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# Preface

The Center on Disabilities at California State University, Northridge is proud to welcome you to the fourth issue of the Journal on Technology and Persons with Disabilities. These published proceedings from the Annual International Technology and Persons with Disabilities Conference, represent submissions from the Science/Research Track presented at the 31 event held March 21-25, 2016.

The Center on Disabilities at CSUN has been recognized across the world for sponsoring an event that for more than 30 years highlights the possibilities and realities which facilitate the full inclusion of individuals with disabilities. Over the last three decades, it has truly into the most significant global platform for meeting and exchanging ideas, continually attracting more than 4,000 participants annually.

We were once again pleased that the third Call for Papers for the Science/Research Track in 2015 drew a large response of more than 50 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 peer-reviewed and only those submissions of the highest caliber were accepted for presentation and publication. Demonstrating a clear focus on scientific excellence, this fourth Journal and the Science/Research Track at the conference, document CSUN's commitment 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 first 31 years. As we begin to move into our 4th decade, we will continue to seek out this support and collaboration and hope you will join us at our 2017 event where we will rebrand the conference as the "CSUN Assistive Technology Conference".

Welcome once again to our 4th 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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# Signing High School Science

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## Abstract

This paper discusses evaluation research conducted by TERC, Inc. in classrooms with students in grades 9–12 who are deaf or hard of hearing and who communicate in sign language. The primary purpose was to begin to establish effectiveness in terms of the kinds of learning gains that are possible with use of Web and app versions of a Signing Life Science Dictionary and a Signing Physical Science Dictionary. A secondary purpose was to find out about usability, use of the universally designed interactive features, and teachers' and students' satisfaction with the dictionaries as assistive tools for accessing science content. Developed by TERC and Vcom3D, each dictionary includes approximately 750 standards-based science terms, definitions, and illustrations; each is intended to enable increased access to life science and physical science content through individualized use. While results of this research reflect the experiences of students who used the dictionaries and do not include comparison with a group that did not use them, the data strongly support the assertion that the signing dictionaries provide the intended audience with assistive tools that add value to their learning experience when used during science classes.

## Keywords

Deaf, hard of hearing, ASL, apps, computers, science.

**Introduction**

The evaluation research that is discussed in this paper was conducted by TERC, Inc. Its primary objective was to begin to establish effectiveness of Web and app versions of a Signing Life Science Dictionary (SLSD) and a Signing Physical Science Dictionary (SPSD). A secondary purpose was to find out about usability, use of the dictionaries and of the universally designed interactive features, and teachers' and students' satisfaction with the dictionaries as assistive tools for accessing science content. To accomplish our first objective, two questions guided our study: 1) What kinds of learning gains in life science are possible with use of the SLSD? 2) What kinds of learning gains are possible in physical science with use of the SPSD? Extrapolating from results of evaluation of our Signing Earth Science Dictionary (SESD), the research team hypothesized that with the SLSD and SPSD, students would have assistive tools that help them: 1) increase their ability to recognize, sign/fingerspell and/or voice, and use the vocabulary of life and physical science; 2) improve their science content knowledge as reflected in their increased understanding of the meaning of terms (Vesel).

Based on recent estimates, there are roughly 76,600 children ages 3–18 with hearing impairments served under IDEA. Approximately 31,000, or 40%, are in grades 9–12 (U.S. Department of Education). Although students who are deaf or hard of hearing (HH) are not necessarily considered "print disabled," those who acquire and use sign language to communicate tend to internalize a linguistic structure that differs greatly from English (Rose and Meyer). This results in significant literacy limitations that lead to the majority of students who are deaf leaving high school with reading levels at the fifth grade or below. In fact, the English vocabulary of the average 15-year-old student who is deaf is about the size of that of a 9-year-old hearing child and will not improve significantly (Karchmer and Mitchell).

Developed by TERC and Vcom3D, each of the dictionaries is a complete assistive tool that contains approximately 750 standards-based science terms used in grades 9–12. Both dictionaries include signing avatars and a range of interactive features that result in each dictionary incorporating the principles of the Universal Design for Learning (UDL) framework. The framework emphasizes three key aspects of pedagogy: multiple means of representing information, multiple means for expression of knowledge, and multiple means of engagement (Rose et al.; Rose and Meyer). Integration of these interactive features was intended to offer deaf and hard of hearing users in grades 9–12 increased access to standards-based life science and physical science content through individualized use of the dictionaries.

## Discussion

### *Methods*

With our research questions serving as the framework, we implemented a within-subjects mixed methods design that integrated qualitative and quantitative methods (Johnson, Onwuegbuzie, and Turner). This protocol, described below, resulted in a "full variety of evidence" (Yin) that was used for analysis.

