialized technologies has assisted these students participate in education at all levels. Specifically for students with visual impairments, assistive technology devices have provided students with a means to overcome the major obstacles attributed to their disability. Assistive technology (AT) provides equal access to information (in digital and print). It provides resources for independent travel in multiple environments. The examples are limitless. Thus, AT is the "great equalizer" for students with disabilities, especially those with visual impairments.

While there is great promise for AT within education, there is little known about the effectiveness of specific devices on learning. Until recently, most AT was deemed to be effective in educational environments based on either anecdotal evidence, solutions to obvious challenges (providing basic access), or because there were well-known practical applications such as enlarging images on a screen, reading email messages, and money management. Compounding the overall belief that technology improves education is the fact that technology innovation progresses at such a fast pace that is it quite challenging for researchers to test the effectiveness of the technologies in authentic, educational environments.

However, the overall philosophy towards educational research of assistive technology has radically changed recently. Because of the Individuals with Disabilities Improvement Act (P.L. 108-446), Individualized Education Program (IEP) teams are not only directed to discuss the needs for assistive technology devices (as mandated in the 1997 Amendments to IDEA), but to focus on using "research-based interventions" (§1411(e)(2)(C)(xi)). Since AT is considered part of a student's supplementary aids and services, then the inclusion of AT in a student's IEP must

be "based on peer-reviewed research to the extent practicable to be provided to the child" (§1414(b)(6)(B)). With federal law mandating the use of research to make decisions, the need for high-quality research on AT has been elevated.

Since AT cannot be deemed effective in education based solely on anecdotal evidence, the logical first step is to conduct a thorough synthesis of the research literature on educational impact of AT. Therefore, the goal of this research synthesis is to review the research literature on AT for students with visual impairments in order to fulfill the following objectives.

Methodology

This synthesis is a combination of a previously reported synthesis (Kelly and Smith) with a replication of research beyond the scope of the first study. The first study analyzed the research literature within this topic area from January 1965 through August 2009 (Kelly and Smith). The replication study of the original study reviewed the literature during the most recent time period of September 2009 through May 2013 (Smith and Kelly). The resulting "unified" research synthesis encompasses the entire time period from 1965 to May 2013 continuously.

As with any study, definitions of terms needed to be developed to narrow the scope of the research.

- Assistive technology (devices) are "any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" (IDEA, 1997, Sec. 602, 20 USC 1401, § 300.5).
- Classroom-based interventions: AT devices and software that provide students with visual impairments access to the common core curriculum and direct instruction in areas of the expanded core curriculum within school classrooms. The study included

studies that a) focused on the use of assistive technology for classroom-based education and b) included participants with blindness or low vision, regardless of co-occurring disabilities, between the ages of 3 and 21 years. The methodology excluded studies that focused on the use of AT “for orientation and mobility, independent living, or augmentative and alternative communication” (Kelly and Smith 39).

- Evidence-based research: the use of scientific research to establish best practices determine by an evaluation of the research.
- Scientific-based research: a research design that determines with the highest degree of probability whether an intervention was the factor that cause the effects. The study used the criteria used by the What Works Clearinghouse as well as the CEC Division for Research standards for scientific-based research across methodologies.
- Effective was defined as "having a positive impact on education" and effectiveness was defined as "the degree to which assistive technology had a positive impact on educational performance" (Kelly and Smith 74).

Five electronic databases were searched using the Boolean search method: EBSCO Education Full-Text, ERIC, Proquest Education Journals, Psychinfo, and Psych Articles. To define the search, the Boolean operator "and" was used while the "not" operator was used to exclude specific terms outside the purview of this study. Articles were retrieved if they included the search terms specified and none of the excluded terms. To see the entire list of terms, refer to Kelly and Smith and Smith and Kelly.

An ancestral search using the same parameters was conducted with the articles retrieved from the database search. A manual search for articles related to the assistive technology topic of interest was also implemented on The *Journal of Visual Impairments & Blindness* (*JVIB*),

Insight: Research and Practice in Visual Impairment and Blindness (named *AER Journal: Research and Practice in Visual Impairment and Blindness* prior to 2011), *the Journal of Blindness Innovation and Research (JBIR)* and *the British Journal of Visual Impairment*. The final step in the search process was to examine the reference lists of all articles. The reference lists were searched and additional articles that met the general search criteria were retrieved (Kelly and Smith 76).

All of the articles that were included through the exhaustive search procedures met the general criteria for inclusion in this analysis, and any that did not were excluded. The articles identified for inclusion in the study were classified into the same nine distinct categories Kelly and Smith (76) used to present the results of the synthesis of the AT literature from earlier time periods. Then the articles that utilized a research methodology (experimental, correlational, descriptive, single-subject, and qualitative) were categorized further using the Council for Exceptional Children Division for Research conceptual groupings for evidence-based research. For further clarification within the replication of this classification system, research articles were specifically identified along with any research articles that were single-subject design or case studies.

Discussion

The literature review synthesis of AT used for educational interventions for students with visual impairments encompassed 48 years. During that time, there were a total of 397 articles that met the criteria for inclusion for analysis. Between 1965-2009, there were 256 while the 2009-2013 time period had a total of 141 articles. As seen in Figure 1, there has been a gradual trend upward the majority of the articles published after 1980. Between 1980 and 1989, the average number of articles published on AT for students with visual impairments was 4 articles

per year. However, publication of AT articles began to trend upward beginning in 1990. In the 1990's, the average article published per year went up to 6.4 article per year with peaks of 10 (1990) and 12 (1999). The first decade in the new millennia (2000-2009) found a sharp increase with 15.1 articles being published per year with a peak of 27 in 2005. The trend continued upward after 2009 with the average between 2010-2012 being 39.3 articles per year with a peak of 61 in 2012. Please note that 2013 was purposely removed from this analysis as it was only part of a year, but it has 16 articles published in five months.

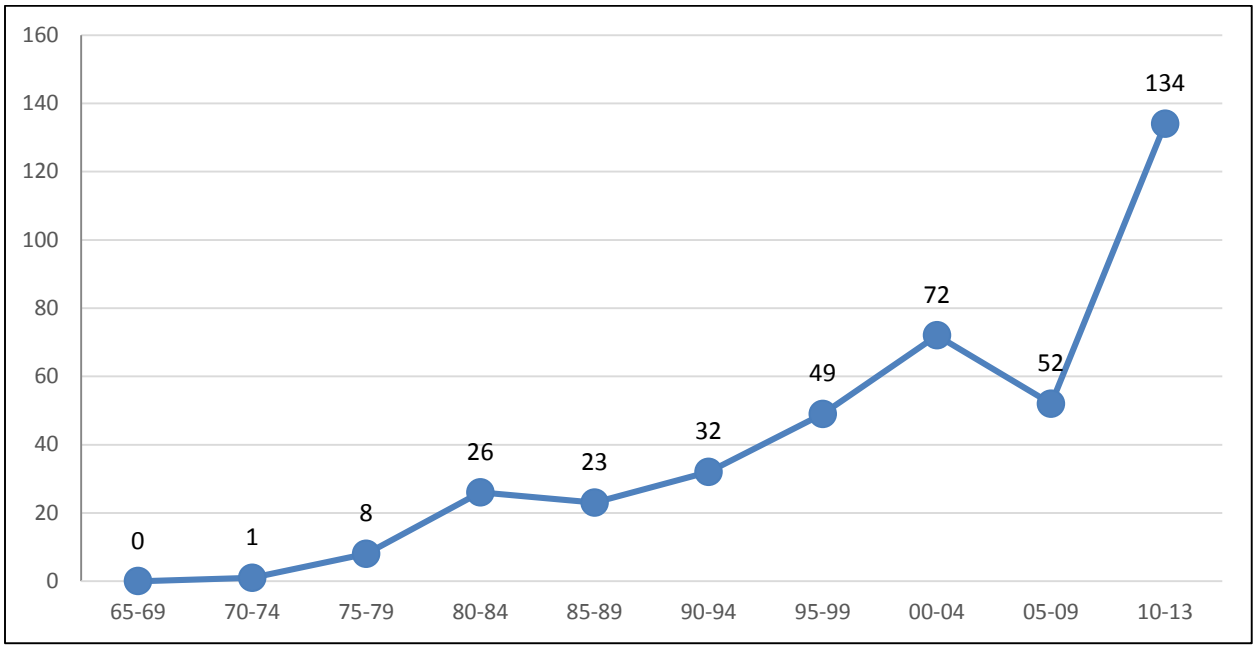

Fig. 1. Number of Articles on AT for Individuals with VI Published (5 year bands).

Closer scrutiny of the Figure 1 within the historical context related to technology provides insight into the reasons for these trends. Between 1965 and 1979, there were a total of eight articles published and four of those were in 1979 alone. The early 1980's saw the advent of the personal computer within education along with advancements in electronic devices. In the early 1990's, another spike in seen in articles published as computers became more sophisticated,

more inexpensive, and the internet was starting to blossom. Major strides in technology took place in the early 2000's with the invention of iOS products (the iPod was released in 2001), smartphones, tablets, Bluetooth-enabled devices, increased wireless internet connectivity, and overall increases in inexpensive technologies that are "universally-designed".

Deeper analysis of the 397 articles finds some major themes regarding the type of research methodology utilized and the rigor of the research. The 397 articles were separated into nine distinct categories (see Kelly and Smith; Smith and Kelly). Of these nine categories, only six used a methodology that met the standards for evidence-based research established by the CEC Division for Research. Due to space limitations, these three categories will be synthesized. Within these three **research** categories, there were a total of 98 articles from 1965 to May 2013 (25%). For a full listing and analysis of all the categories, see Kelly & Smith and Smith & Kelly.

Qualitative Research Design

Qualitative research attempts to gather a deep understanding of behavior and determine the undergirding reasons for the behavior (Shank 12). In these reviews, 24 articles (6% overall, 25% of all **research** articles) were categorized as qualitative research, including multiple case studies. There was a wide range of topics and distinct methodologies used in these 24 studies. Interventions included technology such as audio recordings, vision aids, videophones, screen readers, magnifiers, iPads, and other high-tech to low-tech devices. The types of studies and the participants varied across the studies, thus each study must be reviewed independently to determine if the intervention may have potential for positive educational intervention for students

Quasi-experimental, Correlational, or Single-subject Designs

Twenty-four articles were categorized as having a research design or method that did not include an intervention, control group, and comparison group. The majority of these articles were

correlational studies that used large data sets (such as the NLST2) or quasi-experimental studies that did not follow the rigorous standards of the What Works Clearinghouse. Five articles (1.2% of all articles or 5% of all **research** articles) were classified as single-subject research studies. The single-subject research included a research design or method that demonstrated experimental control within a single participant or small group of participants (Kennedy 19). For low incidence populations such as visual impairments, single-subject designed studies are a mechanism to complete rigorous studies on individual or small groups of students with similar visual impairments. The five studies used different types of single-subject designs, but all consistently focused on the impact of assistive technology.

Experimental Group Design

Four of the 98 research studies (1.5% of all articles or 4% of all **research** articles) used experimental design as defined by the What Works Clearinghouse to research the effectiveness of using AT. There were only four studies identified by the analysis that included a research design with sufficient data to determine the effectiveness of an intervention with an intervention, control group, and comparison group (LaGrow; Koenig & Ashcroft; Kapperman, Sticken, & Smith, "The Effectiveness of the Nemeth Code Tutorial" and "A Follow-Up Study"). LaGrow examined how reading rates were affected by the use of a video magnifier. Reading rates were positively impacted when a video magnifier was used. Koenig and Ashcroft assessed how writing rates and accuracy were affected by the use of an electronic Perkins Brailler. There were no significant differences when the electronic and regular Perkins Brailler was used.

Kapperman et al. ("A Follow-Up Study") was a replication, follow-up, and continuation of the original study by Kapperman et al. ("The Effectiveness of the Nemeth Code") that evaluated the long-term effectiveness of the intervention. In both instances by Kapperman et al.,

the studies evaluated the effectiveness of a tutorial installed on a BrailleNote for learning the Nemeth Code of braille mathematics notation. Each of the two Kapperman studies showed that treatment groups had significantly greater growth in both math reading and math writing than the control group. These two experimental studies identified by this exhaustive review of the literature documented the effectiveness of assistive technology designed specifically to help braille students learn Nemeth math symbols.

Conclusions

This research synthesis set out to determine a baseline of understanding of scientifically-based research on AT for students with visual impairments within the educational context. The synthesis located 397 articles that were published between 1965 and May 2013. Of those 397 articles, only 98 were determined to fall within a "research category" (single-subject, qualitative, descriptive, correlational, quasi-experimental, or experimental). Of the remaining 299 articles, 215 (72%) were articles that did not have a research design or method (product reviews, theoretical articles) and the remaining 82 (28%) had validity issues (insufficient data reported, issues with participants, etc.).

While there were only four articles that met the highly rigorous standards for experimental design as defined by the What Works Clearinghouse, this research did shed light upon some positive movements within the field. First, the sheer number of published articles has grown over time even with the challenges of conducting AT research. Beyond the increase of numbers of articles published, types of research that uses research methodologies is increasing. The use of single-subject designs and rigorous qualitative methods are slowly building a foundation of research to build upon. As the field continues to evolve, it can be hoped that

researchers, practitioners, and AT developers will work more collaboratively to develop and research AT innovations for students with visual impairments.

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Hearing Aid Compatibility of Cellphones: Results from a National Survey

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Abstract

Decades of technological development have not guaranteed compatibility between cellphones and hearing aids. Federal regulations have attempted to reduce the variability in interoperability between these two types of devices by requiring cellphone handset manufacturers and wireless service providers to offer a certain percentage of their devices with sufficiently reduced electromagnetic radiation (meeting American National Standards Institute's M3 and T3 ratings for acoustic and inductive coupling) so that they may be operable with hearing aids. These hearing aid compatibility (HAC) regulations also require labeling on packaging and information on the websites of wireless vendors to help hearing aid users identify compatible phones. This paper presents findings from a national survey research project conducted in 2013 by the Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC) to understand the current experiences of users of hearing aids and cochlear implants with regard to compatibility of their mobile wireless phones with their hearing technology. Data are analyzed for all respondents who use hearing aid or cochlear implant technology, as well as by age and type of aids (behind-ear, in-ear, bone-anchored, cochlear implant).

Keywords

Hearing aid, compatibility, cellphone, mobile phone

Introduction

Since 2005 federal regulations have required mobile phone handset manufacturers and wireless service providers to offer a certain percentage of their devices with sufficiently reduced levels of electromagnetic radiation (meeting American National Standards Institute's M3 and T3 ratings for acoustic and inductive coupling) so that they may be generate less interference in order to be operable with hearing aids. Further, these regulations require labeling on the exterior of cellphone packaging, printed material inside the packaging, and information on the websites of wireless vendors. The goal of these regulations is to ensure that hearing aid compatible cellphones are readily available to consumers, and that sufficient information is provided to make these compatible phones easy to find.

This article presents findings from the Hearing Aid Compatibility (HAC) Survey, a national survey conducted by the Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC). Response data are analyzed to address several core questions related to the experience of finding, purchasing and using a cellphone by people who use hearing technology. Analysis also includes respondents' knowledge of the M and T ratings of their cellphones and their hearing aids, which is critical to choosing a compatible cellphone. Data are analyzed for all respondents who use hearing aids or cochlear implants. Additionally, the data are analyzed by age and type of hearing technology used. This analysis helps assess the impact of federal HAC regulations.

Scope of the Issue

Estimates of the number of people living with hearing loss and the number who own hearing aids vary based on whether hearing loss is self-reported or diagnosed by a physician. Kochkin (2009) estimated this group at 11.3% of the population (34.25 million people). Ikeda,

Murray, and Salomon (2008) estimated that 6%-7% of the U.S. population, or approximately 20 million people, are hearing impaired.

Kochkin (2009) further estimated that approximately 24.6% of the estimated 34.25 million Americans with functional hearing loss have hearing aids (approximately 8.43 million people). Applying the same percentage to Ikeda, Murray and Salomon's (2008) estimate of the hearing impaired population in the United States yields approximately 5.6 million Americans who own hearing aids. This range of 5.6 to 8.4 million people reflects a reasonable growth rate from the estimated 4.2 million hearing aid users in the U.S. in 1994 (Russell, Hendershot, LeClere, & Howie, 1997), given growth of the general population, age composition changes, and possible change in the rate of use of hearing aids. The ongoing aging of the U.S. population since 2009 suggests that the number of hearing aid users in the current period could be higher still.

In the meantime, mobile wireless phone usage has also increased considerably. Among American adults, cellphone ownership rose from 82% in 2009 to 91% in 2013 (Brenner 2013). Though cellphone ownership generally is lower for older individuals, the Pew estimates that 76% of seniors age 65 and older owned cellphones in 2013, up from 57% in 2010 (Lenhart 2010). Survey research conducted by the Wireless RERC indicates that 84% of individuals who are hard of hearing use either a regular cellphone or a smartphone (Morris, et al. 2013).

Hearing Aid Compatibility Regulations

The Federal Communications Commission (FCC) established benchmarks for 2005, 2006, 2008, 2009, 2010, and 2011 to increase the number of hearing aid-compatible digital wireless phones complying with the ANSI standard for both acoustic and inductive coupling (Federal Communications Commission).

There are two ratings systems for reporting the electromagnetic interference generated by a cellphone or hearing aid. First, all digital handsets are rated for their ability to reduce interference with hearing aids operating in acoustic (or microphone) mode – from M1 to M4, with M4 being the best. They are also rated for their ability to operate with hearing aids that contain a telecoil (a tightly wrapped piece of wire that converts sounds into electromagnetic signals) and operate in inductive coupling mode. Ratings for inductive coupling range from T1 to T4. The FCC considers mobile handsets to be hearing aid compatible if they are rated at least M3 for acoustic coupling and at least T3 for inductive coupling.

There are two air interfaces used for cellphone transmission in the United States: Global System for Mobile (GSM) used by AT&T and T-Mobile) and Code Division Multiple Access (CDMA) used by Verizon Wireless and Sprint Nextel). For acoustic coupling, each service provider (nationwide and non-nationwide) is required to meet at least an M3 rating for 50% or 10 of the handset models it offers to consumers, whichever is less, per digital air interface. For inductive coupling, each service provider is required to meet at least a T3 rating for one-third or 10 of the handset models it offers to consumers, whichever is less. Manufacturer requirements for providing minimum numbers of T3 and M3 rated mobile phones are somewhat different but intended to have the same effect. See the FCC's Guide to Hearing Aid Compatibility of Telephones for additional details (FCC).

These benchmarks also require manufacturers to clearly label the packaging of their hearing aid compatible telephones with M and T ratings, and provide explanation of the FCC requirements on package inserts. Service providers are required to provide a means for consumers to test hearing aid-compatible handset models in their retail stores. Beginning on

January 15, 2009, both manufacturers and service providers were required to post information about their hearing aid-compatible handset offerings on their Web sites.

Background to the Survey on Hearing Aid Compatibility Survey

The Hearing Aid Compatibility (HAC) Survey is a multi-year survey on the cellphone shopping and use experiences of people who use hearing technology, conducted by the Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC), which is funded by the U.S. Department of Education's National Institute on Disability and Rehabilitation Research (NIDRR). The survey was conducted annually from 2006 to 2010, and again in 2013. Data analysis in this article focuses exclusively on the most recent survey conducted from April 8, 2013 to December 20, 2013.

Of the 656 people who completed the 2013 survey, 567 reported using hearing aids or cochlear implants. Convenience sampling methods were used to draw a sample of adults over age 18. The protocol for this study was approved by the local institutional review committee at the grant recipient's home institution, as well as the authors' home institution. Minors under age 18 were not recruited due to concerns over conducting research with vulnerable populations. The questionnaire was made available in English and Spanish.

Participants were recruited through the Wireless RERC's Consumer Advisory Network (CAN), a nationwide network of consumers with disabilities. The research team also engaged its Internet and social media assets, including Yahoo! Groups, the Wireless RERC website, and its Twitter, Facebook and LinkedIn accounts. Contacts among organizations focused on communications technology, hearing loss and aging at the national, state and local levels were engaged to disseminate the invitation to participate to their networks of people with disabilities.

Females represent 65% of respondents who use any sort of hearing technology. The relatively high mean age of 58 years (with a median age of 60 and a standard deviation of 15.9 years) for these respondents reflects in part the decline in hearing associated with aging, and in part the exclusion of minors under the age of 18. More than half of the respondents who used some kind of hearing technology, used behind-the-ear aids (60%), with another 11% using in-the-ear aids. More than a quarter (27%) had cochlear implants. Just over 1% of respondents had bone anchored hearing aids.

Discussion

Data analysis focuses on the impact of age and type of hearing technology used as independent variables possibly impacting the behaviors and experiences of respondents. Elsewhere we have shown that age has a stronger effect on cellphone use than other demographic variables like income (Morris, et al. 2014; Wireless RERC 2013). That research supports observations that young people are earlier and more enthusiastic adopters of technology than older people. The type of hearing technology used by respondents might also impact levels of interference and sound quality. Respondents with devices that are more exposed to the cellphone, like behind-the-ear aids, might be more likely to experience interference (American Speech Hearing Association; Federal Communications Commission).

Respondents of all age ranges and types of hearing technologies reported high rates of cellphone ownership, with no discernible impact of either variable on ownership/use (Table 1).

Table 1. Do you currently own or use a cellphone?

(By age and hearing technology used)

Age	**% Yes**
18-29	96%
30-49	88%
50-64	90%
65 or older	89%
Overall	90%

Hearing Technology	**% Yes**
Behind ear aids	88%
In the ear aids	96%
Bone anchored hearing aids	100%
Cochlear implant	89%
Overall	90%

A strong majority (81%) of all respondents who use hearing technology and own a cellphone reported being able to use their current cellphones while using their hearing technology (Table 2). Although only 29% of respondents with bone anchored hearing aids said they could use their cellphones with their technology, the number of these respondents was very low (7 total). Consequently, it is difficult to make generalizations about this group. Behind the ear aids are most exposed to interference from other devices. Yet, users of this hearing aid design reported some of the highest rates of compatibility with their cellphones (82%).

Table 2. Can you use your current cellphone while using your hearing aid, cochlear implant or other hearing tech? (By age and type of hearing technology)

Age	**% Yes**
18-29	77%
30-49	82%
50-64	82%
65 or older	81%
Overall	81%

Hearing Technology	**% Yes**
Behind ear aids	82%
In the ear aids	78%
Bone anchored hearing aids	29%
Cochlear implant	84%
Overall	81%

Despite the relatively high rates of reported hearing aid-cellphone compatibility, a substantial percentage (19% across all respondents) said they were unable to use their cellphone with their aids. This suggests that HAC regulations still fall short in promoting compatibility of hearing aids and cellphones. This is reflected in low levels of satisfaction with cellphone sound quality (Table 3). Fewer than half (46%) of all respondents reported that they were satisfied or very satisfied with the sound quality of their cellphones. Notably, the youngest age group was least likely than the other age groups to say they were satisfied or very satisfied with their

cellphones. As expected, those with behind-the-ear aids were least likely to report being either satisfied or very satisfied with their cellphones.

Table 3. How SATISFIED are you with your cellphone? Clarity is good. You can hear and understand the other person. Volume is loud enough. (By age and hearing technology)*

Age	**% Satisfied or Very Satisfied**
18-29	35%
30-49	49%
50-64	49%
65 or older	43%
Overall	46%

Hearing Technology	**% Satisfied or Very Satisfied**
Behind ear aids	42%
In the ear aids	54%
Bone anchored hearing aids	50%
Cochlear implant	51%
Overall	46%

Low rates of satisfaction with cellphone sound quality are reflected in low percentages of respondents who said that it was easy or very easy to find a cellphone that worked with their hearing technology (Table 4). Only a quarter of all respondents (25%) reported the task as being easy or very easy. As expected, younger respondents more frequently reported that their search was easy or very easy compared to older respondents. There was little variation in ease of

finding a compatible cellphone among users of different hearing technologies. The substantially higher rate for respondents with bone-anchored hearing aids (33%), is unreliable because of the low number of respondents in this group.

Table 4. How EASY was it to find a cell phone that works with your hearing aid, cochlear implant or other hearing tech? (By age and hearing technology)

Age	**% Easy or Very Easy**
18-29	32%
30-49	27%
50-64	24%
65 or older	24%
Overall	25%

Hearing technology	**% Easy or Very Easy**
Behind ear aids	23%
In the ear aids	29%
Bone anchored hearing aids	50%
Cochlear implant	27%
Overall	25%

Knowledge of Interference Ratings, Sources of Information

A key part of federal HAC regulations is the requirement to include ratings for resistance to electromagnetic interference on the outside of the packaging and in the materials inside the packages of compatible handsets. Wireless companies must also include HAC information on their commercial websites. Since not all handsets are required to be compatible, providing multiple methods of identifying compatible phones could in theory help consumers shop for the phone they need. Also, cellphones may have both microphone (M) and telecoil (T) ratings. Therefore, it is especially important to make the different ratings easy to find and understand.

However, low percentages of respondents (Table 5) knew the M and T ratings for their hearing aids (29% overall) and cellphones (39% overall). These results suggest that the HAC regulations might have generated some success in informing hearing aid users, because knowledge of M and T ratings is substantially higher for cellphones than for hearing aids. The HAC regulations do not apply to hearing aids, which are regulated under the U.S. Food and Drug Administration. Therefore, their impact on educating the public about hearing aid ratings is expected to be less than about cellphones.