The research procedure involved placing the dictionaries in the designated classroom context, at the intended grade levels, with students who are deaf or hard of hearing. The intent of the evaluation was to examine effectiveness under normal-use conditions. To this end, prior to using the dictionaries, teachers completed a *Site Data Form* that identified the science unit—one they would ordinarily cover—that they would teach using the SLSD or SPSD. The only difference was that they would teach the unit using at least one of the dictionaries. Teachers also identified 5 key terms that were important for developing an understanding of the content that was the focus of the unit. For example, one teacher identified *mitosis* as the unit topic; the key terms were *mitosis*, *cell cycle, chromosome*, *interphase*, and *replication*. (Each term selected had to be in the SLSD or SPSD.) The form also provided demographic information for each class. It included information about the school, teacher, and students and was used during analysis of the data.

Prior to starting the identified unit, each teacher completed a *Pre-use Vocabulary Assessment Form* to individually assess (as *yes* or *no*) students' ability to recognize each of the 5 key terms and to sign/fingerspell and/or voice them. The teacher also assessed students' ability to explain the meaning of each term and/or to define it using a 0–3 scale (0=no answer; 1= familiarity with the term but no knowledge of its meaning/definition; 2=incomplete knowledge of its meaning/definition; 3=complete ability to explain its meaning/definition). The teacher then taught the unit using the SLSD and/or SPSD as an assistive tool. A researcher conducted observations at sites local to TERC. Using an *Observation Log*, she made notes about how teachers incorporated the dictionaries into instruction and about student use.

After completing the unit, teachers used a *Post-use Vocabulary Assessment Form* to individually assess each student's ability to recognize the key terms, sign/fingerspell or voice them, and explain or define their meaning. Teachers and students also completed separate post-use surveys that supplied feedback about their experiences with the SLSD and/or SPSD.

Purposeful sampling (Patton) was employed to ensure that each class included students who: communicated using ASL; would be doing a unit that focused on standards-based life science or physical science content; could complete the unit within the testing timeframe; and had the requisite technology. This resulted in two cohorts of students using the Web-based dictionaries in different years. Cohort 1 included 5 classes and 28 students. Cohort 2 included 36 students and six classes. One cohort of 39 students from six classes tested the app versions during the same year as Cohort 2. Within each cohort, hearing-loss levels in the best ear without a cochlear implant or hearing aid ranged from mild to profound; signing levels ranged from survival to superior; English reading and writing levels ranged from below grade level to at grade level, with the majority of students below grade level.

To help us answer our research questions, we organized the results for pre/post-use vocabulary data into spreadsheets according to version (Web or app) and cohort. We further organized the data for each class within a cohort according to dictionary used (SLSD or SPSD), ability to recognize English text versions, ability to sign/fingerspell and/or voice terms, and ability to explain the meanings and/or definitions. These data were then analyzed as follows.

Pre/post-use data about students' knowledge of the five terms identified were tallied. Learning gains were expressed as the percentage change in ability to recognize English versions, sign/fingerspell and/or voice terms, and explain meanings and/or definitions. For example, for the ability to recognize English text versions of a term, for a class of 12, 60 correct responses were possible (5 terms x 12 students). If correct pre-responses for the ability to recognize English text versions of the term were 41, and post-responses were 52, students were able to recognize 41/60, or 68%, of the English versions of the term prior to using the dictionaries and 52/60, or 87%, after use. Therefore, this would represent a +19% gain in students' ability to recognize English versions of terms with use of the dictionary.

Survey data for each class were organized according to perceived gains in learning, usability, use, and satisfaction. Coding rubrics were generated to code comments from students and from teachers within each of the categories. Responses to Yes/No or Likert scale items were tallied and sums calculated for the class, for each cohort, and for the 17 teachers and 80 students who completed and returned surveys. Coded responses were analyzed to detect trends in the data that would provide insight from teachers and students about our primary and secondary research objectives.

*Results*

Pre/post-use vocabulary assessment data showed the kinds of vocabulary and learning gains that are possible with use of the SLSD (Research Question 1) and SPSD (Research Question 2). With regard to the Web-based SLSD and SPSD, each class in Cohorts 1 and 2 improved in the class's ability to recognize the English text versions of the terms, sign/fingerspell or voice the terms, and explain the meaning of and/or define the terms. Pre/post-use data for the app version also showed improvement for each class in each of the three areas. One exception was a class whose members were able to sign/fingerspell all five terms prior to using the app version of the SPSD. Consequently this resulted in no improvement after using the dictionary. Overall, improvement with use of each version of the dictionaries was less for classes that demonstrated more ability at pre-assessment than for groups that demonstrated less ability.