Table 5. Do you know the M and T ratings of your hearing aid and cellphone?

(By age and hearing technology)

Age	**% Yes for Hearing Aid**	**% Yes for Cellphone**
18-29	20%	36%
30-49	33%	39%
50-64	33%	44%
65 or older	24%	35%
Overall	29%	39%

Hearing Technology (% yes)	**% Yes for Hearing Aid**	**% Yes for Cellphone**
Behind ear aids	33%	37%
In the ear aids	13%	16%
Bone anchored hearing aids	14%	29%
Cochlear implant	26%	55%
Overall	29%	39%

Online research was the most commonly used source of information on cellphones by respondents who use hearing technology (Table 6). Sales personnel and recommendations from friends, family and others were about equally consulted. The package label was the least common source of information overall.

Table 6. How did you find your cellphone? Check all that apply. (By age)

Age	**Recommendation**	**Package label**	**Sales person**	**Online research**	**Other**
18-29	19%	12%	31%	19%	31%
30-49	20%	21%	9%	34%	21%
50-64	24%	13%	19%	30%	33%
65 or older	24%	11%	27%	26%	26%
Overall	23%	14%	21%	29%	28%

Respondents reported low rates of satisfaction with the HAC information they received from websites of service providers and manufacturers, cellphone packaging, or retail staff (Table 7). Only 25% of those who consulted websites or packaging were satisfied or very satisfied with the HAC information provided; and only 29% of those who consulted retail staff were satisfied or very satisfied.

Table 7. How SATISFIED are you with HAC information received from websites and packaging, and retail staff? (% satisfied or very satisfied)

Method for Receiving Information	**% Satisfied or Very Satisfied**
Websites and packaging by service providers and manufacturers*	25%
Retail staff**	29%

* Respondents who own a cellphone and use hearing technology, AND who researched online or used package information to find their cellphone.

** Respondents who own a cellphone and use hearing technology, AND who consulted a salesperson to find their cellphone.

Conclusions

Hearing aid compatibility regulations implemented by the FCC are intended to ensure that compatible cellphones are readily available on the market and that HAC information can be found on the websites of cellphone manufacturers and service providers. Yet, many consumers who use hearing aid technology report low levels of satisfaction with the sound quality of their devices and high levels of difficulty finding compatible phones. Furthermore, strong majorities of consumers who use hearing aid technology report low levels of satisfaction with the HAC information they received from cellphone packaging, industry websites, and retail personnel.

These low levels of satisfaction and high degrees of difficulty finding compatible cellphones result in part from complex interactions between cellphones and hearing aids, as well as from social dynamics related to how people learn about and use technology. Hearing aids and cellphones are distinct pieces of electronic equipment designed for specific tasks and uses. Electromagnetic interference between these devices can be highly variable, and dependent on how specific models of each device interact. The wireless industry, FCC, advocates and technology specialists all advise consumers to “try before you buy.” HAC regulations likely have helped make compatible cellphones more available and easier to find. However, real challenges in these areas remain.

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Wireless Technology Uses and Activities by People with Disabilities

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Abstract

Access to and use of wireless consumer technology (e.g., mobile devices like cellphones, smartphones, tablets, software and services) has become ever more critical to social and economic participation, particularly for people with disabilities. Rates of *ownership* of wireless devices among people with disabilities have risen considerably in recent years, narrowing substantially the gap in ownership rates with the general population. But what do people with disabilities *actually do* with their wireless devices? This article presents findings from the Survey of User Needs (SUN), a national survey on use and usability of mainstream wireless technology by people with disabilities. Data from the most recent SUN conducted in 2012-2013 will be presented, focusing on the wireless activities of people with disabilities. Data on the following uses will be analyzed: accessing the internet, text messaging, emailing, downloading and using mobile apps, social networking, using GPS and location based services. Results show that as a group, people with disabilities and use wireless services at rates similar to the general population. However, substantial variation exists in use of some services between disability types, mainly those with hearing, speech or vision loss.

Keywords

Wireless, use, accessibility, cellphone, smartphone, tablet

Introduction

Access and use of mainstream wireless technology is increasingly important to full social and economic participation. More than 326 million wireless service subscriber connections in the United States (CTIA-The Wireless Association). The Pew Internet and American Life Project reports a steadily rising rate of cellphone ownership among American adults in recent years, from 73% in 2006 to 91% in 2013, with current smartphone ownership at 56%, and tablet computer ownership at 34% of American adults (Pew Research Center, January 2014).

Fortunately, people with disabilities seem to have access to wireless technology at rates that are only somewhat lower than or equal to those for the general population. Survey research data collected by the Rehabilitation Engineering Research Center for Wireless Technologies show that 84% of people with disabilities own or use a wireless device such as a cellphone or smartphone. Including tablet owners raises wireless device ownership to 91% (Wireless RERC, July 2013). Smartphone ownership and tablet ownership were reported by 54% and 31% of respondents, respectively (Morris, et al., 2014). These figures are comparable to those for the general population.

Overall ownership rates of mobile wireless devices, particularly “smart devices” (smartphones and tablets) provide a fundamental indicator of access to wireless technology. However, understanding *what people with disabilities do with their devices* sheds light on whether they are taking advantage of the rapidly expanding potential of their technology. Additionally, analysis by disability type (blindness, deafness, difficulty speaking, etc.) can provide insight into the specific needs of each group and perhaps identify opportunities for serving them better.

This article presents findings from the Survey of User Needs (SUN), a multi-year survey on use of mainstream wireless technology by people with disabilities. Data are presented on the activities which people with disabilities perform on their wireless devices, including voice calling, text messaging, emailing, using the internet, downloading and using mobile apps, social networking, using GPS, listening to music and participating in video calls/chat.

Originally launched in 2002, the SUN has been updated 3 times to keep up with the rapid pace of technological change. The results presented in this paper focus on the fourth and most recent version (SUN 4) launched in the fall of 2012. Participants were recruited across the eight general disability categories listed in Table 1. These are based on the categories used by the U.S. Census Bureau's American Community Survey (ACS), augmented with categories adapted from the National Health Interview Survey (NHIS) conducted by the Centers for Disease Control and Prevention (CDC). The SUN questionnaire also permits finer segmentation of respondents by disability sub-types (e.g., blindness and low vision as subtypes of difficulty seeing; deaf and hard of hearing as subtypes of difficulty hearing).

Table 1. Survey of User Needs: Sample by Disability Type

Disability Type	**Respondents (%)***
Difficulty walking or climbing stairs	39%
Difficulty hearing	36%
- Hard of hearing	25%
- Deaf	12%
Difficulty seeing	28%
- Low vision	16%
- Blind	8%
Difficulty using hands or fingers	25%
Difficulty concentrating, remembering, deciding	25%
Frequent worry, nervousness, or anxiety	23%
Difficulty using arms	17%
Difficulty speaking so people can understand me	16%

*Many respondents reported having more than on disability type.

Source: Wireless RERC, Survey of User Needs, 2012-2013.

Data were collected from September 6, 2012 through October 9, 2013 using convenience sampling to draw a sample of adults over age 18 with any type of disability. The protocol for this study was approved by the local institutional review committee at the grant recipient's home institution, as well as the subcontracting researchers' home institution. Minors under age 18 were not recruited due to concerns over conducting research with vulnerable populations. The questionnaire was made available in English and Spanish. Participants were recruited through the Wireless RERC's Consumer Advisory Network (CAN), a nationwide network of consumers with

disabilities. The research team also engaged its Internet and social media assets, including Yahoo! Groups, the Wireless RERC website, and its Twitter, Facebook and LinkedIn accounts. Contacts among organizations focused on disability issues at the national, state and local levels. These contacts were engaged to disseminate the invitation to participate to their networks of people with disabilities. These organizations included Federal Emergency Management Agency (FEMA), the Federal Communications Commission (FCC), American Foundation for the Blind, Hearing Loss Association of America, American Foundation for the Blind, National Emergency Numbering Association (NENA), Telecommunications for the Deaf and Hard of Hearing (TDI), Coalition of Organization for Accessible Technology, Shepherd Center, and others.

A total of 1381 people responded to the survey, with 1088 reporting having at least one of the disability types listed in Table 1. Females constitute 58% of the respondents. The somewhat high mean age of 49 for respondents with disabilities is partially attributable to excluding minors under the age of 18.

Discussion

Response data are analyzed to address several key questions related to the impact of income, age and urban-suburban-rural place of residence. These same questions are addressed for the general population using survey data from the Pew Internet and American Life Project. Comparative analysis is conducted between SUN respondents with disabilities and general population respondents to the Pew survey on mobile technology use. Finally, data on wireless activities and uses are analyzed across the several disability types in the SUN survey.

For convenience, the questions to be addressed are listed below.

1. Within each disability group, does income affect use of these wireless functions and services? (income divide, Wireless RERC, March 2013)

2. Do younger adults with disabilities use wireless technology more broadly and more intensively (use of more functions with greater frequency and duration) than older users? (age divide, Wireless RERC, July 2013)
3. Across all disability groups, does residing in rural areas affect use of wireless functions and services? (rural connectivity divide, Duggan 2013)
4. Do people with disabilities use functions and services such as mobile internet, text messaging, email, mobile apps, and GPS at the same rate as the general population?
5. Do people with certain disabilities use these functions and services more or less than people with other disabilities?

Because the list of potential wireless activities and uses can be very extensive, we focus here on just a few core functions (beyond voice communications): accessing the internet, text messaging, emailing, downloading and using mobile apps, using GPS and location based services, listening to music, and video calling/chat. These activities were also chosen in order to compare SUN results with those for the general population as reported by the Pew Research Center's Internet and American Life Project (Duggan 2013). For both surveys the results are for cellphone users, regardless of whether the device is a smartphone or regular "feature" phone. SUN respondents who own only a tablet (i.e., no cellphone) were excluded from this analysis so that the data would be comparable to the Pew Research Center results.

In general, SUN respondents with disabilities who own cellphones report rates of use for a range of wireless activities that are similar to the rates reported for the general population sampled by the Pew Research Center (Table 2). Percentages of cellphone users who use text messaging (71% and 81%, respectively) and email (61% and 52%) in each survey vary

substantially. However, they do not vary much for the other 5 activities listed. Furthermore, the rank orders from most commonly used to least commonly used activity are very similar.

Table 2. Wireless activities for cellphone users with disabilities and in the general population

Wireless Activities	**SUN***	**Pew****
Send or receive text messages	71%	81%
Access the internet	60%	60%
Send or receive email	61%	52%
Download and use apps	48%	50%
Social networking/use social media	48%	Not available
Get directions, recommendations (GPS)	45%	49%
Listen to music	41%	48%
Participate in a video call or video chat	25%	21%

* *Source*: Wireless RERC. Survey of User Needs, 2012-2013.

***Source*: Duggan, Maeve. "Cellphone Activities, 2013." Pew Research Center, September 16, 2013. Web. May 5, 2014.

Three of the activities in Table 2 – web browsing/mobile internet, text messaging, and downloading and using mobile apps) – were selected for closer examination of possible effects on usage caused by income, age and residential location (urban, suburban, rural) of the respondent (Tables 3, 4 and 5, respectively).

The SUN questionnaire asks respondents to identify their income from a list of 7 income ranges. This is intended to minimize respondent concerns over privacy and promote higher response rates. Unfortunately, the SUN income ranges do not exactly match the income ranges

reported by the Pew Center. We collapsed our lowest 5 income ranges to best approximate the income ranges in the Pew. The upper two income ranges for both surveys match exactly. Despite some differences in the income ranges for each sample, both samples show that income has similar direct positive effects on usage rates for the three wireless activities (Table 3): as income rises, so do usage rates for all three wireless activities for both groups.

Notably for both groups, rates for text messaging are higher than for web browsing and downloading/using apps in each of the 4 age ranges, rising from 66% and 78% of SUN and Pew respondents, to 81% and 88%, respectively. This likely reflects the relative simplicity and low cost of text messaging compared to mobile web browsing, and the fact that effective and reliable text messaging was available long before the debut of contemporary app ecosystems and the smart devices capable of running them.

Table 3. Do you use your cellphone for web browsing, text messaging, and using apps?

(By gross annual household income)

Survey of User Needs

Cellphone Uses	**Less than $35,000**	**$35,000 - $49,999**	**$50,000 - $74,999**	**$75,000 or more**
Web browsing	54%	61%	61%	76%
Text messaging	66%	76%	70%	81%
Using apps	44%	45%	48%	65%

Source: Wireless RERC. Survey of User Needs, 2012-2013.

Pew Internet Survey

Cellphone Uses	**Less than $30,000**	**$30,000 - $49,999**	**$50,000 - $74,999**	**$75,000 or more**
Web browsing	55%	60%	63%	79%
Text messaging	78%	80%	88%	88%
Using apps	41%	48%	50%	66%

Source: Duggan, Maeve. "Cellphone Activities, 2013." Pew Research Center, September 16, 2013. Web. May 5, 2014.

As expected, for both samples age generally has an inverse relationship to use of web browsing, text messaging and downloading/using apps: as age rises, usage rates decline (Table 4). For the SUN sample of cellphone users with disabilities, usage rates actually rise from the lowest age group (18-29) to the next age group (30-49), before continually dropping through the last two age groups for all three wireless activities. This trend does not appear in the Pew data for the general population of cellphone users, which shows a continuous decline in usage from the youngest through the oldest age group for all three wireless activities. Low levels of usage among 18-29 year olds in the SUN sample might reflect difficulties paying the cost of wireless

technology, possibly resulting from the lower levels of employment and income of people with disabilities (Brault 2012). Separately, as with income, rates for text messaging use are higher than for web browsing and downloading and using apps in each of the age ranges.

Table 4. Do you use your cellphone for web browsing, text messaging, and using apps? (By age)

Survey of User Needs

Cellphone Uses	**18-29**	**30-49**	**50-64**	**65+**
Web browsing	63%	73%	57%	40%
Text messaging	69%	81%	71%	56%
Using apps	55%	58%	45%	28%

Source: Wireless RERC. Survey of User Needs, 2012-2013.

Pew Internet Survey

Cellphone Uses	**18-29**	**30-49**	**50-64**	**65+**
Web browsing	84%	72%	45%	19%
Text messaging	97%	94%	75%	35%
Using apps	77%	59%	33%	14%

Source: Duggan, Maeve. "Cellphone Activities, 2013." Pew Research Center, September 16, 2013. Web. May 5, 2014.

Generally, it is expected that people living in rural areas would report lower levels of use of various wireless services due to more limited access to wireless (especially, high-speed) service. This rural connectivity divide could perhaps also impact newer suburban areas that are more distant from urban centers as well.

Data from the two surveys show little or no difference in the usage rates among urban and suburban cellphone users for web browsing, text messaging, and downloading/using apps for

both surveys (Table 5). However, they show substantially lower rates for rural cellphone users for web browsing and downloading/using apps in both surveys. Again, test messaging stands out as an exception, mostly likely for the same reasons mentioned above: simplicity, low cost and reliability due to very low data bandwidth requirements.

Table 5. Do you use your cellphone for web browsing, text messaging, and using apps? (By urban-suburban-rural residency)

Survey of User Needs

Cellphone Uses	**Urban**	**Suburban**	**Rural**
Web browsing	60%	63%	56%
Text messaging	70%	72%	71%
Using apps	48%	50%	43%

Source: Wireless RERC. Survey of User Needs, 2012-2013.

Pew Internet Survey

Cellphone Uses	**Urban**	**Suburban**	**Rural**
Web browsing	65%	62%	47%
Text messaging	82%	82%	76%
Using apps	52%	52%	39%

Source: Duggan, Maeve. "Cellphone Activities, 2013." Pew Research Center, September 16, 2013. Web. May 5, 2014.

Closer inspection of wireless activities by disability type is also needed to understand how certain physical, sensory and cognitive limitations might impact usage of wireless services. Table 6 shows usage data by general disability type for the 3 services listed in the tables above,

plus voice calling and social media. The data show little variation in usage rates for each service across disabilities, with three exceptions: respondents with hearing and speech limitations use voice calling services at much lower rates than respondents with other disabilities. Conversely, they use wireless internet services and text messaging at substantially higher rates than the other disability groups. The third exception is that respondents with visual limitations use social media at substantially lower rates than respondents with other disabilities.

Table 6. Do you use your cellphone for voice calling, text messaging, internet, using apps, and social media? (By disability or impairment)

Disability/Impairment	**Voice call**	**Texting**	**Internet**	**Apps**	**Social media**
Cognitive	80%	81%	68%	53%	58%
Anxiety	71%	85%	69%	58%	56%
Seeing	80%	79%	65%	57%	48%
Hearing	54%	87%	74%	57%	53%
Speaking	49%	84%	76%	56%	60%
Using arms	76%	75%	66%	57%	52%
Using hands, fingers	75%	77%	68%	57%	56%
Walking, climbing stairs	75%	75%	63%	51%	52%

* *Source*: Wireless RERC. Survey of User Needs, 2012-2013.

People with hearing and vision limitations can be further segmented by degree of sensory loss: deaf and hard of hearing, and blind and low vision. Table 7 shows that people who are deaf use voice calling at very low rates (14%), while those who are hard of hearing use voice calling at rates much closer to those for other disabilities (68%). Also people who are deaf use text messaging and mobile internet at substantially higher rates than people who are hard of hearing.

Table 7. Do you use your cellphone for voice calling, text messaging, internet, using apps, and social media? (By disability or impairment)

Disability/Impairment	**Voice call**	**Texting**	**Internet**	**Apps**	**Social media**
Deaf	14%	95%	83%	58%	59%
Hard of hearing	68%	84%	71%	59%	52%
Blind	81%	74%	55%	58%	37%
Low vision	75%	81%	65%	54%	51%

Source: Wireless RERC. Survey of User Needs, 2012-2013.

Differences between people who are blind and those with low vision in the use of voice calling and text messaging are less stark. These two groups show much more substantial differences in rates of use of mobile internet and social media, both of which rely more on visual presentation and content.

Conclusions

The data presented here show that as a group, cellphone users with disabilities use wireless functions and services at similar rates as their counterparts in the general population. Furthermore, for both groups income, age, and residential setting had similar effects on the use of three distinct wireless services: mobile internet, text messaging and downloading and using mobile apps. Income was positively related to rates of use of mobile internet and apps, but little

effect on use of text messaging for both groups. Age was inversely related to use of all three services, including text messaging. Finally, there did seem to be some evidence of a rural connectivity divide for mobile internet and apps use for both groups. However, the effect was stronger for the general population than for people with disabilities. This rural connectivity divide was much weaker for text messaging for the general population, and not in evidence for people with disabilities.

Some differences in the use of wireless services were detected between and among the disability groups in the SUN, centered primarily among people with complex communications needs (hearing and speech), and also among people with vision loss. People with hearing and speech limitations, use voice communications less than people with other disabilities. Conversely, they use visual based communications (text messaging and mobile internet) more than other groups. People who are blind use voice communications at high rates, and they use mobile internet and social media at much lower rates than people with other disabilities.

These results point to two main conclusions. First, as a group, people with disabilities behave similarly to the general population in terms of use of wireless services. Second, there is some variability in the use of some wireless services between disability groups. Designers, engineers, and the wireless industry should take both of these conclusions into account when developing and marketing wireless technology and services to people with disabilities. This population represents a large and growing market that can often, but not always, be served by technologies intended for the general population.

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Sonically-Enhanced Tabular Screen-Reading

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Abstract

The World Wide Web has made more information readily available than at any time in human history. This information is often presented visually, which can be an inaccessible medium for people with blindness or low-vision. Presently, screen readers are able to verbalize on-screen text using text-to-speech (TTS) synthesis. However, much of this vocalization is inadequate for browsing the Internet, as it cannot properly convey the structure and relationships that exist in a visual presentation. We have created and tested an auditory interface that incorporates auditory-spatial orientation within a tabular structure. When information is structured as a two-dimensional table, links can be semantically grouped as cells in a row within the auditory table, which provides a consistent structure for auditory navigation. Our auditory display prototype was tested with sixteen legally blind participants, who each navigated four sonified tables enhanced with prepended tones, which were varied with stereo spatialization and tonal variation. The sonified tables were presented in a randomized order to avoid ordering/learning effects. Results from the experiment showed that stereo panning was an effective technique for audio-spatially orienting non-visual navigation in a five-row, six-column HTML table as compared to a centered, stationary synthesized voice.

Keywords

Screen-reading; sonification; assistive technology; tabular navigation; accessibility

Introduction

Screen-reading software has made it possible for many individuals who have lost their vision to use computers. Using dynamically created synthesized speech, this invaluable tool provides a portal to the world of e-mail, news, banking, entertainment, and countless other activities that have migrated to the digital world. Internet access is now ubiquitous and often necessary for gainful employment, and the World Wide Web (WWW) has connected communities across the world. The preeminence of the WWW in the daily lives of many individuals cannot be overstated. However, the WWW is primarily a visual medium, and the nature of this visual content makes it difficult to render in the inherently sequential speech modality of the contemporary screen-reader. When a screen-reader renders visually designed content, spatial orientation and relationships are often lost or disregarded, leaving the blind user to perform complex searches and organizational tasks. To make matters worse, visual content is often arrayed in inconsistent and arbitrary configurations, which can be confusing to the blind user. Much of the Internet is now an exercise in navigation, and this navigation is often intended to be visual. To fully include all potential users, the WWW must be accessible to auditory navigators using screen-readers.

Related Work

Tabular Sonification

Researchers have investigated various modalities of presenting information non-visually. The auditory icon technique involves sonic metaphors posing for visual icons (Gaver). For example, a “cow” icon would sound like “moo.” The “earcon” technique involves composing melodies/rhythms to indicate information (Blattner, Sumikawa, and Greenberg). These two sonification techniques, while often useful, have inherent limitations. Auditory icons are not

appropriate for purely visual icons like a book, or functions that have no obvious sound, like "file...save...as." Composed melodies and rhythms are arbitrary and do not necessarily reflect a meaningful representation for the user.

Researchers have proposed using pitched tones to represent numerical data in a spreadsheet (Ramloll et al.). Considering that each row or column of a spreadsheet is a sequence, the data in that sequence could be proportionally scaled and shifted to integer values. These integer sequences can then be sonified such that when played as successive tones, the sequence is perceived as a melody. This is an ingenious method for non-visually portraying trends in numeric data; however, its application is not easy to generalize, as textual data has no obvious analog in pitch.

A method for audio browsing that involves both 3-D auditory spatialization and metaphorical sonifications was proposed (Goose and Möller). In their implementation, users hear space-ship lift-off and landing sonic metaphors to connote intra-document linking while stereo spatialization conveys the browser's relative focal position within the document. This serves to maintain orientation while giving a sense of overall document length.

Blind individuals, on average, have a significantly better ability to localize sound than do sighted people (Ohuchi et al.). This ability was found by arranging a circular array of loudspeakers around both blind and sighted individuals who were then asked to indicate the speaker from which a test sound emanated. This capability inspired the stereo spatialization technique implemented in this research.

Screen-Reader Optimization and Webpage Reformatting

Researchers have explored automated semantic organization techniques for making the Web more accessible to blind users (Nagao, Shirai, and Squire). These techniques look for

similar content to group together. Gupta *et al.* have proposed parsing HTML documents to strip out extraneous content based on the Document Object Model (DOM) tree structure inherent in HTML documents (Gupta *et al.*). Advertisements, navigational bars, and empty tables can be stripped out to provide a concise presentation for the non-visual navigator. Our spatialized tabular browser presupposes that content can be semantically arranged into a tabular format for a consistent, predictable layout.

Methods

Subjects

We recruited sixteen research study participants from a pool of legally blind screen-reader users. Our implementation assumed no previous knowledge of existing screen-reader software. The participants ranged in age from 20 to 57 years old, with a mean age of 43.17 (SD = 12.73) years. They were recruited from various Lighthouses in the greater South Florida area.

Spatialization Techniques

An inherent limitation in screen-reader presentation is verbosity. We seek to eliminate some verbosity by replacing verbally explicit descriptions of cellular focus with dynamic relative spatialization. We aimed at leveraging two fundamental properties of human psychoacoustics, namely stereo localization and pitch perception, to accomplish sonic spatialization.

Stereo Panning

The psychoacoustic phenomenon of sonic localization can be exploited to artificially localize sound sources. Blumlein discovered that by simultaneously playing a sound from two loudspeakers at a differential in amplitude, a person will perceive the sound as originating from somewhere along the continuum of space between the two loudspeakers. The perceived location of origination is relative to the ratio of amplitudes, where the speaker with greater amplitude will

drag the virtual sound source closer to it from the middle. The technique of varying the perceived sound location is called stereo panning. The synthesized speech output from the screen reader can be panned linearly to indicate the location of a text item along the horizontal dimension of the table.

Tonal Variation

Humans can perceive changes in sonic frequency as distinct pitches on a one-dimensional continuum. Musical scales, or series of notes progressively increasing in frequency, can be exploited to correspond to sonic locations. A tone, prepended to the TTS representation of each item in a table can be manipulated to achieve graduated relative auditory orientation. This prepended tone also serves to alert the user-navigator that she is focused on a link.

Other Sonic Indicators

We utilized sound effects to indicate navigational status, such as an “electrified fence” sonic metaphor for reaching boundaries and audible buzzes to indicate erroneous key presses. These non-verbal sound effects are critical to indicate navigational status, error, and events.

Procedures

Table 1. Grocery Navigational Table

Vegetables	Carrot	Potato	Cucumber	Onion	Lettuce
Fruits	Banana	Apple	Lemon	Orange	Cherry
Bakery	Bread	Cake	Pie	Cookie	Muffin
Meat	Beef	Chicken	Pork	Turkey	Duck
Drinks	Beer	Juice	Milk	Soda	Tea

An online purchasing task was implemented to test the feasibility of sound-spatialized tabular browsing. Each sound spatialization technique was implemented in a separate navigational table (A, B, C, and D), each consisting of five categorical rows and six total columns, serving as a consistent, predictable structure (see Table 1). The relatively small number of columns and rows was influenced by research suggesting that an average person can store "seven +/- two" items as a working memory (Miller). Each user was asked to navigate each navigational table, using the variations in stereo panning and/or changes in the prepended tone as navigational references. We tested the techniques according to a double-binary design (see Table 2).

Table 2. Sonic Augmentation and Enhancement Methods

Stereo/Tonal	Constant	Varying
Stationary	**A**	**B**
Mobile	**C**	**D**

We trained our participants to familiarize them with tabular navigation. Participants were able to use shortcut keys to immediately access either end of a row. Keystrokes were provided to recall the prompted information as well as to recall the order of the category-rows (see Table 3).

Table 3. Keyboard Commands

Key	**Mnemonic**	**Function**
c	categories	repeats all of the category headers
e	end	focuses to the rightmost cell in the current row
r	repeat/recall/remind	prompts user to find a particular link
s	shortcut	focuses to the leftmost cell in the current row
spacebar	N/A	selects a link
left-arrow	left	shifts focus to the immediate left
right-arrow	right	shifts focus to the immediate right
down-arrow	down	shifts focus down one cell
up-arrow	up	shifts focus up one cell

Data Collection

In each of the navigational tables (A, B, C, and D), the participant was verbally prompted to find ten items, in sequence. Primary data such as the time-to-target (TTT) and number of moves were recorded, as well as ancillary data such as number of boundaries reached, wrong links selected, and wrong keys pressed. This ancillary data serves to indicate confusion and disorientation, which may or may not be a result of the system itself.

Results

Quantitative Analysis

As each participant browsed through the navigational tables, his/her navigational data were recorded, such as the TTT and the number of moves needed to reach the stated target. While these two aspects of navigation are readily recorded and understood, it is less clear how to

compare navigational data from one user to another as well as from one navigation task to another. The user's mental model heavily influences non-visual screen reader usage (Kurniawan, Sutcliffe, and Blenkhorn). Each of the navigations was unique in that the user must use her mental model of the table to map out a course toward the intended target. For blind navigators, this path is not straightforward. Many blind navigators will choose to return to the category-column (left-most column of each table), move vertically to the appropriate category-row (e.g. "Fruits" of the "Grocery" table), and then navigate across to the intended cell (e.g., "orange"). There is no ideal path. The existence of a shortcut to the category-column complicates the notion of a shortest or ideal path.

To meet the normality and equality of variances assumptions of ANOVA, we transformed our experimental TTT data using the natural logarithm. The results show that the logarithmically transformed TTT was significantly affected by the tonal variation method, $F(1,15)=6.194$, $p=0.025$. The results show that the logarithmically transformed TTT was marginally affected by the stereo spatialization method, $F(1,15)=4.240$, $p=0.057$. The results show that the logarithmically transformed TTT was not significantly affected by the interaction of both methods, $F(1,15) = 1.381$, $p=0.258$. These results suggest that some confusion may be caused in the subject when employing both of these methods simultaneously.

Qualitative Feedback from Subjects

Based on oral interviews conducted with the participants, many users remarked that they would be more likely to engage in spreadsheet editing and on-line purchasing if tabular navigation were streamlined and presented in an audio-spatial modality.

Several subjects reported that they reflexively moved their heads to follow the perceived origin of the moving voice. This clearly shows that the stereo spatialization is readily perceived

and intuitive. There was a mixed reception to the pitched tones; some users noticed them and made use of them, while others simply ignored them. Some users noted that their sense of hearing was weak in one ear and that the tones were more effective for auditory guidance.

Discussion

Noting the significant effect of stereo spatialization on tabular navigation, we would strongly encourage web designers to consider a tabular layout as a blind-accessible alternative to conventional visually oriented web pages. While there has been progress in automating the conversion of arbitrarily arranged content into semantically structured web-pages, we believe that having a tabular format in mind from the onset would benefit the non-visual browser.

Our design philosophy was to keep everything as simple and intuitive as possible. We opted to use generic, off-the-shelf stereo speakers. Headphones, which vary in style and shape, were not considered, as they tend to create the psychoacoustic perception of hearing sound move within one's own head and restrict a blind person from remaining aware of her ambient surroundings. While a 3-D spatialized sound environment may have been novel and allowed for far more possibilities of sonic localization, the availability of such systems is prohibitive to a user who must be able to access her computer on the go. 3-D sonic spatialization would require a highly customized implementation of hardware and software not available to the typical user.

We used what we believed to be intuitive features of auditory perception: sonic localization and relative pitch. These intuitive features should then not need extensive training and explanation. Through the course of testing, a few of the most experienced screen-reader users remarked that they ignored the tonal guidance to focus better on the navigational task. While this was an unexpected reaction, it does indicate that those who wish to ignore it can tolerate the tones without great annoyance. Some other users stated that their hearing had

deteriorated in one ear relative to the other and, consequently, they would prefer the tonal variation. For more effective implementation, users must be given a choice to enable one or both of the sonic enhancements to adjust for limitations in pitch perception and sonic localization.

Conclusions

The marginally significant effect of stereo spatialization supports our expectation that the presence of auditory enhancements could have an impact on the efficiency and comfort experienced by the experimental users in navigating the tables. This highlights the potential benefits from solely implementing a simple form of stereo panning that do not require any hardware changes. Fortunately, the minimal software modifications needed would be transparent to an end-user of this approach.

The results obtained in the experiments and associated statistical analyses have revealed that the tonal variations we applied to indicate spatial relations between cells were not as intuitive and easy to assimilate, as we would have hoped. We speculate that this may be due to the mental effort necessary to map pitch change to spatial displacement during the browsing of our navigational tables. Musical training may be necessary to appreciate tonal variation fully.

Noting the lack of help provided by the tonal variation method, the interaction of the combined enhancements did not mutually complement each other, as we would have hoped. Since the tonal variation method itself does not seem to be assimilated well, it does not enhance or complement the stereo spatialization method. Rather than making navigation more efficient, the combination of the two methods seems to add to the listener-navigator's cognitive burden.

Acknowledgments

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RSVP-iconCHAT:

A Single-Switch, Icon-Based AAC Interface

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Abstract

Augmentative and alternative communication (AAC) systems are often used by people with speech impairments severe enough to preclude the use of spoken communication. Due to concomitant mobility and language constraints, many of these individuals use icon-based systems controlled by switches. Single-switch AAC systems are typically simplifications of multi-array AAC systems that share elements of the same interface layout, but support some form of scanning, such as linear or row-column. From a development standpoint, this conversion technique makes it easy to transform almost any AAC system into a single-switch system; however, it means that most of these systems were originally designed for users with much greater mobility. The purpose of this work was to design an icon-based AAC interface specifically for use with binary signals, such as switches. A usability study was conducted with both non-disabled adults as well as adults with speech and mobility impairments to determine performance bounds and observe individual use cases. Results indicated similar learning curves for both groups and promising performance characteristics for the target population. These results have immediate applications to the design of icon-based AAC and implications for mobile, icon-mediated communication platforms.

Keywords

AAC, RSVP, assistive, binary, communication, icons, semantic frames, switch

Introduction

Many individuals with speech impairments severe enough to preclude spoken communication also have concomitant physical impairments that limit the use of sign language or written forms of communication (Beukelman and Ansel). Augmentative and alternative communication (AAC) systems, which range from letter boards to dedicated speech output devices, are the primary way for these individuals to convey their thoughts, needs, and desires to those around them. Although letter-based systems allow users to construct fully generative utterances, they can be slow and fatiguing (2 – 5 words per minute) because of the number of selections that must be made to complete a message (Todman). Additionally, many individuals who have sustained impairments since birth have poor or limited literacy skills (Beukelman and Mirenda). Icon-based AAC systems are advantageous because they have the potential to increase message construction speed by allowing whole words and concepts to be accessed in a single keystroke (Todman, Alm, and Elder). They can also be used by children and other users with limited or emerging literacy skills.

Depending upon their mobility impairments and language constraints, many AAC users require icon-based systems controlled by switches (Wolpaw et al). Current single-switch AAC systems are typically simplifications of multi-array AAC systems and display a complex array of vocabulary on the screen, organized into a navigation hierarchy based on categories. To increase the size of the vocabulary on these systems, the screen size must be increased, the button sizes must decrease, or the navigation hierarchy must become more complex. Each of these approaches has its limitations. An increased screen size reduces mobility of the system, smaller buttons are more difficult to view, and complicated navigation hierarchies require more time and effort to find the target button and increase the likelihood of confusing the user. Additionally,

when these interfaces are used with scanning, users must visually locate their target button from among the many options on the screen. People who use single-switch AAC systems often have extremely limited physical mobility or control, making it difficult to repeatedly perform the necessary head, neck, or eye movements when attempting to locate target items (Muller and Blankertz).

Approach

Our single-switch AAC interface, called RSVP-iconCHAT, aims to minimize the amount of head, neck, and eye movements required to efficiently control the system. RSVP-iconCHAT was designed to be robust enough to function with a brain-computer interface (BCI), as well as conventional access methods, such as sip-and-puff devices, eye-blink detectors, surface electromyography (EMG), or physical switches. To that end, we leverage a technique called Rapid Serial Visual Presentation (RSVP), in which the user fixates on a relatively stable location while different images are displayed in that location, one at a time. RSVP originates from the field of psychology and has been used successfully to control letter-based AAC systems (Orhan et al).

To leverage RSVP, our interface focuses the user's attention on the message being constructed instead of displaying all of the available vocabulary. To demarcate different visual fixation areas, messages are represented as semantic frames. Semantic frames are a product of case grammar theory, which asserts that the main action, or verb, is the central component of a message (Fillmore). Each message can be expressed as a formulaic frame for which certain semantic roles are understood and expected. For example, the frame for the verb "to give" might require, at a minimum, an actor that does the giving, a participant that receives the gift, and an object that can be given or received. Semantic frames can be used to constrain relevant roles for

a given action, and these roles can then be populated with appropriate concepts to generate complete utterances.

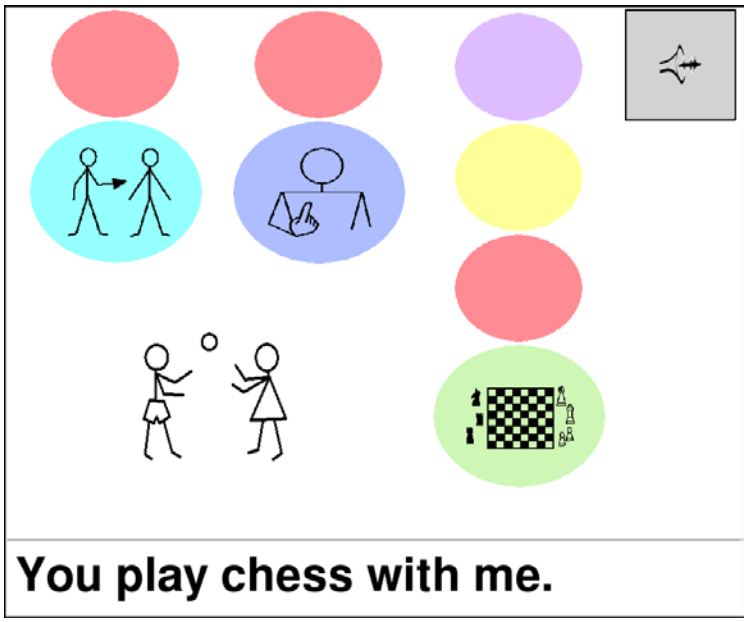

Fig. 1. Functional elements of the RSVP-iconCHAT interface, including: command field (upper right), message in standard grammatical form (bottom), and schematic layout of semantic roles.

In RSVP-iconCHAT, each message is subdivided into semantic roles (e.g. actor, action, participant, and object) and applicable vocabulary options are displayed using RSVP within each semantic role (Fig. 1). This design uncouples required screen real estate and physical movement from the vocabulary size and instead ties them to the length of the desired message. For more advanced or more mobile users, the number of available semantic roles can be increased, enabling users to create longer and more complex messages; for beginning users, or those with severely reduced mobility, the number of roles can be decreased to enable the creation of simpler messages with the same vocabulary.

Fig. 2. Subset of single-action picture cards.

To construct a message using the RSVP-iconCHAT approach, users first select the desired verb or action. Once an action has been selected, the corresponding semantic frame is displayed with semantic roles such as actor, actor modifier, participant, participant modifier, object, object modifier, quantity, and possessives. These roles are displayed as a set of fillable slots that are spatially organized around the verb. Each semantic role is then highlighted sequentially. Once a role has been selected, icons that can fulfill that role are displayed via RSVP and users can select a desired icon to populate the role. After an icon has been selected for a given semantic role, other roles are highlighted sequentially to allow users to populate as many roles as desired, and in any order. Articles (e.g. “a,” “an,” “the”) and prepositions (e.g. “in,” “of,” “to”) are automatically inserted to efficiently generate grammatically complete messages. At any point during message construction, users can select the “command field” to perform conversational actions (e.g. “speak” or “clear” the current message). Selecting a “speak” command, for example, might send the message to an integrated Text-to-Speech (TTS) system, clear the current message, and prompt the user to begin constructing a new message.

Method

We conducted a usability study involving a constrained message elicitation task for the purpose of exploring how potential users would interact with and respond to the interface. After a brief demonstration and training period, participants were shown a series of 30 picture scenes depicting simple actions (e.g. a boy drinking milk, a man combing his hair, and a woman reading a book) and asked to use our prototype RSVP-iconCHAT interface to create a sentence describing each scene (Fig. 2). The order of the picture scenes was randomized across participants in order to observe behavior as users became more familiar with the system. Participants were directed to construct sentences that were as detailed as necessary such that, if the picture cards were shown to another person, that person would be able to match the appropriate description with the scene.

Each experimental session was conducted in one 60 – 90 minute block per participant, and all sessions were conducted in a sound-treated acoustic booth. Each participant was seated in a chair, or personal wheelchair, facing a computer screen. The space bar of a standard QWERTY keyboard was designated as the switch mechanism, and the RSVP process was configured to show images in alphabetical order using a timing mechanism with a starting speed of 700 milliseconds per image; however, participants could increase or decrease the speed in increments of 100 milliseconds per image. Participants were encouraged to change the RSVP speed whenever and however they preferred, either by pressing the up and down arrows on the keyboard or by requesting it verbally. The icon set, or vocabulary size, consisted of 106 items preselected for their relevance to the picture scenes and tagged within each of 8 possible semantic roles. After each session, participants were asked to provide qualitative feedback via an informal interview.

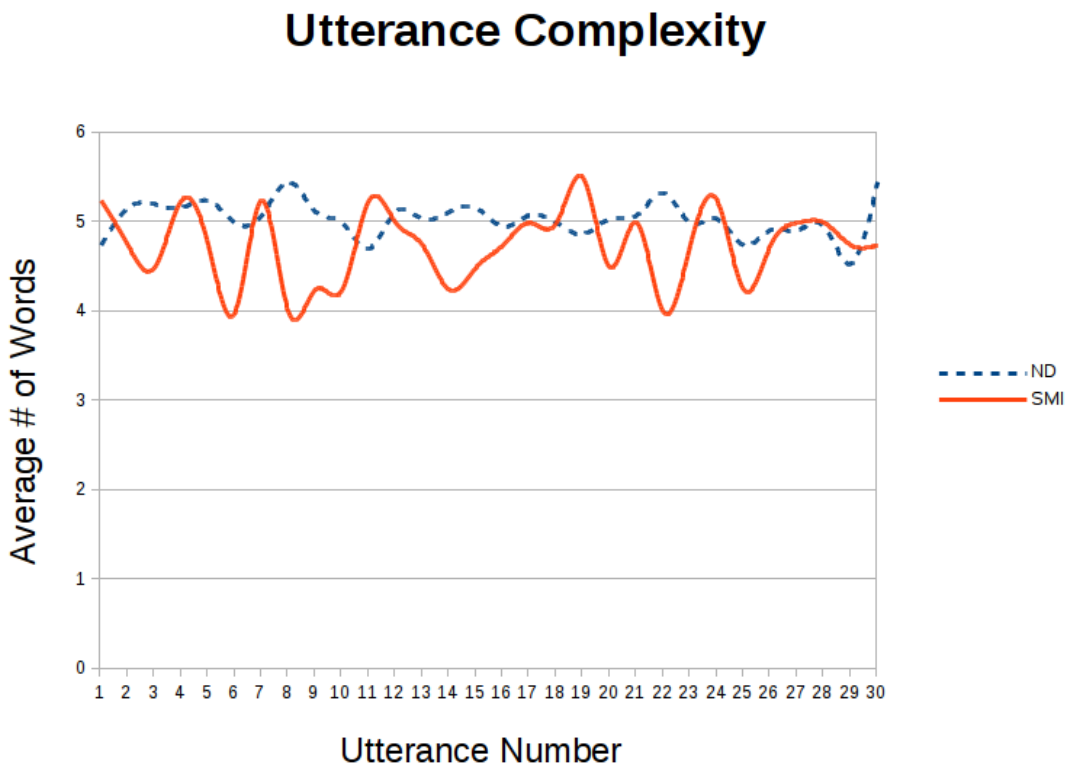

Fig. 3. Average sentence length, excluding the verb and automatically added function words.

Two groups of users were recruited: non-disabled (ND) users to provide a theoretical upper bound on performance, and users with speech and motor impairments (SMI) to provide a realistic evaluation from the target population. For the group of ND users, we recruited 24 English-speaking adults from the greater Boston area, with no declared speech, language, hearing, or cognitive impairments (10 males and 14 females; mean age 24 years; age range 19 – 43). On average, each of these participants had approximately 3 years of formal education following high school and spent approximately 11 hours per week using a computer. The ND users did not have prior exposure or experience with AAC devices.

For the group of users with SMI, we recruited 4 additional English-speaking adults from the greater Boston area (2 males and 2 females; mean age 41; age range 33 – 56). On average,

each participant had approximately 4 years of formal education following high school and spent approximately 15 hours per week using a computer. Two of these participants (P1 and P2) had mild motor impairments; two (P3 and P4) had moderate-to-severe motor impairments. All of these participants used wheelchairs, except for P1 who used a walker. P1 and P2 had experience with AAC devices, but used unaided communication on a normal basis. P3 used both unaided communication and switch-based AAC. P4 was unable to use existing AAC systems and required the assistance of a caregiver to communicate.

Results

Theoretically, the open-ended design of the task allowed for the possibility of users creating nonsensical sentences; however, in practice, there were no such instances. Because our prototype implementation required that every sentence contain at least a verb, the short possible sentence was one word in length. On average, both the ND participants and the participants with SMI created sentences consisting of 5 words, excluding articles and prepositions that were automatically inserted by the system (Fig. 3). Thus, users selected a verb and an average of 4 additional icons to construct descriptions of each picture scene. In fact, the participants with SMI created slightly more complex sentences, up to 6 additional words, on at least 2 occasions throughout the study.

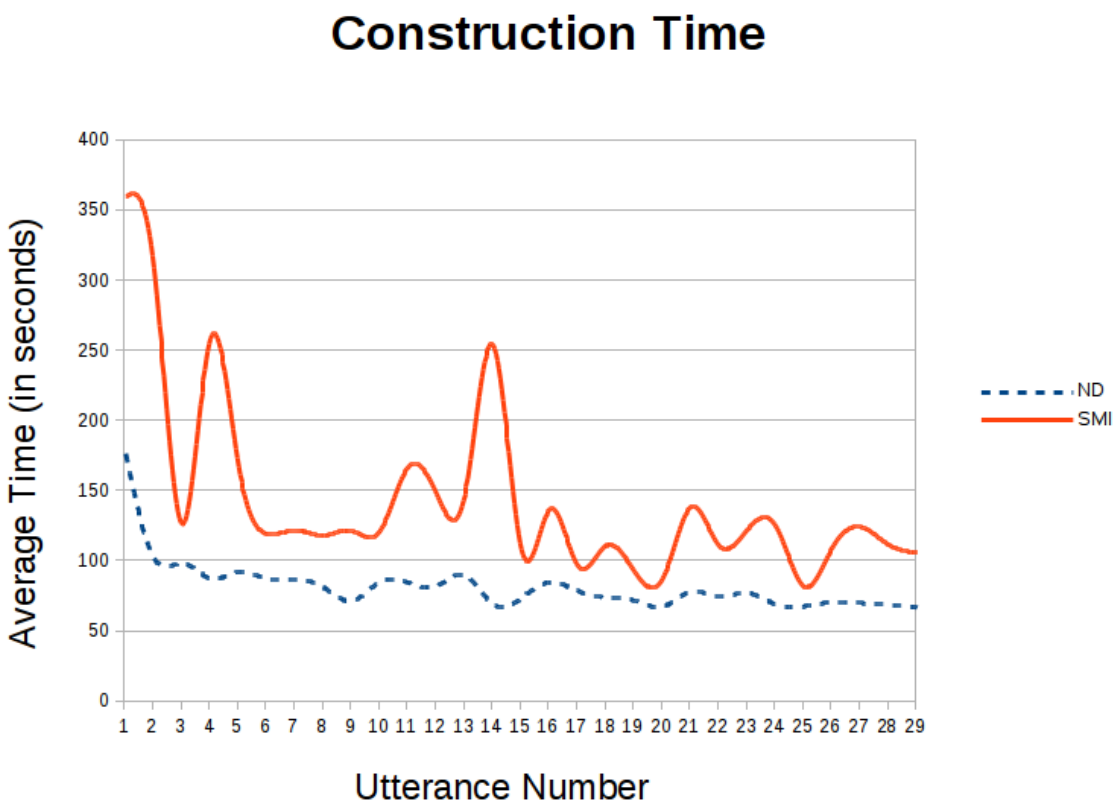

Fig. 4. Average message construction time per sentence.

In terms of message construction speed, both groups of users showed similar learning curves, with the ND group achieving a final speed approximately 1.5 times faster than the group with SMI (Fig. 4). The average time for constructing each of the last five sentences was 70 seconds for the ND users and 107 seconds for the users with SMI.

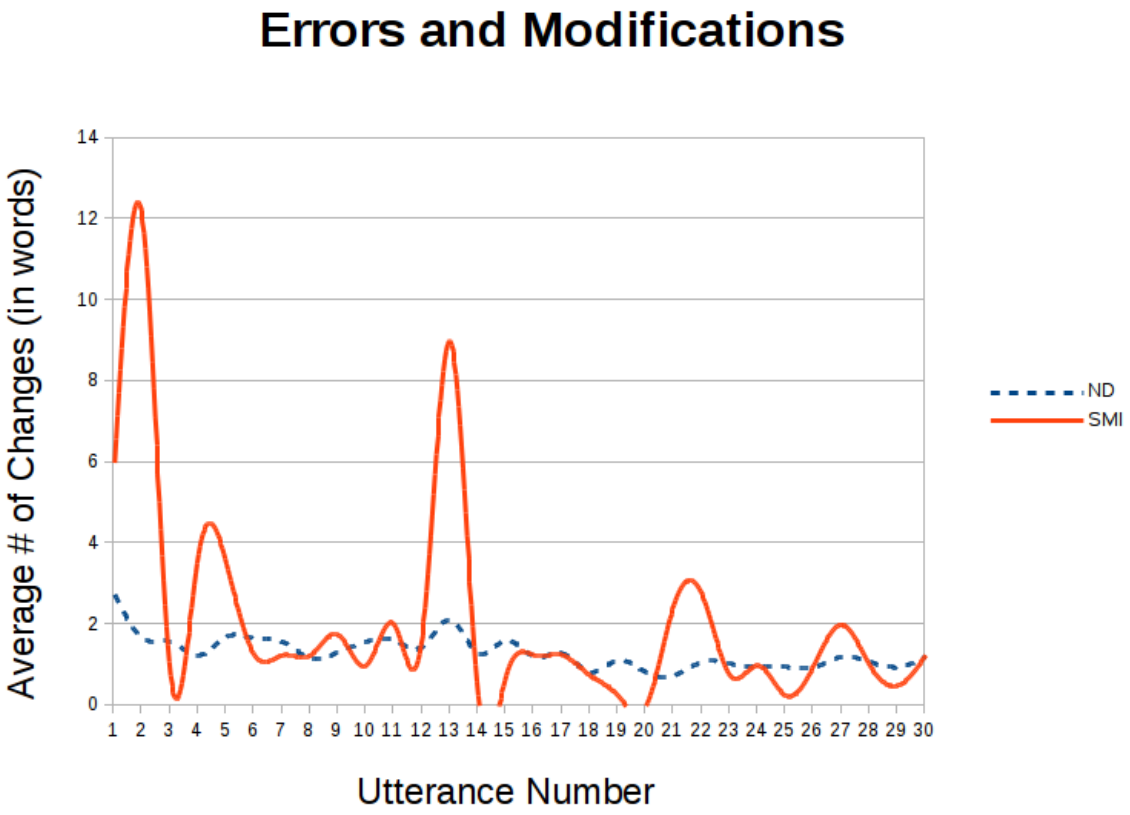

Fig. 5. Average number of self-corrections per sentence.

If users populated a semantic role more than once, even if they selected the same icon or cleared the role of any value, it was considered a self-correction. This metric was used to probe fatigue and learnability of the system. On average, ND users changed or deleted 1 word per sentence before submission, compared to an average of 2 word changes or deletions per sentence for the participants with SMI (Fig. 5).

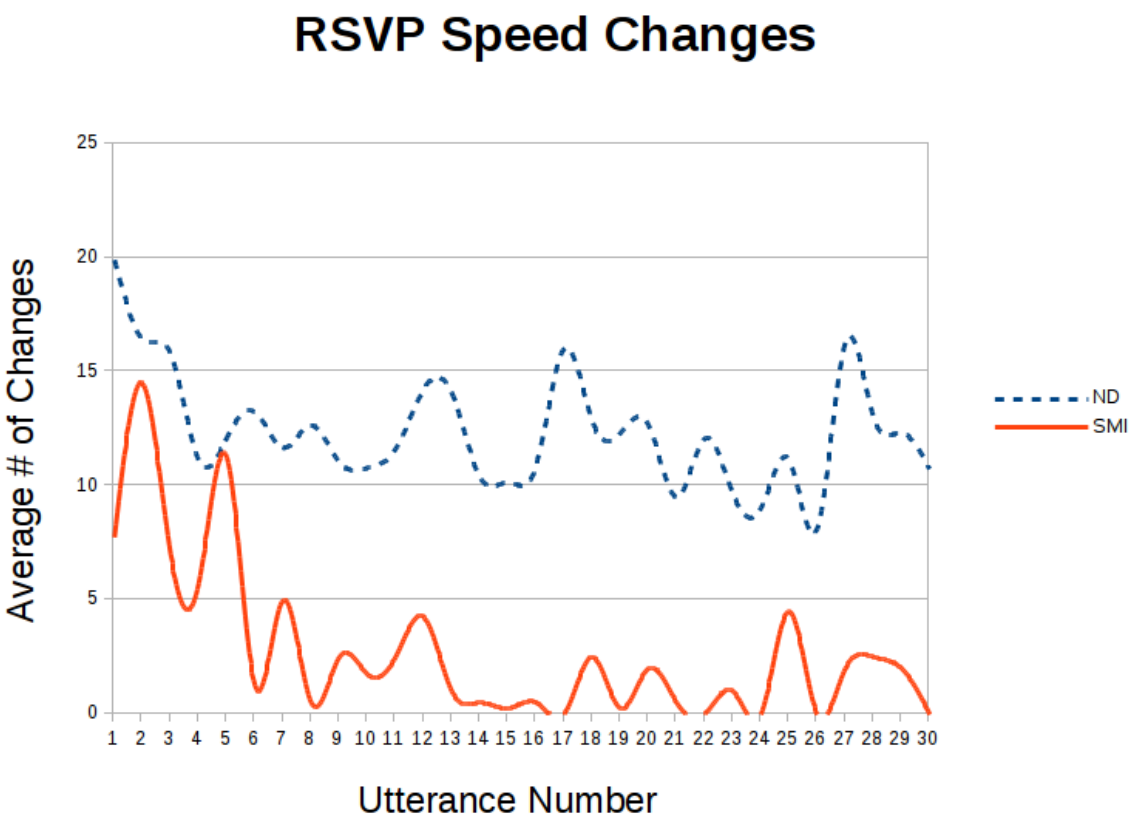

Fig. 6. Average number of RSVP adjustments per sentence.

During the study, ND users adjusted the RSVP speed an average of 10 times per sentence (Fig. 6), returning to an average ending speed of approximately 700 milliseconds per image (Fig. 7). In contrast, users with SMI adjusted the RSVP speed an average of 9 times per sentence for the first 5 sentences and an average of once per sentence for the remaining 25 sentences, returning to an average ending speed of 1200 milliseconds per image.

Discussion

This study examined user behavior while composing messages with the RSVP-iconCHAT interface and a single switch mechanism. The aim was to assess the learnability and ease-of-use of the system. Icon-based message construction via RSVP proved to be learnable

within less than 30 minutes for both user groups. Users were able to construct messages of 4 – 7 words in approximately 1 minute, which is faster than some traditional letter-based systems (Wolpaw et al), but users were unable to surpass the performance of conventional icon-based systems (Muller and Blankertz).

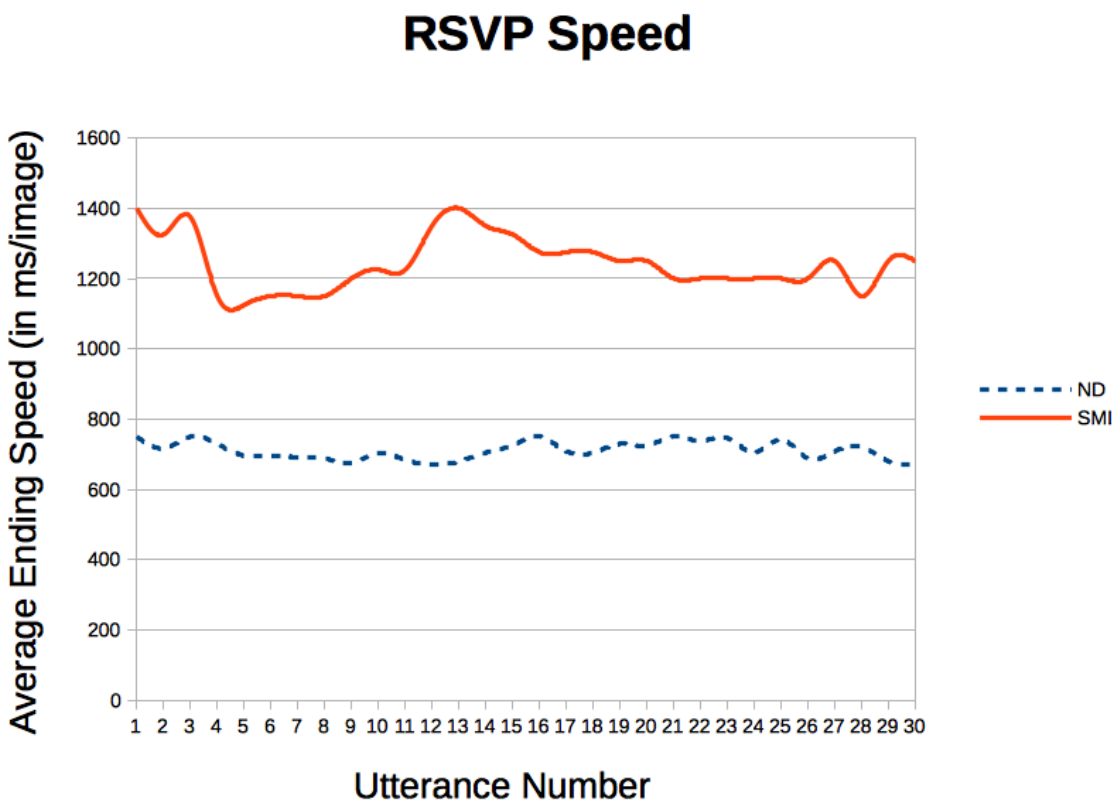

Fig. 7. Average ending RSVP speed per sentence.

The results of our study suggest that expressiveness and generativity are not necessarily compromised by limiting selection tasks to a single key. In fact, both user groups constructed relevant sentences that were an average of 5 selected words in length. Examples of constructed messages included: “an old woman knitting a sweater,” “a small child drawing a house,” and “a man talking on a blue telephone with his friend.” Although this study did not replicate the social

pressures of realistic conversation rates, these sentences are longer and more complete than the simple 2 – 3 word sequences documented using some traditional icon-based systems (Van Balkom and Welle Donker-Gimbrere).

Frequently changed RSVP speed throughout the course of the study suggests that users may have been unsatisfied with a constant presentation speed and may have wanted to skip ahead to specific roles or icons. For ND users, the average of 10 changes per sentence suggests that participants increased the speed 5 times and then decreased the speed 5 times, possibly to skip through a large number of undesirable words; however, this behavior was not displayed by the users with SMI (Fig. 6). Although it is possible that the users with SMI found a comfortable speed within the first few sentences, it may have also required too much effort to change the RSVP speed more often, especially for those with moderate-to-severe motor impairments.

Users with SMI appeared to prefer an RSVP speed approximately 1.7 times slower than ND users, yet it is possible that they may be comfortable with faster RSVP speeds for other input modalities. For example, two users (P3 and P4) indicated they could have constructed messages more quickly if the interface were integrated with a sip-and-puff device. Given that both ND participants and participants with SMI converged to consistent ending RSVP speeds, their respective presentation rates (Fig. 7) may be appropriate defaults for physical input modalities, such as button presses.

Two of the participants with SMI (P1 and P2) explored almost the entire vocabulary approximately halfway through the experiment. Additionally, a spike in self-correction for these users, at approximately sentence 13 (Fig. 5), may indicate that they were exploring more expressive possibilities and testing the boundaries for sentence complexity. This phenomenon was not observed with ND users, possibly indicating different preferences between the two

groups when familiarizing themselves with new communication interfaces. Self-corrections may also be explained by mistaken selection of a word due to slow motor movement, which would have been a sustained problem for the users with SMI, even as familiarity with the system increased.

While quantitative measurements of fatigue or cognitive load were not collected, qualitative feedback indicated that ND users felt “fidgety” and “impatient” at having to wait for a desired icon to be displayed, but almost all users commented that the interface was “simple” and “easy to use.” One user with SMI (P1) also expressed impatience at having to wait for the target icon; however, the other three users with SMI did not indicate any similar frustration. All 28 participants noticed and favorably commented on the fact that the RSVP-iconCHAT approach did not require them to capitalize words, conjugate verbs, or provide articles and prepositions. Two of the users with SMI (P1 and P3) remarked that they had not seen an existing AAC system with similar functionality, and several ND users asked if there were a way to enable this feature in their current mobile devices.

Conclusion

Many individuals with severe speech and motor impairments use icon-based AAC systems with switches; however, these systems often require larger screens, use complex navigation hierarchies, or necessitate repetitive head, neck, and eye movements. We aimed to design an alternative to conventional icon-based AAC systems that would require less screen real estate, yet still be easy to navigate and allow for sufficiently large vocabularies. RSVP was leveraged to display icons and reduce the required motor control to a single action. Furthermore, RSVP was combined with semantic frames to segment the screen into multiple fields and place the burden of search on the system rather than the user. By organizing vocabulary into semantic

roles, rather than lexical categories, the display requirements of this approach are not tied to vocabulary size, but to the number of semantic roles necessary to construct a desired message.

The usability study suggests that an RSVP approach to icon-based message construction is a viable option for users with severe speech and motor impairments. Given that both cohorts of study participants were unfamiliar with the RSVP-iconCHAT approach, their performance should be considered as a reasonable lower bound that can be expected to improve with practice.

The RSVP-iconCHAT design has important implications for mobile devices that have small screens and a limited number of buttons. Depending on the complexity of the desired message, the number of semantic roles can be chosen to match the available display space of a given mobile device. All search and prediction tasks can be delegated to the system, requiring only a single reliable selection mechanism for control. While the minimal control requirements are a single binary signal, as in the conducted usability study, control over the RSVP process can be expanded to include directional control of the display sequence or even the ability to modify RSVP speed.

Our prototype implementation of RSVP-iconCHAT accepts keyboard entry or mouse clicks, but the design can be configured to work with eye blinks, muscle twitches, brain waves, or any other input that can be discretized into binary form. This interface is potentially beneficial for users with profound impairments, such as those with locked-in syndrome who require electromyography (EMG) or brain-computer interface (BCI) solutions. Because many EMG and BCI systems provide a single output signal, and RSVP-iconCHAT requires only a single input signal, integrating such signaling methods is feasible and likely to be successful. Once the need for a voluntary motor response is removed, natural language processing and machine learning could be used to dynamically reorder the sequences of suggested semantic roles and associated

icons, further increasing communication speed.

Acknowledgments

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Lunar Tabs: An Intelligent Screen Reader Friendly Guitar Tab Reader

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Abstract

Lunar Tabs is an intelligent screen reader friendly application that makes the millions of guitar tabs online accessible to persons with low vision. An accessible user interface is designed for different use scenarios including for desktop platforms and mobile devices. Methods are developed to convey repetition information in music effectively over a screen-reader, and capabilities to use the application in several hands-free modes are prototyped. User studies are conducted to evaluate the technology's potential impact in the blind/low vision community.

Keywords

Blind/Low Vision, Accessible Music Learning, Intelligent Accessible Interfaces

Introduction

Over 50 million people worldwide play the guitar. Music has been associated with improved creativity, scholastic gains and increased quality of life (Hargreaves, Marshall, North). Guitar tablature (or "tabs" for short) is a popular notation where a music piece is represented as notes on a guitar fretboard.

Recently, there has been an explosion of user-generated electronic guitar tabs online, with millions of tabs now available. This enables almost anyone to begin playing their favorite songs with just a guitar and the associated guitar tab that they can download online for free.

For the 285 million people worldwide with low vision, however, the existence of these tabs is of limited use ("Visual impairment and blindness"). Many blind/low vision users try to learn guitar purely by ear, but the process is time-consuming and frustrating. A significant effort has been made to build systems that convert sheet music to Braille Music, a format usable with refreshable Braille displays (Inthasara et al; Borges and Tomé; Langolff, Jessel, and Levy). Braille Music, however, is optimized for sheet music rather than guitar tab files. Guitar tab is a unique notation that is easy to understand and more intuitive to many guitarists than sheet music. Also, Braille music requires special hardware displays, which can be costly. Many users would like a software solution to access the litany of guitar tabs that already exist online for free.

While several guitar tab readers exist, none of the available solutions is as accessible to persons with low vision as they could be. Motivated with the goal of helping musicians who are blind or have low vision, we propose Lunar Tabs, a guitar tab reader designed from the ground up to be accessible and optimized to work with screen readers. Lunar Tabs takes as input an electronic guitar tab in a well-structured format and generates a sequence of text instructions for

playing the piece. For example, if an “A” appears in the tab, Lunar Tabs might output {“Play third string second fret, quarter note”}. A person with low vision could use Lunar Tabs to learn any song they wanted by harnessing the expansive tab libraries online.

This paper presents the Lunar Tabs system and user interface design, approaches to conveying repetition information in the music, and hands-free modes for the application. We conducted user studies to evaluate the technology’s impact with several users of screen readers.

Discussion

System Specification

Figure 1 shows the Lunar Tabs system data flow. A tab loader takes as input guitar tabs in structured format such as Guitar Pro (*.gpx) or Power Tab (*.ptb). An instruction generator component generates text instructions on how to play the guitar tab. The text instructions are then fed into the user’s screen reader software.

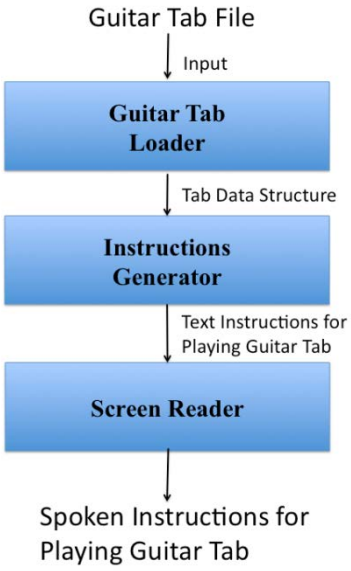

Fig. 1. Lunar Tabs System Flow Diagram

Guitar tabs can contain a lot of information, and design attention must be paid to what instructions should be presented to a user using a screen-reader, so as not to overload the user with information. The instruction generator component must generate sufficient instruction so the user can learn to play the tab but not be verbose. In vanilla Lunar Tabs, instructions are displayed to the user music measure by measure. Instructions are generated for each musical event (e.g. notes, chords, rests) in the measure. By default, instructions contain a description of the musical event, duration of the event, and playing effects (e.g. vibrato, tapping) for the event.

Instructions can be generated in two modes – "String/Fret" mode and "Note/Chord" mode. In String/Fret mode, the hand configuration of a playable event (e.g. note, chord) is presented in terms of the strings and frets to be played. Thus, the screen reader might indicate playing "third string, open fret" for playing a "G." Many intermediate to advanced guitar players, however, are conversant in higher-level elements of music such as chord progressions, keys, and note names. For these types of players, we also built a "Note/Chord" mode. This mode uses a database of chords and note names matched to hand configurations to generate the actual name of the chord or note signified by a particular hand configuration. Thus, if a "G Major" chord is coming up in the piece, instead of providing the verbose hand placement description, this mode succinctly tells the user about the "G Major" chord. This does rely on the user knowing the hand configuration for this chord and thus is a feature targeted at more advanced users.

User Interface Design

People traditionally have kept guitar tabs on their desktop/laptop computers, though an increasing number of users are using mobile devices for music learning. Thus, we prototyped both a Java Swing version that is usable with Java Access Bridge on all major desktop platforms (Figure 2a), and a version of the software for mobile devices (Figure 2b) currently on Android.

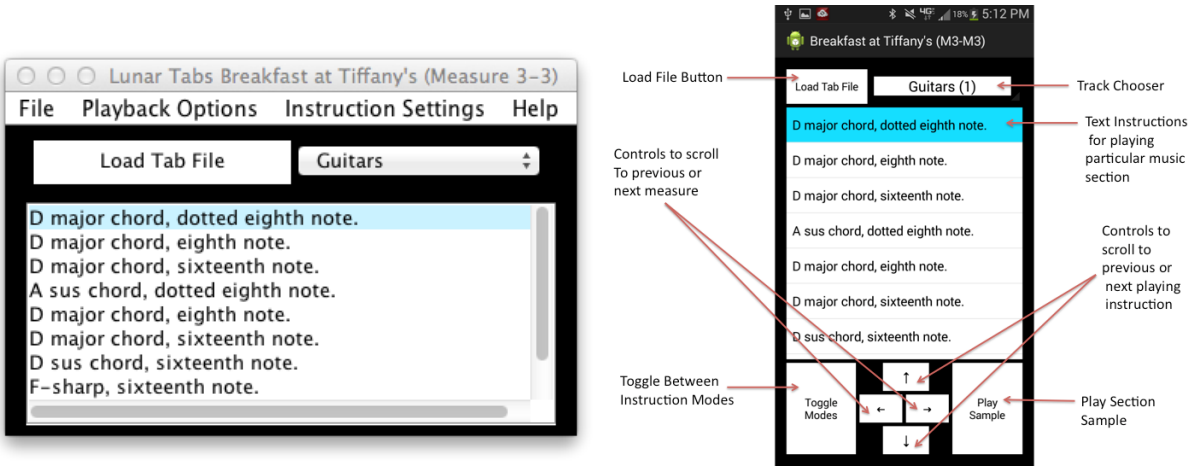

Fig. 2. GUI for Lunar Tabs Desktop application (left) and Mobile Device application (right)

The user interface for each version is designed to maximize functionality for a blind user. The Java Swing version features a grid layout that is completely usable via the keyboard "tab" key. All components are compliant with accessibility standards regarding clear labels and tool tip text so that a screen reader will pick them up when the user accesses a component. The mobile device version features a similar top-down layout that is usable via the "Talkback" (also known as "Explore by Touch") feature that provides the user a two-tap interface. The first tap only reads the component label, and the second tap actually performs the click action. Key components are placed on the edges of the screen, where low vision users normally look first for application controls.

Large and clear components on each version allow the user to load a guitar tab file from their file system, choose an instrument track in the file to generate instructions for, and see the instructions in either String/Fret or Note/Chord mode. A list presents playing instructions for a musical measure. The Java Swing version features hotkeys that allow the user to switch between modes, scroll back and forth between musical measures, as well as synthesize and play a MIDI sample of the currently viewed musical measure to hear a sample of what the measure sounds

like when played as written. In the mobile version, these hotkey features have corresponding buttons whose labels can be accessed via explore by touch.

Advanced Technical Features: Repetition Segmentation Mode

A person without visual impairments can scan the entire musical piece at once, identifying key repetitions. For a user with visual impairments, such capability must be facilitated through the instruction presentation. We experimented with algorithms to intelligently identify repetition in a music piece for presentation with a screen reader.

Users often find it helpful if unique measures are only taught once over a screen-reader. For instance, one arrangement of the song Breakfast at Tiffany's (originally by Deep Blue Something) contains 118 measures of acoustic guitar instruction. However, the rendition contains only 10 unique measures. The time required for scrolling through and hearing playing instructions for those 10 unique measures over a screen-reader pales in comparison to scrolling through and hearing the entire instruction stream.

Computer Music has studied approaches to identifying musical repetition such as Chrochemore's algorithm and the Local Boundary Detection model (Cambouropoulos). Drawing inspiration from such ideas, we developed Repetition Segmentation, a mode in Lunar Tabs that (1) finds the unique measures in the piece, (2) identifies how many times they repeat, and (3) presents the unique measures in chronological order while informing the user of number of subsequent repetitions. This allows users to get an understanding of the key unique measures in the piece and their occurrence frequency.

To estimate timesaving of Repetition Segmentation, we defined the compression ratio of an instrument track as: **Compression Ratio = 1 – (#Unique Measures / #Total Measures)**

Since a user's time in learning in piece over a screen-reader is dominated by the number of screen-reader instructions read out to the user, the compression ratio measures the time savings of Repetition Segmentation in terms of the number of saved audio playing instructions. Tested on a data set of guitar tabs from Ultimate Guitar's "Top 100 Downloaded Guitar Tabs," the repetition segmentation mode achieved favorable theoretical timesaving with a mean compression ratio of 0.58. We estimate the algorithm can save a user nearly 50-60% of the time by listening to the instruction stream from Repetition Segmentation rather than the full one.

Advanced Technical Features: Hands-Free Application Use Scenarios

When one has a guitar in their hands, it can be inconvenient to press buttons on an application. We prototyped three hands-free modes to automate Lunar Tabs: voice actions, stomp mode, and midi following.

Lunar Tabs allows voice commands like "next," "back," "up," and "down" to enable scrolling through sections in the piece. A "play" command generates a midi synthesis of the current measure. Audio icons help users understand a chord by playing its component notes.

Stomp Mode allows a user to go to the next playing instruction by stomping their feet. If a mobile device is placed on a sufficiently tensile floor surface, a user's foot stomp vibration will propagate through the floor surface and register as a spike on the accelerometer. Using a filtering algorithm, Lunar Tabs detects foot stomps near the device to advance playing instruction.

In Midi Following mode, inexpensive hexaphonic guitar pickups are used to allow Lunar Tabs to follow the user's playing. Hexaphonic pickups (such as Fishman Triple Play) mounted on the guitar can be used to obtain midi from the guitar, streamed over Bluetooth to a USB receiver on the mobile device. Lunar Tabs uses string-matching algorithms to match what the

user plays with instruction, advancing instruction upon successful playing of current instructions.

Interviews and User Studies

To measure the usability and usefulness of Lunar Tabs, end user studies were conducted with seven low-vision guitar players. Users communicated feedback through semi-structured interviews, independent test sessions, and survey questionnaires. Feedback was compiled into a text corpus, and analyzed for emergent themes. Key identified themes are shown in Figure 3.

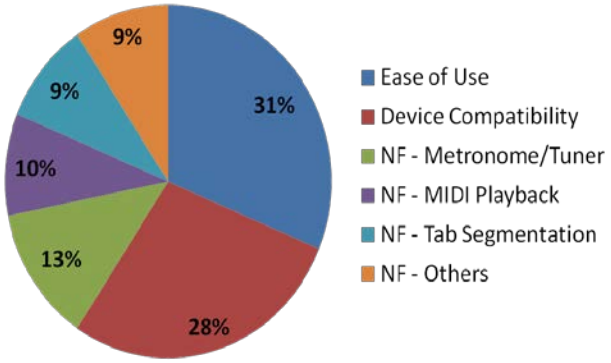

Fig. 3. Thematic Analysis of User Feedback Sessions

User feedback was categorized into three specific themes: Ease of Use, Device Compatibility, and New Feature Suggestions. Ease of Use is defined as any discussion surrounding the user's efficiency in accessing guitar tabs. The survey asked users to compare Lunar Tabs to other guitar tab readers they knew about, and Lunar Tabs consistently ranked first in Ease of Use. Users appreciated the range of methods available to interact with the application, especially the hands-free modes. Device Compatibility includes all the user discussion around integration of Lunar Tabs with their existing mobile and desktop technology. Users owned a variety of devices, and requested implementations across different platforms. The remainder of the user feedback was comprised of New Feature Suggestions – specific features that would

improve the overall functionality of Lunar Tabs for users. These included metronome functionality, MIDI playback capability, and additional song segmentation options.

A key finding is that incorporating the user-inspired features created a more usable and useful application for both low-vision and sighted users. For example, the Repetition Segmentation mode described earlier would enable all guitar players to learn tabbed songs more quickly than they otherwise might. The hands free modes could be useful to many different types of users. The application of usability principles in the design and development of Lunar Tabs allows us to create improved and universally inclusive technology.

Conclusions

We have created Lunar Tabs, a screen-reader friendly guitar tab reader that allows persons who are blind or have low vision to access information in guitar tabs. In addition to building an accessible user interface, we experimented with intelligent methods to convey repetition information in the piece and use the application in hands-free modes. User studies with guitar players with low vision identified key dimensions of user feedback that help evaluate the technology's impact. By implementing our experimental designs and incorporating users feedback, we hope to empower persons with low vision to access the wealth of guitar tabs online.

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Effects of Assistive Communication Training on Stereotypy with Individuals with ASD

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Abstract

Participants with autism spectrum disorder were exposed to communication training using the ProxTalker®. Two male participants were selected with histories of limited use to effective assistive communication and defined stereotypic behaviors. Participants were exposed to a systematic communication training using the device. Modifications to the systematic teaching procedures for communication training were made to delay increasing distance from the device. The effects of the communication training on observed stereotypic behaviors were measured through scheduled videotaped observation using a time sampling procedure. The results showed a decrease in motor stereotypic behaviors in the participants as they progressed through communication phases.

Keywords

Autism spectrum disorder, communication training, behavior

Introduction

When establishing an effective training method to increase communication for people with autism spectrum disorder (ASD), it is important to determine the type of methodology to be used (selection-based or topography-based) to achieve functional communication. Early verbal behavior studies found more favorable results with the use of a topography-based program; it was not investigated specifically for individuals with ASD (Sundberg and Sundberg). Individuals with ASD with an inability to vocally communicate and/or inability to perform fine motor tasks involved with sign language were excluded from early studies.

A later study found in comparison to typically developing children of the same intellectual age, children with ASD study reached mastery sooner with the selection-based communication for tacts and intraverbals (Vignes). The use of augmentative and alternative communication (AAC) with naturalistic teaching procedures demonstrated an increase in communicative interactions with others for four young children with ASD (Schepis, Reid, Behrmann, and Sutton).

Selection-based methods of communication are increasing in applied settings with AACs, advances in technology and utilizing the Picture Exchange Communication System (PECS). PECS has six distinct training phases that systematically increase to phrases with a sentence strip using line drawings, photos or pictures (Bondy, Tincani and Frost). A significant difference was not found in acquisition of requesting skills between use of PECS book or AAC device using PECS training for three children with autism (Boesch, Wendt, Subramanian and Hsu).

The combination of the PECS phases and behavioral intervention was found to be effective to decrease identified stereotypic behaviors and increase communication with individuals on the autism spectrum (Malhotra, Rajender, Bhatia and Singh).

The purpose of this study was to assess the effect of utilizing the phases of PECS for communication with an AAC (ProxTalker®), on defined stereotypic behaviors for two participants with histories of limited use to effective assistive communication.

Method

Participants & Settings

Two boys with ASD were the participants of this study. Don, 10, had limited independent and effective communication and had previous exposure to a photo communication book and had not mastered Phase II of PECS. Ronnie, 9, used verbalizations of phrases (prompted or spontaneous) as a primary mode of communication with no exposure to AAC. Stereotypic behaviors (motor and vocal) occurred persistently throughout the school day for both participants and limited time for academic instruction.

All sessions to date occurred in the participants' school while following their normal school day routine and academic programming. During intervention and school hours, all participants had access to the ProxTalker® and picture tags. Instruction for the AAC was at each participant's communication training phase determined by phase criteria.

Response Measurement

Vocal stereotypy examples included: nonfunctional vocalizations, echolalic responses, lips moving with/without audible sounds. Motor stereotypy examples included: tapping surfaces, rubbing hands together in repetition, jumping up when not instructed, clapping when not functional and/or placing 1 or more fingers in clothing with a twisting motion.

The effects of communication training using an AAC for stereotypic behaviors were measured using a time sampling procedure. In all phases, stereotypic behaviors were scored for

presence or absence in 10 minute sessions divided into 15 second intervals. All sessions were videotaped.

Reliability

A second observer independently collected data on stereotypic behaviors and eye gaze shift from videotaped sessions. Interobserver agreement data were collected for a minimum of 30% of sessions in each condition across all phases and participants; mean agreement was 86.5% for participant Ronnie and 74% for participant Don.

Procedure

During baseline, the staff collected partial-interval recording data on stereotypic behaviors during varied times throughout the school day in the absence of the AAC and communication training.

Phase I

A second staff member was placed behind the student and manually guided the steps to create voice output. The target objective was defined as the participant demonstrating the ability to pick up the picture tag of the item in a single array and place the tag on a location button on the ProxTalker®, creating a voice output when presented with a highly preferred item with a minimum of 8 out of 10 correct and independent trials. Data probes were conducted to determine participant acquisition of this phase.

Phase II

Phase II was modified from the traditional communication training of increasing distance between the user and the book. The terminal objective for the modified Phase II was for participants to discriminate between highly preferred item pictures and distracter pictures until a

minimum of 8 out of 10 correct and independent trials occurred. The student requested desired items that were placed in their line of vision, by selecting the appropriate picture from an array on the ProxTalker® and placing the tag on a location button creating voice output. This phase had three parts; highly preferred versus non preferred, highly preferred versus highly preferred and up to 5 highly preferred items. The error correction procedure was the same as Phase I.

Phase III

The terminal objective for the modified Phase III was for participants to request present and non-present items using a multi-word phrase by going to the ProxTalker®, picking out the tag "I want" and placing on the location button, picking out the tag of what is wanted on the location button and pushing each tag to create voice output until a minimum of 8 out of 10 correct and independent trials occurred. The error correction procedure was the same as previous phase.

Phase IV

The terminal objective for the modified Phase IV was for participants to request present and non-present items/activities using a multi-word phrase by going to the ProxTalker®, picking out the tag "I want", the appropriate verb "to_____" and placing on the location button, picking out the tag of what is wanted on the location button and pushing each tag to create voice output until a minimum of 8 out of 10 correct and independent trials occurred. The error correction procedure was the same as previous phase.

Phase V

The terminal objective for the modified Phase V was for participants to request present and non-present items/activities using a multi-word phrase by going to the ProxTalker®, picking out the tag "I want", the appropriate verb "to_____", one descriptor word tag (colors, shape or

size) and placing on the location button, picking out the tag of what is wanted on the location button and pushing the green circle all play button. The student commented on present items using a multi-word phrase by going to the ProxTalker®, picking out the tag, “I see”, one descriptor word tag (colors, shape, size), the tag for the item described and placing all on the location buttons and pushing the green circle all play button. The objective was met when a minimum of 8 out of 10 correct and independent trials occurred. The error correction procedure was the same as the previous phase.

Phase VI

The terminal objective for the modified Phase VI was for participants to seek out communication device from increasing distances within the classroom environment (1 foot, 3 feet, 5 feet) when instructed or presented with opportunities to communicate with others until a minimum of 8 out of 10 correct and independent trials occurred. The error correction procedure was the same as the previous phase.

Discussion

The results for participant 1 are shown in Figure 1 and Figure 2. For Don, there was a continued variable engagement of stereotypic behaviors, with vocal stereotypy increasing. During sessions 16 & 17, Phase II B trials required increased prompting when selecting from two highly preferred items. Stimulus prompts were placed on the device to assist with placing the tags on the correct location buttons. The results for Figure 1 reflect that the amount of vocal stereotypy did not decrease between baseline and intervention phases. The baseline average for engagement in observed trials of vocal stereotypy was 44% of measured trials. The intervention average for engagement of observed trials of vocal stereotypy was 51% of measured trials. The results of displayed in Figure 1 and Figure 2 reflect that the amount of motor stereotypy did

decrease between baseline and intervention phases. The baseline average for engagement in observed trials of motor stereotypy was 25% of measured trials. The intervention average for engagement of observed trials of motor stereotypy was 10% of measured trials. Figure 2 shows the motor stereotypy decrease in isolation.

The results for participant 2 are demonstrated in Figure 3 and Figure 4. Ronnie had a decrease in both vocal and motor stereotypy in the intervention phase in comparison to the baseline phase. The summary graph in Figure 3 shows that the amount of vocal stereotypy engagement did decrease from baseline average of 59% of measured intervals to an intervention average of 35% of measured intervals. Figure 4 shows the motor stereotypy decrease across phases in isolation.

Conclusions

The results reflect that for both participants there was a decrease in motor stereotypy with the use of the ProxTalker® using a modified communication training protocol. For both participants, there was also an increase in mastered communication exchange phases. Also for both participants there was an increase in independent communicative intent, vocalizations for Don and typing/use of a tablet device for Ronnie.

Anecdotal staff notes did show that for participant Don, there was an increase in reported vocalizations throughout the school day. It should also be noted that for participant Don, any vocalization was counted as vocal stereotypy. This may lead to discounting vocalizations that are intended to communicate with another individual and scoring them as stereotypic behaviors leading to higher percentages.

Anecdotal staff notes for participant Ronnie included that after mastery of modified Phase V, the participant showed independent interest in using text for communication. The

continued combination of the ProxTalker® training with communication with text was maintained after the student mastered Phase VI of the phases.

The participant sample in this study was relatively small and the focus of the behaviors targeted did not include those with extreme severity. For future investigations, it would be recommended to increase the number of participants with more intensive behaviors (eg. aggressions to others and self-injury). It would also be recommended to examine the effects of using the ProxTalker® on the rate acquisition of receptive identification programs with non-verbal students compared with traditional materials.

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Using Tablet Devices to Engage Children with Disabilities in Robotic Educational Activities

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Abstract

In a number of prior efforts, robotics-based activities has been shown to encourage K-12 students to consider careers in science, technology, engineering, and math (STEM) and has been incorporated into a number of engineering and computer science disciplines at a number of universities. Unfortunately, for children with disabilities, there are still inadequate opportunities for teaching basic science and engineering concepts using robotics-based curriculum. This outcome is generally due to the scarcity of accessible interfaces to educational robots. On the other hand, the widespread availability and ease-of-use of tablet computers have given rise to opportunities to engage children with visual, cognitive, and learning disabilities through various Apps. Due to their pervasive characteristics, these mobile platforms provide an ideal opportunity to integrate robots into the learning environment for children with disabilities. As such, in this paper, we discuss the integration of tablet computing platforms with alternative interface modalities to engage children with disabilities in robotics-based educational activities. We provide an overview of the interaction system and results on pilot studies that engaged nine children with disabilities in a number of Saturday robotics camps.

Keywords

Accessible Robots, Switch-to-Tablet Interface, Programming, K-12 Education, Assistive Technologies

Introduction

The percentage of entering college freshman reporting disabilities continues to increase in the academic environment [1, 2]. Among those undergraduate students with reported disabilities, only 8.7% majored in engineering or computer science [1]. Differences in precollege math and science education, which provides a foundation for pursuing a technical degree, are a large contributing factor to this disparity. At the pre-college level, approximately 11% of children between the ages of 6 to 14 have a reported disability [3, 4], and yet these students took fewer science and mathematics courses than those without disabilities. These differences are generally due to the unavailability of information in accessible formats [3]. However, many students with disabilities, like most students in K-12, are naturally interested in robotics [5]. Educational robotics has been shown to encourage non-traditional students to consider careers in engineering and science and has been incorporated into a number of engineering and computer science disciplines at a number of universities [6]. Robotics has even been used as a mechanism to teach mathematics [7] and science [8] to K-12 students. As such, as long as these robotic systems can be made accessible, robotics-based curriculum could provide a motivating factor to encourage children with disabilities to consider careers in engineering and science.

Currently, due to the pervasiveness of tablet devices and their ease-of-use, the emergence of tablet-based applications (Apps) for providing educational opportunities for children with disabilities is fast growing. With advances in Augmentative and Alternative (AAC) communication Apps [9] to cognitive memory Apps [10], resulting studies indicate that the use of Apps can provide effective therapeutic solutions for children with disabilities. And yet, the few efforts that are currently deployed to engage students with disabilities using robotics [11-14] are not utilizing these tablet devices as a delivery mechanism. As such, our efforts differ from

other related projects in its attempt to engage pre-college level students with disabilities by integrating accessible interfaces with tablet-based robotic applications. In this paper, we discuss our interaction interface for making robotic platforms accessible and provide results from conducting a number of Saturday robotics camps that engaged nine children with disabilities, including those with Cerebral Palsy, Spina Bifida, Spinal Muscular Atrophy, Traumatic Brain Injury, and Autism.

Methodology

To enable delivery of accessible robotic educational activities, we require a platform that is adaptable to children with diverse needs. Due to the ease-of-use and portability of tablet devices, we developed such a platform by combining accessible interfaces and switch-accessible Apps for robot interaction. This interface was then integrated with multiple robotic platforms for engaging children with disabilities into the robot activities.

Accessible Interfaces and Apps

Although the current assistive technology market has provided speech, hearing, and visual aids using tablet devices, the market has overlooked the large populace that has difficulties using the touchscreen interface. Unfortunately, these interfaces are developed assuming a child is capable of 'touching' a specific small region with appropriate intensity and timing (i.e. effecting press and swipe gestures). This assumption does not generally hold true when considering children who possess limited upper-body motor control, such as observed in children living with cerebral palsy or recovering from traumatic brain injury. Given that over 200,000 children with disabilities being served in the public school system have an orthopedic impairment [4], there is a large demographic of children that are now being overlooked by the introduction of the tablet device into mainstream society. For such children with motor impairments, general access to

computing platforms is currently accomplished using a physical device, such as a switch. Switch types of devices range from hand switches, head switches, foot switches, mouth switches, and even switches that can detect muscle movement. To enable use of software applications with switches, an application should enable scanning, a technique that enables movement through a pre-set list of elements that can be selected. Step scanning (or single-switch scanning) allows transitioning through the elements in a pre-set order whereas two-switch scanning enables a range of scanning options that include row and column navigation. The speed and pattern of scanning, as well as the way items are selected, must be individualized to the physical, visual and cognitive capabilities of the user. Although there are a variety of switches that can translate consistent and voluntary movement from any body part, the switch, itself, cannot be directly plugged into a computer or tablet device. In order to use a switch, a switch interface must be used to connect the switch to the computer. Thus, in order to provide children access to robotic platforms, we utilized a wireless controller called TabAccess™, which increases accessibility to tablet-based Apps that are used to interact with the robotic platforms (Figure 1). This alternative interface is designed to engage children that have difficulties affecting the common pinch and swipe gestures required for touchscreen-based interaction.

To enable direct command of the robot, we also designed switch-accessible robot interaction Apps that integrated step-scanning and two-step scanning options (Figure 2). The robot interaction Apps provide various robot control commands - typically forward, back, left, and right, as well as options to store a logical sequence of commands, which enables replay of a child's stored program. Images (e.g. directional arrows) are used to identify the robot commands and, during the scanning operations, the commands are also highlighted with sufficient contract to reduce cognitive load. The switch-accessible robot interaction Apps, coupled with the

accessible interface, allowed the development of an accessible robot interaction system that could be individualized to the capabilities of the child and engage a wider demographic of children with disabilities.

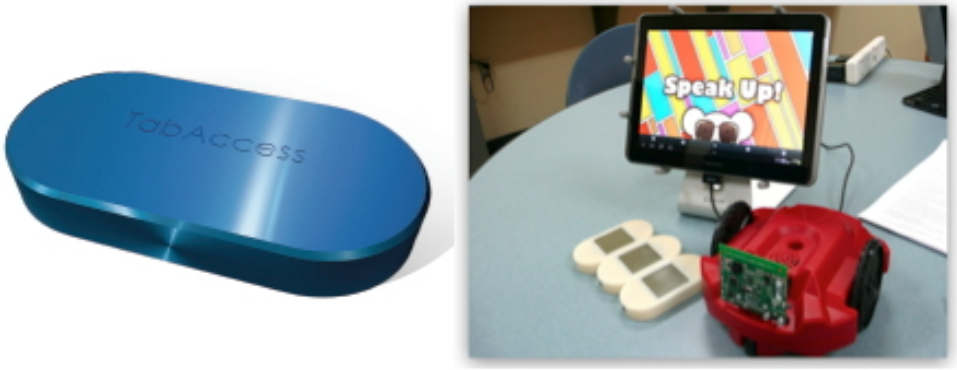

Fig. 1. Accessible Interface for Tablet Interaction

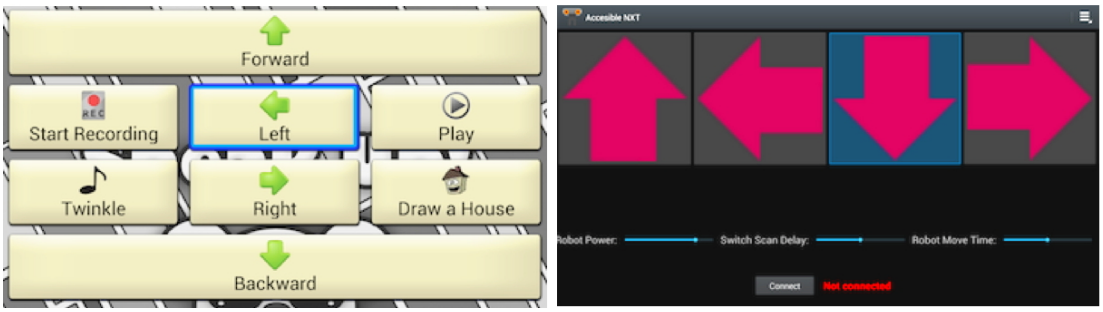

Fig. 2. Switch-Accessible Robot Interaction Apps

Robotic Platforms and Challenges

To address the unavailability of accessible interfaces for interacting with robotic platforms, we developed switch-accessible tablet Apps to interact with three Bluetooth-enabled commercial robots – the Lego Mindstorms, the Scribbler robot, and the Romibo. Lego

Mindstorms (http://mindstorms.lego.com) is a popular robotics kit that contains software and hardware parts (microprocessor, sensors, motors, and Lego parts) for creating customizable, programmable robots. The Scribbler robot (http://www.parallax.com/product/28136) is a small, low-cost fully programmable robot that also provides a pen port to enable the robot to physically draw as it drives. The Romibo platform (http://www.romibo.org) is an open-source do-it-yourself social robot that is designed for autism-based research. To provide a focused objective for the robot educational activities, we initiated a curriculum that centered on different challenges using these three different platforms, depending on the needs of the child. One competition focuses on the use of Lego robots in a Kick-the-Can competition (Figure 3a). In this challenge, the Lego robot was equipped with a wide base that allowed the robot to knock down objects. Children used their App to directly command, or program, their robot to knock down small blocks in a given time period. Another challenge focused on the use of the Scribbler robot in a drawing challenge (Figure 3b). In this challenge, the robot was equipped with a drawing pen of their color choice. Children used their robot App to draw different shapes, with the ultimate goal of having their robot draw a picture of their own choosing. The remaining challenge was focused on the use of the Romibo robot in a Maze-Solving challenge (Figure 3c). The Romibo, a DIY platform assembled at Georgia Tech, was used to navigate a maze from a start to a goal position, by controlling it with the tablet App. These challenges were non-destructive, kid-friendly, and a great learning experience for the students.

Fig. 3. (a) Lego robot and the Kick-the-Can Challenge (left), (b) Scribbler robot and the Drawing Challenge (center), and (c) Romibo robot and the Maze-Solving Challenge (right)

Pilot Study and Evaluation

To evaluate the effectiveness of the accessible interfaces for engaging children with disabilities in robotic educational activities, we ran a number of Saturday robotics camps. A total of 9 children with disabilities participated, each having various technical experience levels (Table I). Primary diagnosis of these children ranged from those with Cerebral Palsy, Spina Bifida, Spinal Muscular Atrophy, TBI, and Autism (Table II). Children ranged in age from 8 years old to 14 years old, with an average age of 10.2 years of age, and standard deviation of 2.2. Of particular interest was to evaluate the change in perspective of the children based on their experience interfacing with the robots (Table III). Based on pre-camp perception, on average, the students only considered working with computer/robotics a little when older. After participating in the robot camp, it can be noted there was strong agreement that they were capable of working with computers/robotics as a career possibility.

Table 1. Statistical Measures on Experience (A lot = 4; Some = 3; A little = 2; None = 1)

Experience	**Average**
Experience with a Computer	3.3
Experience using a switch or button to control a computer	3.4
Experience with programming	1.7
Consideration of working with computers or robotics when older	2.4

Table 2. Demographic profile of children

Number of Children	**Primary Diagnosis**	**Age (Avg ± Stdv)**
3	Cerebral Palsy	11.3 ± 3.1
3	TBI, Spinal Muscular Atrophy, Spina Bifida	10 ± 2
3	Autism	9.3 ± 1.5

Table 3. Measures on Perception

	Mean	**Stdv**
Pre-Session: How much have you considered working with computers or robotics when you grow up?	2.4	1.1
Post-Session: How much do you think this workshop helped show you that you are capable of working with computers or robotics?	3.6	1.0
How much has this workshop encouraged you to consider working with computers or robotics when you grow up?	3.1	0.6

Discussion and Conclusions

The field of robotics is extremely popular across generations of students. The use of robotics to teach Science, Technology, Engineering, and Math (STEM) concepts flourish in the literature and cover the entire educational spectrum from K-12 through graduate school. Unfortunately, the scarcity of accessible interfaces to educational robots can lead to children with disabilities not having equal participation with peers in these robot-based educational activities. In this paper, we have discussed how robotic educational platforms can be made accessible to children with disabilities by integrating tablet computing platforms with alternative interface modalities. The results from integrating these accessible interfaces into a number of educational modules was highlighted in a series of Saturday robotics camps that show the possibilities of utilizing this interaction system to engage children with disabilities.

Future work in this domain will focus on the dissemination of learned practices and the accessible robotic platform kits. A strong benefit of this effort is the development of alternative interfaces that can be shared with others such that educators can engage students with disabilities in the classroom environment. Teachers should be able to utilize the accessible infrastructure to encourage participation of students with disabilities in robotic educational activities. Students

themselves should also be able to use the provided infrastructure to enable independent exploration of other activities.

Acknowledgement

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Using Mathematics eText in the Classroom: What the Research Tells Us

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Abstract

This paper discusses the findings from two research studies where middle-school students with learning disabilities used eText containing MathML with assistive technology, and draws conclusion from these combined findings. The University of Kentucky Curriculum Conversion and Implementation research strand was conducted as part of the Mathematics eText Research Center (MeTRC), a federally-funded national research, led by the University of Oregon. This research strand was designed as a follow-up to Project SMART (Supported Math Accessibility Reading Tool), an earlier project at the University of Kentucky. Project SMART indicated the utility of math eText using Mathematical Markup Language (MathML) as an effective accessible format for students with reading disabilities. The subsequent MeTRC/KY research project was a case study examining the pragmatic issues around the utilization of math eText in a middle-school classroom setting, such as the conversion of a complete math curriculum using MathML, training needs for staff and students, hardware and software issues, and technical support needs. While both studies noted implementation challenges in real-world classroom settings, student results nevertheless indicated better utility and improved academic performance when mathematics eText was available.

Keywords

Mathematics, etext, MathML, learning disabilities, assistive technology

Introduction

The utilization of eText with synthetic speech technology has a long history in the disability field. One of the first coordinated efforts to produce accessible eText materials for use with assistive technologies was led by George Kerscher, when he founded Computerized Books for the Blind at the University of Montana in 1988 (Lingane, Noble & Senge, 2002). However, the nature of math notation--which makes extensive use of non-ASCII symbols and two-dimensional layout--the ability to include math equations and elementary 2D math problems in a format that synthetic speech technologies can interpret, the availability and usage of math eText has been slow to emerge. This situation has changed in recent years due to the standardization of Mathematical Markup Language by the W3C, which issued the first MathML specification in 1998. The most current specification, MathML 3.0, was released in 2010, and the 2nd edition was issued in 2014 (http://www.w3.org/TR/MathML3/). The support for MathML in both mainstream and assistive technologies continues to grow, with integration in most of the newest major format specifications, such as DAISY3, HTML5 and EPUB3.

Nonetheless, there are pragmatic concerns and questions within the education community as to the utility and effectiveness of accessible mathematics eText as a viable alternative format for the widespread population of K-12 students with reading impairments. While larger postsecondary institutions and state schools for the blind often have designated staff and teachers with specialized training and experience in alternative format creation and assistive technology support, such personnel are typically lacking in mainstream school districts. Therefore, the findings of research actually conducted in K-12 school settings, as detailed in this paper, are highly valuable to the field.

Discussion

This paper discusses the findings from two classroom-based research studies where middle-school students with learning disabilities used eText containing MathML with assistive technology. The University of Kentucky Curriculum Conversion and Implementation research strand was conducted as part of the Mathematics eText Research Center (MeTRC), a federally-funded national research, led by the University of Oregon. This research strand was designed as a follow-up to Project SMART (Supported Math Accessibility Reading Tool), an earlier project at the University of Kentucky. Project SMART indicated the utility of math eText using Mathematical Markup Language (MathML) as an effective accessible format for students with reading disabilities (Lewis, Noble and Soiffer, 2010). The subsequent MeTRC/KY research project was a case study examining the pragmatic issues around the utilization of math eText in a middle-school classroom setting, such as the conversion of a complete math curriculum using MathML, training needs for staff and students, hardware and software issues, and technical support needs. While both studies noted implementation challenges in real-world classroom settings, student results nevertheless indicated better utility and improved academic performance when mathematics eText was available.

One of the fundamental questions for the field, however, is whether supplying accessible math eText to K-12 students with identified reading disorders (e.g., a specific learning disability affecting reading) who then use it with synthetic speech technology is useful to students as a reading accommodation. Throughout the K-12 education community, one of the most commonly provided reading accommodation--in both classroom instructional and assessment settings--is having a teacher or staff member read aloud to the student whose disability adversely impacts

their ability to read print. This is especially true on end-of-year state assessments (Clapper, Morse, Lazarus, Thompson, & Thurlow, 2005).

The rationale for human readers is easy to see, since it requires little preparation or planning. However, in practice, it is unclear if this form of accommodation is truly useful for students with reading impairments, as it is typically dependent upon students to request a read-aloud each time it is needed. For instance, during classroom observations conducted as part of the MeTRC KY research strand, researchers found that the provision of read-aloud accommodations by human readers in the context of math classroom instruction among middle-school students was very rare, even though included on students' IEPs. This was true even for students who were taught in a resource room setting.

However, one important finding of this study was just how inaccessible printed math material was for these students. The project's testing of students' ability to properly decode mathematics instructional content showed that these students had significant issues with processing the symbolic content of middle-school math. Students in the study sample exhibited an average error rate of 6.7% in reading plain text, but there error rate for reading math symbolic content soared to 36%, which illustrates the significant obstacle these students were facing in reading math content on their own (Lewis, Lee, Noble & Garrett, 2013). In many respects, this finding defies common belief that sighted students with reading disabilities studying math only need to use text-to-speech applications when trying to read word problems. Much to the contrary, students need speech access to the math notation itself, even more so that to the textual portions of math materials.

This realization of a true access barrier to the comprehension of mathematics materials in print form helps to set the state for an understanding of what happens when these same students have access to accessible digital math content instead of printed math. Students in both the prior SMART study as well as MeTRC/KY research exhibited marked improvement in math performance when given math eText which included MathML, which allowed their assistive technology software (in this case, Read&Write Gold by TextHelp) to read both the text and the math expressions in a seamless manner. In the case of Project SMART, when 8th grade students using MathML-encoded eText versions of the pre-algebra textbook "Say it with Symbols" (from Pearson's Connected Mathematics 2 Program) were given pre-post unit tests, intervention students from all three different schools in the study fared better than those in the control group who received standard read-aloud accommodations, ranging from an average increase of 8%, to 14% to 16% among the intervention students when compared to the control group (see Table 1 below). The fact that the other textbooks in the study which had lesser amounts of symbolic math content (and hence, a lower MathML density as referenced in Table 1) showed less consistency in student outcomes helps to confirm the fact that for such students reading the plain text is not near as much of an issue as reading the type of symbolic math notation commonly found in middle-school and later math content.

Table 1. Comparison of Pre-Post Test Difference in Intervention vs. Control Samples for Students Using Math eText with MathML (Difference Intervention vs. Control in Four Classroom Settings (3 semesters))

Book Title	**Notational Complexity**	**MathML Density**	**CW-Spring 08**	**CK-Spring 08**	**SE-Fall 08**	**SE-Spring 09**
Say it with Symbols	High	10.95	+14%	+16%	+8.01%	--
Filling/ Wrapping	Low	0.86	+16%	--	--	--
Samples	Very Low	0.35	-3.4%	+10%	--	-5.4%

The results from the MeTRC study revealed similar results. In this case, both the intervention classroom and the control classroom were taught by the same teacher using the identical curriculum, the primary difference that the intervention group used MathML-encoded eText while the control group used standard read-aloud accommodations. Students using math eText outpaced students who did not by more than double, with a yearlong average gain in MAP (Measure of Academic Progress) math scores of 16.67 points for the students using math eText and only 8 points for the control students. One remarkable aspect in this study was that the special education students who used the math eText outpaced even the whole seventh grade as an average, in which the special education students represented the students who--before the study--had the most trouble with math performance. In a sense, these special education students with a history of struggling in math were able to compete on par with their non-disabled peers when they had access to their math content in MathML. That finding is certainly noteworthy.

Table 2. Comparison of MAP Math Scores for Intervention vs. Control Samples for Students Using Math eText with MathML

Students' Math Class	**October Math Score**	**January Math Score**	**April Math Score**	**Oct-Jan Math diff**	**Jan-Apr Math diff**	**Oct-Apr Math diff**
2nd period res. avg. (control group)	196.60	196.20	204.60	-0.40	8.40	8.00
5th period res. avg. (intervention group)	**187.00**	**193.177**	**203.67**	**6.17**	**10.5**	**16.67**
7th grade overall avg.	223.4	226.8	238	3.4	11.2	14.6

Furthermore, qualitative data tracked by both research projects indicated that both students and teachers found math eText to be highly effective in providing access to math instructional content. Positive factors for teachers included that not only did students seem to do better with math eText, but it also freed up more teacher time for real teaching rather than reading text out loud to the class. In addition, students generally preferred reading support through the computer as a independent access to text and which gave opportunities to reread passages at their own pace, something which has been noted in other research (Flowers, Hong Kim, Lewis, and Davis, 2011).

Conclusions

On the down side, both research studies uncovered problems related to the reliability of hardware and software in school settings. These problems actually had no connection to using MathML per se, but were rather connected with the fact that using any digital content requires access to computer technology of one form or another. In both of these studies students used

laptop computers which were connected to the school's wireless networks. Common issues included dead laptop batteries, wireless access problems, forgotten passwords, and IT updates which caused previously working software installations to suddenly stop working. Furthermore, teachers and students even found the time it took to start up and shut down computers problematic. Of course, these issues can occur with any technology, but such problems--if pervasive enough--can be a motivating factor for schools, teachers, and students to abandon use of eText of any form and revert back to the "old reliable" human read-aloud accommodation.

Additional questions which these studies uncovered include:

- How do schools support technology and train staff and students when there's only one teacher? Again, this would be true of any use of technology, but it is a question which must be addressed before an effective implantation of eText usage can occur.
- Where do schools get math eText content already made and ready to use? Only a few publishers are doing this now, so this continues to be a question to consider.
- How can teachers create their own math eText? Some teachers still use pen and paper and chalk boards to write math. While many math teachers have figured out how to use word processing applications like Microsoft Word to write math equations (or perhaps use products like MathType), most don't understand how to export those documents to MathML so that assistive technologies can render the math as speech. Training and support of teachers in creating their own accessible math materials is an area needing much more attention in the field.

What's next?

To further support schools wanting to implement math eText, a number of steps have become evident to move the field forward:

- The need for awareness and training resources on the use and creation of math eText. There are precious few resources available to teachers and support staff which discuss all the steps and software needed to create and use math eText.
- The need for publishers to adopt MathML in mainstream eBook production. One great help to schools would be the availability of accessible eBooks that are "ready to use" from the publisher complete with MathML. Though Pearson has started to do this with their HTMLBooks collection, few other publishers have done the same.
- The need for MathML support in OCR scanning applications. Other than a little-known application called InftyReader, none of the standard OCR applications support MathML.

In conclusion, while some aspects of the need for supporting teachers and schools in the use of mathematics eText using MathML still need further attention by the field, the outcome of classroom-based research projects like the two discussed here demonstrate the growing evidence of promise for accessible digital mathematics content. With the growing support for MathML in both mainstream and special technology applications and growing adoption among publishers, the education community will be well served by embracing efforts to implement math eText for all educational mathematics materials.

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Futures of Disabilities: Is Technology Failing Us?

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Abstract

This paper examines possible reasons why technology may not be living up to its promise for some people with disabilities (including poor policy implementation, low accessibility, cost, disinterest, lack of awareness, prejudice) and describes preliminary results from the first round of a futures-oriented Delphi survey.

Keywords

Futures, technology trends, policy, culture

Introduction

A remark attributed to Marshall McCluhan, that "we shape our tools and thereafter our tools shape us," suggested that technological developments are the basis of social and environmental change. For people with disabilities, the hope has been that the implementation and application of new technologies, in particular wireless technologies, could have the potential for a transformative impact in their lives in key areas like education, employment and social inclusion. There is some evidence that this is happening, in particular for youth with disabilities (White et al, 2011, Takahashi et al, 2012).

But the reality differs for many people with disabilities, in particular the older generation. People with disabilities only make up 22% of the labor force, for example, compared to 69% of their non-disabled counterparts. Jobs for people with disabilities have tended to be in secondary labor markets characterized by subsistence level pay, low level skill requirements, few opportunities for advancement, and a high number of part time jobs (White et al, 2011).

At the same time, wireless networks and new digital media technologies are having a transformative effect on the ways that people collaborate and act together. Approximately 102% of the US population use wireless products and services (“Wireless Quick Facts”). Wireless phone service expenses surpassed landline service expenses in 2007 with youth (those under 25) spending the most on cellular service, indicating that youth are driving the move away from landline use (“Consumer Expenditure Survey,” 2009). The networks these services support are likely more important for persons with a disability than for the general population (White et al, 2011). For example, telework as an accommodation has the potential to improve the employment rate of people with disabilities, and tablet computers, eReaders and distance learning could positively impact inclusive educational environments. In terms of educational

attainment, some indicators are positive. The high school completion rate of students with disabilities compared to people without disabilities has narrowed over the past two decades, from 24% in 1986 to 6% in 2010 (Kessler Foundation and NOD, 2010).

However critical attainment gaps persist for students with disabilities, in particular to meet new academic content standards (National Center on Educational Outcomes , 2013). NLTS2 in 2006 noted that "a considerable gap in achievement" in reading, mathematics, science, and social studies existed between students with disabilities and their peers in the general population (Wagner et al 2006). Only 12% of people with disabilities 21-64 have earned a Bachelor's Degree or higher ("Profile America," 2011).

Despite the body of disability access law, problems persist for people with disabilities gaining and maintaining access to information communications technologies and the benefits that ensue. In some cases, new technological advances may result in some parts of the population being left behind. For instance, TTY (teletype) use among people with hearing loss is in rapid decline ("Comments of the National Association of the Deaf," 2010). Yet, there is only limited alternate access via a few pilot programs for a person who is deaf or speech impaired to contact 9-1-1 from their mobile device ("Comments of the National Association of the Deaf," 2010). Maintaining access is central to the discussion because technological developments far outpace the rules and regulations that govern their use. For example, laws that were in place and applicable to accessing basic phone service, are suddenly unsuitable for access to voice over Internet protocol (VOIP) (Lev, 2013). More often than not, the competing priorities of government, industry and consumers create a stalemate on the progress and implementation of rules and regulations concerning accessible ICT. A prime example is the to-and-fro of rules and regulations governing broadband (Beck, 2014).

Methodology: Futures and Delphi

The Wireless RERC (see end note) is in the process of researching what kinds of physical, economic, social and policy factors serve as the context for the migration from legacy, analog technologies to mobile, digital technologies, and, more broadly, what the futures of disabilities might look like. A specific focus is on the split between migrators and non-migrators, e.g. what is the nature of those who are falling behind, is the gap closeable and what if any are the consequences. As part of this endeavor, the Wireless RERC embarked on a futures visioning exercise in 2013, based on a modified, policy-oriented Delphi method, which serves as the foundation for this paper.

Futures

Different cultures, fields, and disciplines have recognized the future as an area worthy of exploration (Bell, 1997). The aim of “futures studies” is to understand the different possible futures that might unfold, and understand why trends and factors may drive the future in one direction versus another equally plausible one (de Beer, Mogyoros, and Stidwill, 2014). There are numerous theories and methods that futurists have developed, tested, and applied in recent years, including the Delphi technique described below. The fundamentals are that futures studies do not pretend to predict "the future." Rather, the intent is to study ideas about the future, "alternative futures" which should be envisioned, invented, implemented, continuously evaluated, revised, and re-envisioned as "preferred futures"(Dator, n.d.).

Delphi

One technique for arriving at possible preferred futures is known as the Delphi process, a set of procedures for eliciting and refining the opinions of a group - usually but not always a panel of experts (Dalkey 1967, Brown 1968). It is a group communication process aimed at

"allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff, 1975). The aim of a policy Delphi is not to achieve consensus but to generate a wide range of views: in short to act as a forum for ideas and to explore a range of positions on different topics related to the issue (Bijl, 1992). For this study, the primary issue focus of the Delphi is on the migration from legacy technologies to advanced communications services and wireless technologies. Migratory trends are interpreted broadly, to include macro trends (e.g. analog to digital, fixed to mobile, and content migration including social media, cloud, and smart/connected everything) and micro trends (e.g. print to electronic text, TTY to mobile, etc). The overarching theme is as indicated above, to seek to understand the nature of the ongoing gap between the potential and the reality of technology, and to use visioning techniques to develop alternate futures for people with disabilities.

Three basic research questions inform the development of the Delphi:

RQ1. What kinds of physical, economic, sociopolitical and policy factors serve as the context for the migration from legacy, analog technologies to mobile, digital, Internet Protocol (IP) based technologies?

RQ2. A) What are the implications for positive impact from these migratory trends on people with disabilities? B) What are the implications for negative impact from these migratory trends on people with disabilities?

RQ3. What practical policy solutions are available for raising the positive impact in order to continue the improvement of the lives of people with disabilities?

In preparation for the Delphi, Wireless RERC researchers concluded a literature review and environmental scan designed to identify plausible factors to answer RQ 1. The research team

identified search filters and possible impacts which could be affected by migratory trends (see figure 1 below).

Figure reference:

In preparation for designing the Delphi survey tool, researchers conducted a literature review and environmental scan designed to identify plausible factors to answer RQ 1: *What kinds of physical, economic, sociopolitical and policy factors serve as the context for the migration from legacy, analog technologies to mobile, digital, Internet Protocol (IP) based technologies?* The research team identified search filters and possible impacts which could be affected by migratory trends.

Fig. 1. Literature Review and Environmental Scan Schematic

The review/scan included a cross-reference with categories of opportunities and barriers (such as education, employment, social inclusion) which in turn were analyzed and broken down into subcategories (such as health services, emergency access, entertainment, commerce, travel, etc). In the final analysis of the literature, 16 areas of focus were identified as being integral to migratory trends in technology and disability access: defining disability; cloud computing; near field communications; wearable devices; 3-D printing; ageing; shifts in familial patterns;

environmental changes; employment; economic fundamentals; policy time lag with technology; implications of a more transparent policy process; privacy; secondary health conditions; health/environmental impacts; and veterans. Following multiple assessments of the literature review, the research team drafted the first Delphi questionnaire consisting of 44 open and close ended questions. Round 1 of the Delphi was distributed to 303 experts; ultimately the panel consisted of 50 respondents of whom 36% self-identified as having a disability. Participants were asked to identify their backgrounds, which were varied: education/academia (39.6%); policy/law (18.8%); business/industry (16.7%); other (14.6%); disability organization or interest group (8.3%); communications/media (2.1%)

Discussion

The closed questions broadly addressed the 16 focus areas identified above, asking respondents to rate the issues as very important, important, slightly important or not important. The top seven issues identified by respondents as important or very important were:

- The potential of digital technologies, such as apps, specifically in communications (98%)
- The level of the adoption of technology relies heavily its accessibility (94%)
- The life expectancy of people with disabilities has increased, and for the first time a generation of people with disabilities are outliving their parents (94%)
- The time lag between innovation and policy/regulations affects accessibility and technology inclusion for people with disabilities (92%)
- Affordability's influence on the technology adoption rate of people with disabilities (90%)
- The role of the family caregiver is expanding to performing medical/nursing tasks (88%)
- People with mental health issues face more stigma than people with other types of disabilities (88%)

For the open questions, the issues that attracted most attention were diverse, with one in particular drawing a lot of comment: “What is the best way to capture or reflect the diversity that underlies the concept of ‘people with disabilities’?” Other popular themes concerned the disproportionate impact of economic realities; the need to inform policy makers about the potential of technological changes to help people with disabilities; the question about what systems are needed to support the aging population; and concern about privacy issues impacting people with disabilities.

The research team analyzed all the responses to the first round, and produced a preliminary summary in four clusters. As described above, these clusters reflected the issues that the Delphi panelists saw as being the most important and those that received the most feedback.

Technology Cluster

The Delphi panel generally acknowledged that digital technology and its applications will become more important in the lives of people with disabilities, and that increased use of accessible digital technologies will increase levels of communications and social inclusion opportunities for them. The level of adoption of technology was seen as heavily dependent on its accessibility. In addition, questions of privacy emerged as an area of concern, ranging from the specific (“Blind users don't want text-to-speech to read aloud for anyone in earshot to hear”) to the general (“the key should be for everyone, that they are able to disclose (and/or keep confidential) the personal information most relevant for them under the circumstances they choose”), with many caveats about the changing nature of privacy as technology evolves.

At the same time, many respondents were sanguine about the promise of change that technology embodies, the hope that one day having a disability will not be perceived as synonymous with having a deficiency. One vision offered was when having a disability will not

impede communication with people across all linguistic groups, including ASL, while another respondent pointed out that by definition a disability is a functional limitation, but once technology is sufficiently adaptive and nonintrusive disability can become virtually irrelevant.

Cultural Understanding Cluster

This cluster embraced a number of concepts, in particular the rise in the life expectancy of people with disabilities, but also covered what proved to be a question that attracted heavy feedback, on how to capture or reflect the diversity that underlies the concept of "people with disabilities." The Delphi question about how, for the first time there is a generation of people with disabilities outliving their parents also attracted a lot of attention, with a particular focus on the challenges of technology migration in the face of the needs of that older population. There were pleas for keeping some technology simpler for older generations with disabilities. In the words of one commentator: "There is currently little to no consideration of the needs of older technology users in the US… The issue is not just physical hardware adaptation, but also software and services." Concomitantly, there was a general consensus on how the role of the caregiver is expanding, the need to acknowledge that change and to provide caregivers with more support. There was a clear agreement with the notion that people with mental health issues face more stigma than people with other types of disabilities.

Economic Realities Cluster

A major hindrance to higher levels of technology adoption by people with disabilities was seen to be the question of affordability. In the blunt words of one respondent, "technology needs to be accessible and affordable both, or else it is useless." The explanations offered covered a range, from low expectations from parents and schools to lack of knowledge of successful role models; dependence on government support and fear of leaving it for unsure work situations;

limited availability of affordable housing in safe areas; transportation challenges, and more. But the biggest factor by far was the lack of educational opportunity and resources, and the resulting poor employment options.

Policy Cluster

There was strong support from the Delphi panel for the notion that the time lag between innovation and policy/regulations affects accessibility and technology inclusion for people with disabilities, but little consensus on how to tackle this issue going forward. One futures-oriented suggestion was to create and maintain an emerging technologies roadmap, intended to convey the likely impact of new technologies on people with disabilities (and, presumably, incorporate it in the policy development process). Otherwise, there were several calls for the disability community to get more involved directly in the policy process (to ensure policy makers buy in through knowing someone with a disability who has experienced improved quality of life because of technological changes) as well as for "technology professionals" (especially those in the disability community) to call the attention of policy makers to what is happening. One trenchant opinion called for a process to get policy makers to see both the analytical data and financial impact of providing new and enhanced technologies, and hear from consumers who are directly impacted by receiving and using the enhanced technologies. A sour counter comment saw policy makers as the problem, not the solution. "If indeed we want to see emerging technologies exist, it is better if Congress stops making policy."

Conclusion: Technology as Transformer?

One of the general research themes early identified was to seek to understand the nature of the ongoing gap between the potential and the reality of technology. Preliminary analysis of round 1 of the Delphi seems to indicate that the respondents felt technology *can* have a

transformative impact on how people with disabilities are perceived, with the suggestion that technology is not failing us, our attitudes are. For example the expert respondents overwhelmingly deemed digital technology such as apps, and by extension the wireless devices they operate on such as smartphones and tablets, as the most important migratory trend.

Where could this trend lead? Due to the relatively short development cycle of apps (compared, for example to operating systems and hardware), as well as their wide availability and generally low cost, the apps market has a low barrier entry for people with disabilities. Mobile apps serve to extend the functionality of smartphones and tablets and in some cases, augment dedicated assistive technology. By design, mobile apps (not just those created for people with disabilities) are meant to assist the user with some task. In a sense, mobile apps universalize "assistive technology," making it in the broadest sense, applicable to all people at any given moment in time.

Could this shift the paradigm of thinking about disability and access from niche to norm? Such a line of thinking seems to presuppose the transformative power of technology on perception and attitude towards disabilities, but when asked specifically about perception ("*Can you conceive of a time when having a disability will not be synonymous with having a deficiency?"*), there was a clear divide among responses.

The work of the Delphi is ongoing. The second Delphi round will ask participants to refine each idea, commenting on its strengths and weaknesses for addressing the issue and to identify new ideas, and ultimately develop a shared understanding of how the panel views the issues.

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Computerized Decision Support for People with Disabilities: Review and Outlook

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Abstract

People with disabilities often need professional support and advice in daily life decisions such as choosing a job, a health care plan, or an access product that best fits their needs. However many people face barriers to professional support due a large part to lack of funding and lack of adequately trained providers. Recent years have seen many applications of computerized decision support, showing great potential to aid decision-making with populations as diverse as people with disabilities. In this paper, we review the state of the art technology and research on decision support systems for people with disabilities, and point out problems, potentials, and research needs.

Keywords

Decision support, people with disabilities, computer access, clinical decision support, inclusive design, cloud computing.

Introduction

Many people with disabilities do not have the funding to seek professional advice on important decisions such as finding jobs, legal issues, selecting access technology, etc. For those who are covered or can afford by themselves, there is always a shortage of adequately trained support providers (World Health Organization 144). Some applications of computerized decision support have shown the potential to aid decision-making with populations as diverse as people with disabilities (Beak 2; Bigham, Ladner, and Borodin 3; Gerdes, Karl, and Jäckel 16; Hine et al. 85; Gross et al. 597). They can be used by people with disabilities themselves (sometimes with the help of family, friends, or caregivers), or assist health care practitioners who provide services for people with disabilities, or provide a platform through which people with disabilities can call up assistance anywhere and anytime they need it. This paper reviews the current state of research in decision support systems for people with disabilities, and provides possible implications for future research.

Discussion

Supporting clinical decisions for people with disabilities

Computerized decisions support systems have been widely used in clinical settings such as diagnosis aids, prescribing systems, etc., and have shown improved practitioner performance and patient outcomes (Garg et al. 1223; Hunt et al. 1339; Kaushal, Shojania, and Bates 1409). But applications that support decision-making for people with disabilities are few, and limited empirical evidence of their effectiveness exists. Such applications are reviewed as follows.

- *Computer Access Selector* (Stapleton, Garrett, and Seeger 351) allows clinicians to use a series of device criteria to identify the most appropriate device from a list of known devices.

- *Computer Aided Support for Deciding on Applications for Rehabilitation – "CEBRA"* (Gerdes, Karl, and Jäckel 16) helps funding administrators assess whether to approve an application for rehabilitation devices. A half-year long pilot study was conducted to compare the approval rate of administrative decisions and that of the system recommendations, showing a similar rate of 80%.
- *The rehabilitation interventions selection tool* (Gross et al. 597) provides clinical decisions support to categorize injured workers toward optimal rehabilitation interventions. The algorithm was developed using machine learning techniques, based on the personal information of workers receiving compensation, their type of rehabilitation undertaken, and the outcomes. The system outperformed clinicians in selecting intervention programs that lead to successful return-to-work (classification accuracy ROC = .94 versus .86).
- *The Disability Grading Decision Support System* (Chi et al. 473) can determine the presence, severity, and category of disability an individual has. It was developed to assist the Taiwan government in allocating social welfare and medical resources.

In addition, computerized assessment tools present evaluation tests for a range of computer operations to help clinicians identify clients' needs and preferences for computer access technologies. See Simpson et al. (4) for a comprehensive review of assessment tools.

Supporting daily life decisions for people with disabilities

In addition to clinical purposes, decision support systems have also been used to help people with disabilities make daily life decisions.

- *WorkWorld* (Hine et al. 85) and its web-based version *PlanIT* (Beak 2) are job recommendation systems to help people with disabilities achieve higher income through

the best use of work incentives and benefits. The systems integrate users' personal situations and information about benefit programs and program policies across multiple agencies to make employment-based recommendations.

- *The health care plan decision support system* (Hanson, Smith, and Simon 5) helps people with physical disabilities choose health plans that best meet their needs. The support includes both low-tech forms such as brochures and guidebooks, as well as high-tech products such as videos and a CD-ROM computer program.
- *The Computer/Electronic Accommodations Program* (Department of Defense) provides users with a web-based questionnaire for needs assessment and access devices recommendation. Users are asked to rate their abilities in vision, hearing, cognition, communication, and motor skills, as well as their job requirements such as note taking or text editing. Then the system recommends access solutions that can be provided by the government agency.

Problems, Potentials, and Research Needs

The reviewed clinical decision support for access technology selection are mostly device-centric and designed for clinicians who already have a certain level of expertise in assistive technology (AT). But for most clinicians, AT is only a portion of their practice. They will find the systems hard to understand if they cannot keep up with the ever-increasing variety of AT. In this regard, decision support systems holds the potential to support AT selection in a preference-based way that is understandable for non-specialized clinicians, as well as help practitioners keep up with AT advances.

A major limitation in many of the reviewed systems is that they are stand-alone programs that do not necessarily connect to continuously updated information sources. As technologies

and policies rapidly change over time, the systems may not be able to provide reliable and correct information, and may deliver perverse suggestions (Beak 7). Future development of support tools should consider moving the service into the cloud environment, and linking to information that will be updated to keep up with technology and policy changes.

For decision support tools to be used by people with disabilities, designing accessible and usable interface is challenging but often inadequately considered and evaluated. For example, designers would assume that users are computer-literate (Hine et al. 86), or can read, understand and answer the questions (Beak 20) which may not be true for many users. The common process of decision-making—information searching and filtering, decision forming, evaluating and selecting—further complicates the design. Universal design principles should be followed to maximize the number of people who can use the system (Vanderheiden 2). Usability testing with target users is also necessary to identify accessibility issues. Research is required to study what decision support interfaces can be used by people with a diverse range of types, degrees, and combinations of disability.

Assistance-on-demand holds great potential to be applied to the supported decision-making model. Supported decision-making is to empower people whose rights to make decisions are taken away due to cognitive limitations (e.g., to vote, sign contract, defend themselves in court, choose medical treatments, etc.), to regain these rights through the help of their authorized and trusted support providers ("Nidus"; Stainton 287; United Nations and Inter-parliamentary Union 89–91). The support person may explain the issues, and when necessary, interpret the preferences and signs of the individual. The use of assistance-on-demand techniques will allow support to be delivered from remote by one or more providers. It can significantly reduce the

cost of face-to-face support. Future research may explore user and stakeholder needs, privacy and policy issues of remote and on-demand supported decision-making.

Recent years have seen an increasing number of patient-centered applications that support self-management for people with chronic conditions. One example is the CHESS system which provides web-based information, social support, and problem-solving tools for breast cancer patients (McTavish et al. 599). It has shown improved health outcomes and emotional well-being (Shaw et al. 133). Such applications and research may potentially be extended to assist people with disabilities or aging-related limitations.

Conclusions and Future Research

Computerized decision support systems have been used to aid decision-making for people with disabilities in both clinical settings and daily life. Applications include clinical decision support such as needs assessment, AT selection, rehabilitation interventions selection, etc.; and daily-life decision support such as job recommendation, health plan purchase, and AT selection. But their effectiveness to improve decisions and/or decision outcomes is noticeably missing from literature. Many of the clinical support tools in this review tend to be device-centric and oriented toward access technology experts so nonspecialized clinicians may have difficulty to use. In addition, universal design is often inadequately applied to the development of decision support systems to be used by people with disabilities. The effectiveness of these tools would be compromised if they provide recommendations based on stand-alone data sources, most of which are not kept up-to-date with policy or technology changes. One opportunity for potential improvement is the use of data in the cloud. An open-source, joint collaborative tool is under development to use data federated from multiple databases (EASTIN, AbleData, GARI, etc.) to help people with disabilities find out access technology with best fit in a preference-centric way,

and assist practitioners in clinical selections and keeping up with technology advances (Vanderheiden and Treviranus 517). Future research may also explore the possibilities of using assistance-on-demand technology in supporting decision-making for people with disabilities, as well as using computerized decision support to help people with disabilities manage chronic conditions and health behaviors.

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Smart Voting Joystick for Accessible Voting Machines

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Abstract

Our research team created an accessible dual-axis, force feedback joystick to enable individuals with limited dexterity to independently vote using electronic voting machines. Usability evaluations were conducted with individuals with moderate to severe dexterity and motor impairments to evaluate the Smart Voting Joystick and determine what modifications might be needed to enhance its usability and accessibility. Results indicated that individuals with moderate impairments could successfully use the device without modification, however slight changes would be beneficial for this group. Individuals with severe impairments had difficulties that need to be addressed, including changes to the shape of the joystick and settings. With these simple changes, it is likely that the Smart Voting Joystick would become a viable input device for individuals with wide range of dexterity impairments.

Keywords

Accessible, voting systems, joystick, usability, dexterity

Introduction

Persons with disabilities report encountering a number of barriers to full participation in social and civic life in the United States; significantly, this includes substantial impediments to voting independently. As a result, people with disabilities are less likely to vote than people who do not have disabilities (7% less likely in 2008 and 3% less likely in 2010) (Kaye et al., 2000). The most common barriers to voting cited by people with disabilities are transportation, having an illness, voter registration problems, and problems with voting equipment. They are also far more likely to need help voting, which can infringe on their right to cast a private ballot. Currently, voting equipment that is deemed "accessible" cannot be successfully used by many individuals with disabilities, and the amount of time required to vote using such equipment can be prohibitive (Swierenga & Pierce, 2012).

Manufacturers of accessible voting machines have attempted to create a universal access method that includes a touch screen and a two-button switch. Users without adequate dexterity to use a touch screen have no other choice but to use the two-button switch, which uses step scanning (a technique for using a switch press to advance to the next selection item). This type of interaction requires the user to press buttons hundreds of times to scan through the selections, which is a tedious and difficult task, and users can become frustrated, fatigued, and potentially injured.

This research project addresses the problem by creating an input device that is more usable for people with limited use of their hands and arms. According to the U.S. Census Bureau, 2.8% of the U.S. population has difficulty grasping objects (Brault, 2012). An estimated 125,000 people in the U.S., including many with dexterity impairments, use joystick controls for powered wheelchairs (Fehr et al., 2000; Kaye et al., 2000). Joysticks are used because they offer precise

control with minimal effort, even for people with fairly severe dexterity impairments. Due to these advantages, and because many users that are in need of a more accessible input method are already familiar with their use, joysticks are an ideal alternative input device.

Through this project we created a joystick that will enable individuals with dexterity impairments to vote independently. The joystick could be plugged into the binary interface port on existing voting machines, dramatically reducing the effort required to complete the voting process. Thus, the "Smart Voting Joystick" has been designed to enable many individuals with dexterity limitations and disabilities to successfully vote without significant discomfort and within a reasonable amount of time, in contrast to existing options.

Method

Smart Voting Joystick Design

Usability and accessibility experts from Michigan State University (MSU) Usability/Accessibility Research and Consulting (UARC) partnered with rehabilitation engineers from the MSU Resource Center for Persons with Disabilities (RCPD) and a senior engineering student capstone design team from the MSU Department of Electrical and Computer Engineering to create a dual-axis joystick (see Figure 1) with force feedback that interacts via USB interface with a ballot on a computer, to simulate use with an electronic voting system. The Smart Voting Joystick prototype has adjustable tension and provides the user with auditory and haptic feedback; the joystick is used in conjunction with three separate buttons, and was connected to a desktop computer on an adjustable-height table that displayed a sample voting ballot. Buttons were affixed to a mat with hook-and-loop fasteners to keep them securely in place, while still allowing their placement to be adjusted. The joystick is programmable and customizable, and its operation can therefore be modified and refined through firmware upgrades and modifications.

Programmable settings include return-to-center force, force feedback amount, and debounce delay time (with very long debounce times, data entry is slowed to help users with tremors, while with very short debounce times, multiple commands can be sent in quick succession). Customizable elements include the joystick handle and shaft, which can be replaced.

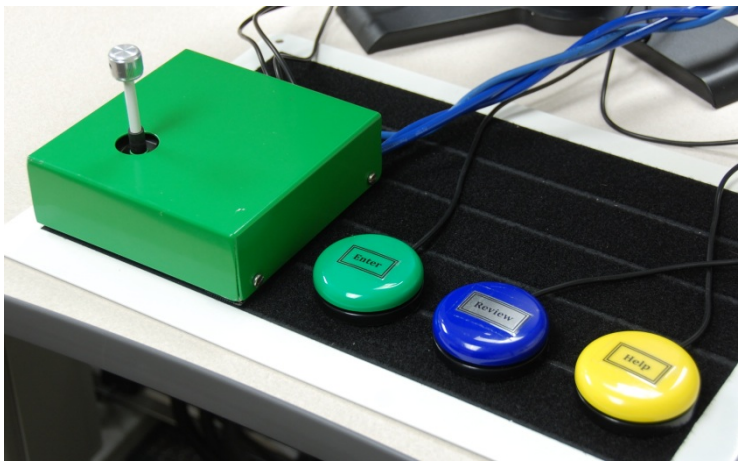

Fig. 1. Smart Voting Joystick with Enter, Review, and Help buttons (from left to right)

Usage and Interaction

In one mode of operation, the joystick simulates a **proportional** return-to-center function, similar to a typical wheelchair joystick. This means that displacement of the joystick handle causes an increase in speed as the handle is moved farther from the center. As the user pushes the joystick handle to the right, for example, it begins to send switch closures for step scanning through the selections on the voting machine. The further the joystick is pushed to the right, the faster the step scanning pulses are sent, allowing the user to step slowly for short distances or to rapidly advance through long lists. A brief haptic pulse enables the user to feel the output pulses and levels of approach to these thresholds as the joystick is moved. This force feedback helps produce a resistive force when moving to different selections of a ballot and improves overall accuracy and control.

Once a user has moved focus to the desired candidate or choice, they press the Enter button to select it. If a user wants to change a selection, they must deselect it using the Enter button, and then scroll to the desired option and press Enter to select it. To advance between contests, users can either move the joystick to the right or left twice in succession (right for next contest, left for previous), or move once in the relevant direction to bring focus to an arrow icon and then press the Enter button. Instructions are presented at the start of the voting process, but if a user wants to view them again, they can press the Help button at any time. If a user wants to review all of their selections on a single page, they can press the Review button.

Evaluation

UARC researchers evaluated the usability of the Smart Voting Joystick, testing the joystick's potential for improving access to voting by collecting qualitative and quantitative data on the usage of the joystick prototype from one-on-one sessions with six participants (five male and one female) with varying degrees of dexterity and motoric disabilities. All participants were between 30 and 60 years old. All had voted in a federal or state election previously: Three using a paper ballot at a polling place (one independently and two with the assistance of another person), and three had voted via absentee ballot. All used a desktop computer regularly, four via keyboard and mouse, and two via joystick. After analysis, the sample was split into two groups: those with moderate dexterity impairments (Group 1; four participants), and those with severe dexterity impairments (Group 2; two participants). Moderate dexterity impairments include muscular weakness, while severe impairments include spasticity and limited motor control.

Participants used the Smart Voting Joystick to interact with a digital version of the NIST Test Ballot, presented on a computer simulating a voting system, in separate sessions in the UARC lab. Participants were asked to vote according to a specific set of Voting Instructions,

which indicated the selections they were to make for each contest. The joystick was assessed by measuring the percentage of accurate votes, the mean time that participants spent voting the ballot, the mean time to go back and change a vote, the types of errors committed by users, user satisfaction and accessibility ratings, user comments and feedback while voting, and user feedback at the end of the session. While the Smart Voting Joystick can be customized, the same joystick handle and programmable settings were used for all participants.

Results and Discussion

Most participants said that they would like to use the Smart Voting Joystick to vote in the future and that they would recommend it to others who had similar dexterity limitations. Participants gave a variety of suggestions to improve the joystick and buttons, and a few encountered problems that would need to be corrected before they could successfully use it to vote independently.

Group 1

Three of the four participants with moderate dexterity impairments (Group 1) completed the ballot with 100% accuracy, and the remaining participant had only one incorrect vote.

Table 1. Group 1: Participants with moderate dexterity impairments

Participants	Time spent voting the sample ballot	Time to go back and change a vote	Percentage of accurate votes
Participant 1	10:33	00:36	96%
Participant 3	6:58	00:26	100%
Participant 5	8:53	00:21	100%
Participant 6	10:51	00:38	100%

Across all participants in Group 1, the mean time to vote was 9 minutes and 19 seconds, and the mean time to change a vote was 30 seconds. Moderators provided minimal assistance to three participants. For example, the moderator directed a user to go back to a prior contest after they accidentally moved past it without voting and became confused.

Participants were generally successful and accurate in voting with the Smart Voting Joystick. The majority noted that the amount of force feedback and return-to-center force should be reduced and that a shorter, thicker joystick would be easier to use. While some participants were not confident that the joystick would work for everyone with dexterity or motor impairments, they indicated that they would recommend it to those whose impairments or needs are similar to their own.

Group 2

Participants in Group 2 made more errors than Group 1, namely unintended actions and incorrect inputs due to more limited fine motor control (strength did not appear to be an issue). Their time and effort required to vote were therefore greater than for participants in Group 1.

Table 2. Group 2: Participants with severe dexterity impairments

(*Task not successfully completed)

Participants	Time spent voting the sample ballot	Time to go back and change a vote	Percentage of accurate votes
Participant 2	*	*	*
Participant 4	29:39	5:38	87%

One of the participants used the ballot successfully with minimal assistance (similar to participants in Group 1), while the other was unable to vote the full ballot. The participant that did not complete the task encountered difficulties due to the lack of a support for their arm, though the size and shape of the Smart Voting Joystick also contributed. This participant required significant assistance throughout the session, and their session was therefore treated as informational, being used for qualitative, not quantitative data. The two participants in Group 2 used a wide variety of techniques to vote with the joystick, including operating the joystick with their chin or forehead.

While one participant did successfully complete the voting task, it is clear that the prototype, in the configuration used for testing, does not currently meet the needs of users with severe dexterity and motor impairments. Both participants strongly endorsed a joystick in principle, and noted that modifications to the Smart Voting Joystick would make it a viable input.

Conclusion

The usability evaluation of the Smart Voting Joystick demonstrated that it is a viable input for users with moderate dexterity impairments. Users with severe dexterity and motor impairments should also benefit from the joystick once minor changes to the design and interface are made, including different button debounce time as well changes to the size, shape, and feedback settings of the joystick.

The Smart Voting Joystick represents a major advancement in technology to allow people with dexterity and motor impairments to vote independently, and to do so in a reasonable amount of time and without major negative consequences (such as fatigue or discomfort). Election officials around the country have expressed interest in the Smart Voting Joystick, suggesting that it could make an appearance at polling places in the future. With minor changes to improve its usability, the Smart Voting Joystick has strong potential for commercial development and inclusion in voting system designs.

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http://elections.itif.org/projects/grants/round-2-funded-projects/michigan-state-university/

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Towards Universally Accessible Typography: A Review of Research on Dyslexia

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Abstract

Within the last decade, especially the last two years, there has been a great deal of research regarding the effect that typography has on the readability and accessibility of text for individuals with dyslexia This research provides new insights into specific typographic features such as font size, letter spacing, line length, line spacing, font type (i.e., serif versus sans serif and roman versus italic), and specialized fonts for individuals with dyslexia. All of this work provides a framework for better understanding the basis behind the personal observations and preferences of many individuals with dyslexia, and presents opportunities to develop new guidelines for accessible typography. This paper will discuss how this new research fits in with existing theories of dyslexia, its implications for the development of universally accessible typography, and future research directions.

Keywords

Dyslexia, typography, literacy, reading, specific learning disability, universal design

Introduction

It is very common for individuals with dyslexia to note that when text is presented in particular ways (such as in particular editions of books) it becomes significantly easier for them to read. More recently, many individuals with dyslexia have also begun to remark that text is easier to read on mobile devices (Schneps et al.), where aspects of how type is set tend to differ from traditional print media (i.e. line length is often smaller due to the small size of screens) and users are often allowed to control certain aspects of how type is presented. While formal research regarding the effect that typography has on the readability and accessibility of text for individuals with dyslexia has historically been sparse, recently, especially within the last three years, there has been a significant amount of new research which investigates the effect of specific aspects of typography.

The remainder of this paper will discuss the new research, how it fits within existing theories of dyslexia, and potential future directions for developing more accessible typography.

Discussion

Typography and the Phonological Model

While feedback from individuals with dyslexia has been incorporated into guidelines such as the British Dyslexia Association's "Dyslexia Style Guide" and related documents (BDA New Technologies Committee), until recently, typography's impact on the readability of text for individuals with dyslexia has not been studied in a systematic and robust way.

One potential reason that the study of dyslexia and typography has only received limited scientific attention is that the dominant model of dyslexia (the phonological model) supports a physiological cause of dyslexia that is outside of the visual system, implying that changing how text appears would not address the fundamental difficulties faced by individuals with dyslexia

when reading text. However, while impairments in phonological processing are still likely the main contributor to literacy related impairments, some differences in visual processing have been well documented, for instance, differences in how individuals with dyslexia experience lateral masking (Geiger & Lettvin 1238-1243; Geiger, Lettvin, & Zegarra-Moran 39-52; Perry et al. 445-448; Lorusso, et al. 2413-2424). Furthermore, recent research, including the finding that phonetic representations are intact in individuals with dyslexia (they are just difficult to access)(Boets et. al. 1254), points towards phonological processing impairments (while still likely being the main contributor to literacy related impairments) are themselves the result of more general processing differences.

However, because we know that typography affects the readability of text for everyone (Rayner et. al. 451), recent research notwithstanding, a phonological origin of dyslexia does not in itself dismiss the possibility that manipulating typography can improve readability for individuals with dyslexia, thus making the development of literacy skills easier. Essentially, even if the primary difficulty is linking letters and words with their phonological representations rather than processing them visually (Shaywitz Kindle Locations 1718-1721), developing typography that is easier to read (and better fits the specific needs of individuals with dyslexia) would allow individuals with dyslexia to expend more cognitive effort retrieving the difficult-to-access phonological representations, as opposed to processing text visually. In addition, because individuals with dyslexia likely have a greater need for readability of text, the development of more accessible typography could have significant readability benefits for the average reader as well.

Research on Specific Typographic Features

Letter spacing

Because of documented differences in how individuals with dyslexia experience lateral masking (Geiger & Lettvin 1238-1243; Geiger, Lettvin, & Zegarra-Moran 39-52; Perry et al. 445-448; Lorusso, et al. 2413-2424)—a visual distortion experienced by all readers that makes letters more difficult to distinguish when they are close together—increasing the space between letters has been one of the most promising and well studied means of improving typography for individuals with dyslexia, and in three separate studies (Zorzi et. al. 11455-11459; Perea et. al. 420-430; Schneps et. al. n. pag.) increasing letter spacing has been demonstrated to improve readability for people with dyslexia, especially the dyslexic readers with the least developed literacy skills.

In the study conducted by Perea et. al., slightly increased letter spacing not only improved word identification for young readers and readers with dyslexia, but also skilled adult readers as well (420). However, Schneps et. al. found that increased letter spacing did not benefit dyslexic readers who had spent considerable time and energy developing their literacy skills, though it did allow dyslexic readers with less developed literacy skills to catch up with their more experienced peers (n. pag.). These mixed results indicate that the exact amount of spacing, as well as other variables like line length and font size, likely play a role in whether or not increased letter spacing provides a benefit in a given circumstance, but they also validate previous data indicating that larger-than-average letter spacing can improve readability for all readers, especially those with the least experience.

Line Length

When Schneps et. al. used sophisticated eye tracking techniques to investigate why some individuals with dyslexia often report that reading on mobile devices is easier, they discovered that while the short line lengths associated with reading on some mobile devices (e.g., an iPod) increased the number of times participants had to go back to the left margin, they also dramatically decreased the number of errors caused by doing this, improving readability. Shcneps et. al. also speculate that these extremely short line lengths could benefit average readers as well.

Font Size

Font size is one of the least studied aspects of accessible typography for individuals with dyslexia, however O'Brien, Mansfield, and Legge have found that the critical print size (the minimum font size necessary for an individual to attain their best reading speed) for individuals with dyslexia is larger than the average (332), meaning that larger print sizes can improve the speed at which individuals with dyslexia read.

Font Type

One of the most long standing typographic recommendations for individuals with dyslexia has been the use of sans serif rather than serif fonts, which has been endorsed by the British Dyslexia Association (British Dyslexia Association). This recommendation also makes theoretical sense because serifs may increase the effects of lateral masking, by decreasing the space between letters, and recently, fonts that are sans serif, roman (not italic or bold), and monospaced, have been demonstrated to be, in general, more readable for individuals with dyslexia (Rello and Baeza-Yates).

Specialized Fonts for Individuals with Dyslexia

Some specialized fonts for individuals with dyslexia have also been developed including Dyslexie (dyslexiefont.com), OpenDyslexic (Gonzalez), and Read Regular (Frensch). While these fonts may incorporate some aspects of typography that are beneficial for individuals with dyslexia, what research that has been done has produced mixed results. Specifically research on Dyslexie (de Leeuw) has demonstrated that while it decreased one type of error, it increased others, and did not have an overall effect on reading speed (and presumably fluency) (3). This research also likely translates to OpenDyslexic because it is designed to mimic Dyslexie. Furthermore, there is evidence that, at least in some use cases, individuals with dyslexia prefer a standard sans serif font over specialized fonts (Harley et. al. 28).

While specific characteristics of individual fonts (such as x-height or inherent letter spacing) likely have an impact on the font's overall readability, research and design energy would be better spent investigating these characteristics specifically, as well as how they interact with other typographic elements not directly tied to the font (such as line height) rather than developing specialized fonts from whole cloth. Furthermore, given the potential that the research detailed in this paper has for universally accessible typography, specialized fonts do not seem necessary.

Conclusion

Research and Design Challenges

Several challenges to both the study of typography and the nature of literacy and dyslexia complicate the development of holistic design guidelines.

In order to demonstrate statistical significance, most of the studies cited in this paper rely on testing only a limited number of specific conditions, for instance, Zorzi et. al. tested only two

letter spacing conditions (p. 11,456). While this approach provides significant validity to the notion that typography is an important component for accommodating individuals with dyslexia, it is limited to demonstrating that manipulating a particular variable has an effect, rather than determining the optimal condition for that variable.

The vast majority of the research on dyslexia and typography has also been conducted using participants under the age 18, and much of it focuses on participants who are far younger, making it difficult to extrapolate particular findings to larger populations including adults with dyslexia. A further complicating factor is the reality that both dyslexia and literacy are developmental. That is, as individuals with dyslexia develop their reading and writing skills and the types of reading related tasks they need to accomplish expand, their needs from typography will likely change (this is something that can be seen in Schnepp et. al.'s finding that increased letter spacing only benefited readers with less developed literacy skills).

Future Directions

While there remain challenges to understanding how typography affects the readability of text for individuals with dyslexia, the existing research demonstrates tremendous potential for developing reading technology that can support the widest range of users. In particular, both the research and design challenges point towards the potential of digital reading environments, especially mobile technology. Text that is digitally presented can be manipulated to fit a specific user's needs, regardless of their literacy skill, or whether or not they have dyslexia.

However, additional research is required to better understand which aspects of typography users should be guaranteed easy control over, what range of values for each typographic feature should be supported, and what the defaults for these features should be (i.e.,

what is the combination of typographic features that will result in the most readable environment for the most individuals).

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The Accessibility of Mobile Health Sensors for Blind Users

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Abstract

Mobile health (mHealth) applications are becoming popular and could be useful for people who are blind as they allow the data from mainstream health sensors to be accessed on the smartphone. However, in order for the health sensors to be accessible, the smartphone applications must be accessible. In early 2014, we conducted a survey of the accessibility of nine mHealth applications for the iPhone and found that none of them met our criteria (based on the guidelines provided by Apple and Section 508) for being accessible. We found that the majority of the accessibility problems encountered were relatively simple and believe that it would only take a small amount of effort on the part of developers to fulfill the potential for mHealth applications to make mainstream health sensors fully accessible to blind users of smartphones.

Keywords

Accessibility; blind; smartphones; mHealth.

Introduction

A number of research studies suggest that blind people have worse health than those without disabilities (Capella-McDonnall; Thylefors). Because people who are blind are more likely to report poor or worsening health (Capella-McDonnall) and more likely to have serious health issues such as diabetes (Thylefors), they may benefit from health sensors, such as blood pressure monitors or scales, and it is important to ensure these devices are accessible.

Versions of these health sensors can now connect to smartphone applications (part of a larger group of applications called mHealth or mobile Health applications) to log health information. As the mainstream versions of many of these health sensors are not accessible on their own, connecting them to a smartphone equipped with a screen reader such as VoiceOver (iOS) or TalkBack (Android) could be a way to make these mainstream devices accessible out of the box for people who are blind. Because many of the applications and devices in the mHealth industry are targeted for the sighted community, they reach a larger consumer base and are likely to become widespread and less expensive than narrowly targeted assistive technology. However, because developers are not thinking about the broader market that includes blind customers, they may not be following the recommended accessibility guidelines provided for smartphones.

To determine the current state of the accessibility of mobile health sensors that connect to smartphones, we conducted a survey in March 2014 of commercial iPhone health applications and determined how accessible they were with VoiceOver. We did not examine other accessibility features such as the ability to zoom, the use of high contrast or large print. We looked at mHealth applications that connected to different types of external sensors including blood glucose monitors and blood pressure monitors, as we were interested in whether the smartphone applications succeeded in making a previously non-accessible device accessible. We found that none of the

applications surveyed met all of the accessibility standards that we established based on iOS and Section 508 accessibility guidelines.

Related Work

mHealth Applications

There are a number of reviews of smartphone medical applications (Mosa, Terry), but these reviews focus on healthcare practitioners' use of smartphones and do not consider accessibility. We have found no academic reviews of mobile healthcare applications from an accessibility lens. However, within the blind community, people often generate lists of the most accessible applications, which can include health applications, such as those listed in "Apps for the Blind" (see citation).

Accessibility Guidelines for Smartphones

To the best of our knowledge, there is no universal set of guidelines for smartphone accessibility. Instead, some smartphone companies have developed a set of specific guidelines for their own products: Apple provides "Accessibility Guidelines for iOS", and Android has an "Accessibility Developer Checklist." These guidelines vary based on the screen readers and the other features available on the smartphones. In general, these guidelines recommend that all elements of the screen report themselves to the screen reader (or other accessible device) and that the applications be navigable by switching the focus from one element to another. In the best case, this means that elements are accessible to screen readers, Braille displays, and other assistive technology.

More broadly, the US Federal government has standards set out in the Section 508 amendment to the Rehabilitation Act (Rehabilitation Act. *Section 508 Standards Guide)* that apply to all information technology provided by Federal agencies. Section 508 has standards for software

applications, portable computers and telecommunication devices. These standards are broad, but include elements applicable to smartphone applications.

Accessibility Guidelines for Webpages

Although there is no universal accessibility standard for smartphones, there are standards governing webpages, and we can derive some necessary accessibility features for smartphones from these standards. The Web Content Accessibility Guidelines (WCAG 2.0) provides a list of 65 standards to make webpages accessible, and there have been surveys to determine how well websites meet those standards (Kane).

Methods

Data Sources

We conducted a survey to evaluate smartphone applications that work with an external sensor to replace two types of devices: glucose monitors and blood pressure monitors. To find the smartphone applications, we searched internet technology blogs and articles related to mHealth and reviews of medical smartphone applications. We also searched through the Apple App Store using the following keywords: “glucose,” “glucose meter,” “blood pressure,” and “blood pressure monitor.” As we were mainly interested in whether people would be able to access the information received from the external sensing devices once it synced with the phone, we did not evaluate the external devices (glucose meter or blood pressure cuff). Instead, we manually input the data and then evaluated accessibility of the entire application, with the exception of iHealth’s iGluco application, for which we used the external device as we were unable to manually input data. All applications were evaluated on an iPhone 4s and an iPhone 5 running iOS 7 with VoiceOver. We evaluated the applications with the latest updates in March 2014 (Appendix 1).

Inclusion and Exclusion Criteria

We chose to only evaluate iOS applications that were primarily for helping with medical problems rather than general fitness applications. We evaluated medical applications designed for use at home by patients rather than in clinical settings by healthcare practitioners and focused on applications that received information from an external device (glucose monitors and blood pressure monitors). All applications evaluated are listed in Appendix 1.

Accessibility Rubric

While there is no set of accessibility standards specific to smartphones, there are recommendations provided by each smartphone platform ("Accessibility Guidelines for iOS", "Accessibility Developer Checklist"). The Federal Government also provides a standard for software applications created or funded by the government through the Section 508 amendment to the Rehabilitation act (Rehabilitation Act. *Section 508 Standards*). We drew from both the Apple accessibility guidelines and those set forth in Section 508 to create the Accessibility Rubric to evaluate each of the applications. We evaluated our applications according to the following seven guidelines:

1) Labels Correct: All elements have labels that correspond to what they do (e.g. an "Add" button is labeled "Add").
2) Traits Correct: All elements have traits that correspond to what they are (e.g. an "Add" button has the trait "button").
3) Values Accessible: The values of each element are accessible (e.g. a blood pressure measurement text field might have the value 120/80).

4) Hints Provided: Hints are provided to help users navigate application (e.g. “double tap to enter information”).
5) Table Data Coherent: All the information in a table is accessible and read in a coherent manner (measurement values and units are read together).
6) Traits and Labels Read Together: All of the labels and their corresponding traits are read together (e.g. a label for a button such as “add readings” is read either right before or right after the corresponding button is focused on).
7) Non-textual Data Accessible: Graphs, charts and other images are explained or information on them is accessible.

The first four criteria (Labels Correct, Traits Correct, Values Accessible, and Hints Provided) are based on Apple’s recommendations that all elements must “provide accurate and helpful information about its screen position, name, behavior, value and type.” The next two criteria (Table Data Coherent and Traits and Labels Read Together) were not explicitly mentioned in the Apple guidelines, but were developed by us when we encountered usability problems. The final criterion (Non-Textual Data Accessible) was based on Section 508’s guideline that “when an image represents a program element the information contained by the image must also be available in the text.” All the traits were evaluated in a binary manner: if all the elements in the application conformed to the standard for each guideline, the application passed (received a Y in Table 1); if only some of the elements conformed, it did not (the box in Table 1 is left blank).

Table 1. Accessibility of mHealth application across seven features. If all the elements in the application met the accessibility guideline, it received a Y. If the application did not have a certain element it received a N/A.

Application	Labels Correct	Traits Correct	Values Accessible	Hints Provided	Table Data Coherent	Labels with Traits	Non-textual Data Accessible
iBGstar*	Y						
Glooko Logbook*	Y	Y	Y	Y	N/A	Y	
Telcare*			Y				
iGluco*		Y	Y		Y		
iHealth BP Monitor*			Y		Y		
Withings**		Y	Y		Y		
iBP**	Y		Y		Y	Y	
myVitali**		Y	Y				
DigiFit**	Y		Y			Y	

***Glucose Monitors, **Blood Pressure Monitors**

Discussion

The results of our study are summarized in Table 1. We evaluated glucose monitoring applications from four companies: iBGstar, Telcare, Glooko, and iHealth (Appendix 1). Both the iBGstar and Telcare applications allowed one to manually input blood glucose data without the external device. For the Glooko application, we were unable to evaluate one of the guidelines (whether the table data was coherent) without the external device, and that is labeled N/A in Table 1. We used the external device to add measurements for the iHealth iGluco app, as we

were unable to manually add data. We evaluated blood pressure monitors from iHealth, Withings, iBP, myVitali and DigiFit (Appendix 1).

Although the majority of the features in all the applications were somewhat accessible, we found that none of the applications met all the guidelines. On average, applications met 2.6 out of 7 accessibility guidelines, with two applications (iBGstar and Telcare) meeting only one guideline, and one application (Glooko) meeting 5 of the 6 guidelines it was graded on (one of its features was not evaluated). In general, elements that were standard iOS elements, such as tabs for multiple pages in an application or add buttons for adding data, were accessible, as they had the correct labels, traits, values, and often had hints. However, when the developers added their own elements, they rarely included the information that would make them accessible and often did not provide the correct labels, traits or values for the elements.

One problem with many of the applications was that the visual design of the elements often did not correspond to an understandable audio layout. For example, in many applications, the labels for buttons would be above the buttons, and if there were multiple buttons in a row, the labels would receive the focus first then the buttons themselves, making it difficult to determine which buttons corresponded to which labels. Additionally, the measurements in many tables were difficult to read as values and their units were separated (e.g. a blood pressure reading of 120 mmHg/70 mmHg and 80 beats/min taken on Sept. 28th, might be read as “120, 70, 80, Sept. 28, 2013, mmHg, mmHg, beats/min”). Finally, two of the applications (iHealth and Withings) did not switch pages correctly; the application would switch pages, but VoiceOver would continue relaying information from the previous page.

Conclusion

None of the mobile health applications that we evaluated met all of the accessibility criteria recommended by Apple and Section 508. Additionally, many of them had problems that were outside of the scope of the Apple guidelines (which generally are concerned with making individual elements accessible as opposed to making sure the flow of the application is accessible). In the future, we would like to extend this study to other smartphone platforms such as Android and Windows, and we believe a universal set of smartphone accessibility guidelines needs to be developed. Although there is exciting potential for mHealth applications to make both inaccessible devices and health records usable by people who are blind, there is a great need to ensure that the developers include accessibility considerations when designing applications.

Appendix 1: mHealth Applications Evaluated

1) iBGstar Diabetes Manager Application, sanofi-aventis, Version 2.2
2) Telcare, Telcare Inc., Version 2.0.1
3) Glooko, Glooko, Inc., Version 2.5.0
4) iGluco, iHealth Lab, Inc., Version 3.0.1 (used with Wireless Smart Glucose Meter, Model BG5)
5) iHealth MyVitals App, iHealth Lab, Inc., Version 2.3.4 (BP)
6) Health Mate, Withings, S.A.S. Version 1.32.2
7) iBP, Leading Edge Apps LLC, Version 6.1
8) myVitali, myVitali AG, Version 1.5.1
9) DigiFit, DigiFit, Inc., Version 7.51

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Improving Write-In Candidate Text Entry for Audio-Only Voting Interfaces

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Abstract

For voters who cannot read a graphical ballot, audio-based voting systems currently in use can provide a private and independent path for entering the first and last names of write-in candidates, but the process tends to be slow, difficult to comprehend, and inaccurate. Challenges range from technical and procedural to cognitive and emotional, and have led, at times, to disenfranchisement, according to the Government Accountability Office's 2013 Statement before the National Council on Disability. Entering candidate names without difficulty is crucial to the fairness — and ultimate legal standing — of our election system. To resolve these issues, we developed and tested three novel audio interfaces that enable navigation and selection of characters through simple techniques that allow users to linearly access an alphabet for the purpose of typing a specific name. A number of factors were found to improve character input speed, input accuracy, and user comfort, including using as few as keys as possible for navigation, using high-quality keys such as those found in commercial QWERTY keyboards, and assuring that there is no lag in feedback to user inputs.

Keywords

Audio, voting, screen reader, text-entry, low vision, interface, design

Introduction

When creating an accessible voting experience for voters who cannot read a graphical ballot, there are many constraints to consider. While a tactile-braille interface is often suggested by those new to the problem, in the United States only 10 percent of blind individuals are proficient at using braille (Jernigan 7), and not all voters are familiar with typical text-input and assistive technologies, such as standard keyboard layouts (Granata 4) or screen readers. As a result, the 2005 Voluntary Voting System Guidelines specifies that the inclusion of audio-based voting be provided (56), while allowing for voting privately, independently, and verifiably (the ability to confirm one's choices before casting a ballot) (46). Because of the lack of voter training opportunities, expected future requirements will ask that features be able to be performed in a manner that does not require prior training. To fulfill these requirements, direct record electronic voting machines (DREs) have been developed with a simplified button-input array that controls a simple audio-only user interface observed by the voter via the use of attached earphones. (in DREs, screens are typically blank during audio voting to preserve the privacy of the vote.) While this simplified interface reduces the need for training on many tasks, when inputting the name of a write-in candidate, the process of selecting characters, checking accuracy, making edits, and submitting one's choice is typically frustrating and time consuming. Many voters who use the audio write-in feature need extra time and commonly fail to enter a name at all. In practice, such interfaces have presented voters with their most difficult task of the election experience, according to Herrnson (3), contributing to a higher ratio of unrecorded votes (Niemi 86). For this reason, we have focused on how to improve the write-in experience by exploring how to better use controls, provide instruction, and improve input editing strategies.

To improve text entry for writing in a candidate's name in audio-only DRE interfaces, two technologies typically come to mind: speech recognition and auto-completion of text. Unfortunately, these technologies are inappropriate for voting. Using speech recognition for direct text entry in the polling place, where others can listen in, would jeopardize one's right to vote privately. In the case of auto-completion, there are also many issues that cannot be resolved. To begin with, auto-completion requires that words be previously known by the system, but many states do not require write-in candidates to pre-register (Helm). Additionally, in the context of voting, auto-completion can potentially introduce coercion, by priming the voter to one candidate over another through the ordering of suggestions. For these reasons, we focused on creating new text entry methods for audio-based write-in that does not rely on alphabetic keyboards, speech recognition or auto-completion of text.

This paper covers the development and testing of three novel audio interfaces that enable navigation and selection of characters through simple techniques that allow users to linearly access an alphabet for the purpose of typing a specific name, discussing the strengths and weaknesses of each in relation to existing methods.

Discussion

Voting machines can be designed according to several sets of guidelines, most notably the Federal 2005 VVSG, which designates that every polling place should have at least one accessible voting station, typically a DRE machine. Such devices are intended to allow people to use a range of adaptive input devices such as an Audio-Tactile Interface (ATI), intended to provide voters with earphones and a set of buttons, or sip and puff device for non-manual use (with graphical or audio interfaces). The VVSG includes guidelines for volume, frequency, and speed of audio between 75 and 200 percent of normal rate of speech. The VVSG does not

specifically address how write-in candidates should be entered by voters who do not use graphical interfaces. We followed guidelines on how operational instructions are to be given by audio at initial activation and repeated as desired during the voting session. Our prototypes also fell within the VVSG guidelines for audio speed after iterative testing and refinement.

Several researchers and students participated in experiments to determine reasonable rates for presenting audio. Each participant found that audio with the standard speech rate equivalent of 200 words per minute (WPM) seemed slow, while an equivalent rate of 700 WPM and higher was incomprehensible. Though audio at a rate of 500 to 600 WPM could be understood, users found it too fast for maintaining comfortable and accurate navigational control. As a result, audio generated at 400 WPM was considered appropriate, in line with the VVSG's upper limit of 200 percent above normal. This also fits with the findings of Asakawa, et al, on general comprehension of listeners of sped-up synthesized speech, which saw an upper limit for comprehension at around 300 to 500 WPM (278). We strayed from the Guidelines in regard to providing multiple modes for navigation keys, depending on whether the key is tapped quickly or held down.

The VVSG suggests that press-hold commands (for instance, repeating the entry of a letter if a key is held down) be avoided as an attempt to limit unintended letter entry, but we introduced such a capability into two of our three prototypes to see if the command's utility might outweigh the concerns posed in the VVSG. The potential to positively impact future criteria is a goal of our work, adding to the motivation to work outside some of the federal guidelines.

Our goals in developing the three prototypes were to test how to best orient the user during the text entry task, shorten the amount of time required to enter a candidate's name, and

improve accuracy. The prototypes were created as a Google Chrome browser extension for the Macintosh and Windows operating systems, built with HTML and JavaScript. The extension utilized Chrome's text-to-speech capabilities to generate audio feedback and also HTML5 to manipulate audio files. These were generated using text-to-speech features in the MAC OS X command line interface. The testing was conducted on a 2012 MacBook Pro.

A version of the prototype was created for each condition listed below:

- Condition 1, Single Tap with Two Navigation Keys: Participants moved through the alphabet one letter a time by tapping the left or right arrow keys to navigate; selections were made by pressing 'enter'.
- Condition 2, Four Navigation Keys: Participants used the up and down arrow keys to navigate through the alphabet at 400 words per minute (WPM), pausing to distinguish marker letters (A, G, M, T, Z), and the left and right arrow keys to navigate one letter at a time.
- Condition 3, Two Navigation Keys Utilizing Two Speeds: In contrast to the single tap, with these two-key conditions, participants used only the left and right arrow keys for navigation. By holding down the keys, users moved through the alphabet at 400 WPM, pausing to distinguish marker letters (A, G, M, T, Z), and they navigated one letter at a time with single taps.

The rationale behind the development of marker letters was to provide a fast way to navigate closer to an intended target letter by browsing through groupings and then zero-in on the target letter with only a few key presses. The initial exploration divided the alphabet evenly, but informal testing indicated that most people do not have an adequately stable model for where

lesser-used letters fall in the alphabet. Most people, however, could easily establish a letter's location in the alphabet by recalling its proximity to commonly used anchor letters. Through trial and error we found A, G, M, T, and Z to work best as markers (or waypoints) to segment the alphabet.

Fig. 1. Three test conditions offered various key configurations.

Built-in instructions presented to participants for the three conditions:

1. "To write in a candidate's name, follow these instructions:

   [Condition 1] "Single tap the left or right arrow key to move through each letter. Press enter to select a letter."

   [Condition 2] "Press and hold the up or down arrow key to find the general area for the letter you are looking for. Single tap the left or right arrow key to narrow in on the letter. Press enter to select the letter"

   [Condition 3] "Press and hold the left or right arrow key to find the general area for the letter you are looking for. Single tap the left or right arrow key to narrow in on the letter. Press enter to select the letter."

2. "To move through the alphabet quickly, like this [play audio sample], press and hold the left or right arrow key. Try it [allow user to try]."

3. "To move one letter at a time, like this, press the left or right arrow key. Try it [allow user to try]."

4. "To select a letter, press Enter. Find and select the letter S [allow user to try]."

5. "To review what you have already typed, press the UP arrow key [allow user to try]."

6. "To remove the last letter typed, press Delete [allow user to try]."

7. "To listen to the instructions again, press the Down arrow key. To begin, press an arrow key."

To test our prototypes, 30 computer science graduate students participated. All possessed average vision, none were regular users of text-to-speech technology and only one was a native English speaker. For each condition, participants were asked to enter two different names. The order of conditions was randomized. The time taken to input eight letters using each approach was compared. Each test condition had a sample size of ten participants.

The data shows a statistically significant improvement between Condition 2 and Condition 3 with a 25 percent reduction in task time when using a two-key interface over a four-key interface (with a t-test p value of 7.1E-06). In contrast, there is no statistically significant performance difference between condition one and two (t-test p value of approximately 0.88). A critical finding was that all conditions improved audio-enabled write-in speeds over existing and prototype DRE systems with a similar functionality. The majority of our testers completed audio write-in entry in less than one minute in every trial. DRE voting equipment with audio write-in capability tend to utilize a condition similar to Condition 1, yet in the field, this method is very difficult. In field tests and observations of various deployed and emerging voting devices, selecting eight letters for a name can rarely be done in one minute. As a gauge, we looked at efforts using machines going through or carrying VVSG certification. For instance, on a Sequoia AVC Edge machine, manufactured by Dominion, tested in January 2014, a user entered four letters in 56 seconds with great effort. In addition, when the tester accidentally entered a letter erroneously on the AVC Edge, he was unable to correct it.

Table 1. Data Comparing Task Speed Under Three Conditions: Single Tap, Four Keys, and Two Keys. The Simpler Two-Key Interface Allowed Participants to Complete Tasks Faster than with Four Keys, but Not Necessarily Faster than Simple Typing.

Condition 1: Single Tap

Participant	Order	Trial 1	Trial 2	Average
1	1, 2, 3	34	36	35
2	1, 2, 3	37	38	37.5
3	1, 2, 3	46	49	47.5
4	1, 2, 3	40	38	39
5	1, 2, 3	37	41	39
6	1, 2, 3	51	41	46
7	1, 2, 3	52	49	50.5
8	1, 2, 3	55	53	54
9	1, 2, 3	55	41	48
10	1, 2, 3	38	42	40
11	2, 3, 1	31	35	33
12	2, 3, 1	27	40	33.5
13	2, 3, 1	39	36	37.5
14	2, 3, 1	42	40	41
15	2, 3, 1	32	32	32
16	2, 3, 1	44	53	48.5
17	2, 3, 1	41	36	38.5
18	2, 3, 1	36	36	36
19	2, 3, 1	--	--	--
20	2, 3, 1	--	--	--
21	3, 2, 1	--	--	--
22	3, 2, 1	--	--	--
23	3, 2, 1	--	--	--
24	3, 2, 1	--	--	--
25	3, 2, 1	--	--	--
26	3, 2, 1	49	36	42.5
27	3, 2, 1	34	33	33.5
28	3, 2, 1	53	52	52.5
29	3, 2, 1	40	--	40
30	3, 2, 1	--	--	--

Table 1 (Cont.).

Condition 2: Four Keys

Participant	Order	Trial 1	Trial 2	Average
1	1, 2, 3	34	40	37
2	1, 2, 3	43	36	39.5
3	1, 2, 3	40	43	41.5
4	1, 2, 3	47	49	48
5	1, 2, 3	56	58	57
6	1, 2, 3	--	--	--
7	1, 2, 3	--	--	--
8	1, 2, 3	--	--	--
9	1, 2, 3	--	--	--
10	1, 2, 3	--	--	--
11	2, 3, 1	--	51	51
12	2, 3, 1	50	60	55
13	2, 3, 1	63	65	64
14	2, 3, 1	63	58	55.5
15	2, 3, 1	--	53	53
16	2, 3, 1	66	61	63.5
17	2, 3, 1	69	68	68.5
18	2, 3, 1	62	48	55
19	2, 3, 1	64	65	64.5
20	2, 3, 1	64	50	57
21	3, 2, 1	--	--	--
22	3, 2, 1	--	--	--
23	3, 2, 1	--	--	--
24	3, 2, 1	--	--	--
25	3, 2, 1	--	--	--
26	3, 2, 1	65	55	60
27	3, 2, 1	41	42	41.5
28	3, 2, 1	45	46	45.5
29	3, 2, 1	53	58	55.5
30	3, 2, 1	--	--	--

Table 1 (Cont.).

Condition 3: Two Keys

Participant	Order	Trial 1	Trial 2	Average
1	1, 2, 3	45	42	43.5
2	1, 2, 3	30	40	35
3	1, 2, 3	41	39	40
4	1, 2, 3	36	40	38
5	1, 2, 3	39	--	39
6	1, 2, 3	--	--	--
7	1, 2, 3	--	--	--
8	1, 2, 3	--	--	--
9	1, 2, 3	--	--	--
10	1, 2, 3	--	--	--
11	2, 3, 1	48	37	42.5
12	2, 3, 1	38	32	35
13	2, 3, 1	35	43	39
14	2, 3, 1	46	50	48
15	2, 3, 1	40	39	39.5
16	2, 3, 1	42	55	48.5
17	2, 3, 1	39	48	43.5
18	2, 3, 1	25	39	32
19	2, 3, 1	--	--	--
20	2, 3, 1	--	--	--
21	3, 2, 1	49	44	46.5
22	3, 2, 1	48	32	40
23	3, 2, 1	50	45	47.5
24	3, 2, 1	39	37	38
25	3, 2, 1	44	40	42
26	3, 2, 1	45	50	47.5
27	3, 2, 1	40	45	42.5
28	3, 2, 1	38	49	43.5
29	3, 2, 1	49	48	48.5
30	3, 2, 1	48	40	44

There are a number of reasons for slower write-in speeds on current equipment. Many DRE voting machines in current service present a lag in response—a detectable or sometimes uncomfortably long period of time between when the user presses a button and when device responds. DRE machines with older hardware and software may suffer delays because software has not been optimized or hardware is underpowered to keep up with the voice interface. (The MacBook Pro laptops used in the test did not present noticeable lag.) As well as lag, some systems do not register button input while audio is playing, meaning the voter cannot skip past or truncate (cut short) any information, which can impede alphabet browsing. Another factor may be key design.

DRE machines may not match the effectiveness of the prototypes using a computer keyboard because of the actual design of the DREs' specialized buttons, which are typically large and made from plastic, soft rubber, or silicone, which behave quite differently from the type of computer controls most people encounter in their daily lives. Although standard computer keyboard keys are pressed with 182 to 193 grams of pressure anywhere on their surface (Rempel 255), many accessible ATI buttons on voting systems vary in actuation pressure across the key, requiring pressures that are multiple times the minimum pressure needed near the hinge. Recently, our researcher team had access to a newer DRE that responded with no perceivable lag, but used the standard ATI button design. Although, not available for our study, in a limited hands-on test the new machine yielded vote times closer to those experienced in our test conditions, but still not as fast. It is likely that differences in key feel contributed to this difference.

Faster overall entry speeds in the experimental conditions may have also resulted from the ways the conditions attempted to orient users on how to go forward, backward, and navigate

the interface itself. This data shows that using fewer keys increased performance in both of the experimental conditions. The four-key interface was more difficult for participants to learn, remember, and use efficiently. Surprisingly, the data did not show a significant improvement for the novel press-hold feature of Condition 2 and Condition 3 over the simple tapping of Condition 1. Simply tapping through each letter one at a time enabled users to enter letters faster than they could with Condition 2 and at similar speeds as Condition 3. In interviews, however, the majority of participants reported a preference for the sped-up letter browsing of Condition 3. Participants also reported that utilizing A, G, M, T, and Z marker letters to chunk the alphabet into four sections improved their sense of location in the alphabet. Although these preferences did not significantly increase text-entry speeds, participant feedback speaks to an increased comfort level with having an overview of the alphabet and a greater context for navigating it.

The testing also revealed the importance of suggesting an efficient strategy to voters, not simply listing features in the instruction set. Without any instruction on strategy (when we described what each feature was, but not the purpose), only some participants developed efficient methods for text entry while others struggled, either sticking to using single tap or sped-up letter browsing, or frequently changing strategy. Testers who developed an efficient strategy did so by taking a moment to experiment with the controls before commencing to spell the name, but such experimentation is not easily available while voting, given the pressure of time and the fear of making an error that would affect a live ballot. When we changed the instructions to clarify various strategies (for instance, initiating a press-hold on an arrow key to quickly move to a letter region, or tapping the arrow keys to browse one letter one at a time), almost all used an efficient strategy from the start. The testers' response prompts the question of whether polling guidelines

should encourage a period of practice, sample vote completion, or simple drills before commencing to enter write-in candidate names.

While not part of our formal prototype testing, an important benefit of using sped-up reading of the alphabet with marker letters became apparent when demoing the prototypes in noisy surroundings (such as found in typical voting sites). Many users stated that when the volume of the prototype could not fully compete with ambient noise, it was still easy to hear the pattern of the marker letters as the alphabet sped by. This pattern made it possible to easily get within range of the target letter, and the cognitive model it developed provided secondary context to discern only partially heard letters when zeroing-in on the target one letter at a time. This suggests that while there were not significant improvements in speed between Condition 1 and Condition 3, that in the noisy environment of the polling place, Condition 3 may present a valuable benefit.

Conclusions

This work demonstrates techniques for write-in design that could be introduced in future voting machines and highlights underlying questions related to the ongoing design strategies of DRE equipment. The previous discussion concerning ATI button design and our experience with these specialized buttons caution that the presence of such unusual, specialized input hardware (presumably to show extra care and attention to voters with disabilities) may actually introduce difficulties for many users. Experiments indicate that a typical consumer-grade keyboard is much easier to operate than available adaptive input devices and would speed input. As well, the arrow configurations on such keyboards (sometimes a cross style or inverted T with up and down arrows sandwiched between left and right arrows in Figure 1) are familiar to most people. While the goal may be a variety of input methods to suit the user's tastes (common QWERTY

keyboard, Braille keyboard, or audio-tactile interface) in line with the findings of Oliveira (8) in "Blind People and Mobile Touch-based Text-Entry: Acknowledging the Need for Different Flavors," a functional interface that follows the most successful conditions in our testing would form an appropriate path for simplified entry of write-in candidates. Eliminating keyboard-to-audio lag, allowing keys to trigger audio at any time, and changing audio speed all improved audio-based character input. In addition, structuring the alphabet with fixed marker letters did not slow input and indeed should make performance more reliable in the context of the perceptual and cognitive challenges of real-world voting input. The results of this work should also be useful for entry of passwords or proper names in any computer interface not relying on speech recognition or keyboard input.

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