**Table 1. Learning Gains of Students Who Used Web-based Versions of the Dictionaries***

| Dictionary | Cohort: Class | Number of Students | Recognize English Versions | Sign/Fingerspell and/or Voice Terms | Explain Meanings and/or Definitions |
|---|---|---|---|---|---|
| SLSD | I: 1 | 12 | +30% | +52% | +67% |
| SLSD | I: 3 | 1 | +100% | +100% | +80% |
| SLSD | I: 4 | 7 | +46% | +63% | +43% |
| SLSD | I: 5 | 2 | +50% | +90% | +43% |
| SLSD | II:3 | 3 | +47% | +80% | +50% |
| SLSD | II:4 | 10 | +90% | +90% | +70% |
| SLSD | II:5 | 8 | +65% | +53% | +53% |
| SLSD | II:6 | 8 | +35% | +53% | +40% |
| SPSD | I: 2 | 6 | +40% | +67% | +77% |
| SPSD | II:1 | 1 | +100% | +100% | +87% |
| SPSD | II:2 | 6 | +80% | +43% | +70% |

*Learning gains are expressed as the percentage change in the number of pre/post “yes” responses in ability to recognize English versions, sign/fingerspell and/or voice terms, and as the percentage change of pre/post 0–3 scores in ability to explain meanings and/or definitions.

**Table 2. Learning Gains of Students Who Used App Versions of the Dictionaries***

| Dictionary | Cohort: Class | Number of Students | Recognize English Versions | Sign/Fingerspell and/or Voice Terms | Explain Meanings and/or Definitions |
|---|---|---|---|---|---|
| SLSD | I: 3 | 9 | +40% | +47% | +37% |
| SLSD | I: 6 | 1 | +80% | +80% | +63% |
| SPSD | I: 2 | 5 | +72% | +0% | +18.5% |
| SPSD | I: 5 | 2 | +40% | +30% | +53% |
| SLSD & SPSD | I: 1 | 5 | +20% | +16% | +17% |
| SLSD & SPSD | I: 4 | 17 | +35% | +52% | +44% |

*Learning gains are expressed as the percentage change in the number of pre/post “yes” responses in ability to recognize English versions, sign/fingerspell and/or voice terms, and as the percentage change of pre/post 0–3 scores in ability to explain meanings and/or definitions.

Responses in the post-use surveys, when students were asked to name a term and explain what they learned, provided additional insight into effectiveness of the dictionaries for learning new signs for terms and what the terms mean. While using the SLSD to study the topic of genetics and heredity, students reported learning the signs for and meanings of terms such as *nucleus, chromosome, spindle, recessive, chromatids,* and *replication*. While studying the topic of interactions among living things, they reported learning "an ecosystem has living and nonliving things." They also reported never having known this before they used the SLSD. While using the SPSD to study the topic of solutions, students reported learning the signs for and meanings of terms such as *dissolve, solute, solvent, concentration, and solution*.

Evidence from students' survey data also supplied information about usability and use. With regard to usability, most students found the SLSD and SPSD easy (45/80) or fairly easy (33/80) to use. With regard to use, students used the dictionaries during science activities and while doing homework to learn new signs (71/80) and to find out what terms mean (43/80). Their new vocabulary knowledge helped them understand written information (44/80) and discuss and explain content related to the topic of study (59/80). Observations made at sites within commuting distance of TERC supported these results from survey data.

With regard to use of the interactive features, more than half of the students reported viewing text in ASL (66/80), looking at illustrations (41/80), changing the signing speed (47/80), or selecting an avatar character (45/80). About 40% of the students zoomed in on an avatar character to see the signing (35/80), read the English (34/80), or view signed text. Students with sufficient hearing reported using the voice feature (20/80). Several students reported listening to terms and definitions voiced in Spanish and using the Signed Spanish feature (7/80).

Evidence from teachers' survey data offered information about usability, use, and effectiveness. With regard to usability, teachers found the SLSD and SPSD easy (12/17) or fairly easy (5/17) to use. With regard to how they used the dictionaries, all teachers (17/17) reported using them to introduce vocabulary. They used the dictionaries with students to "preview material" that they would be studying. This made "the actual teaching of the content faster and smoother." Teachers had students use the dictionaries to review key terms that were introduced previously as they encountered them during the unit. Most teachers used the dictionaries to supplement discussion (15/17) as well. They also had students use the SLSD and SPSD as resources for looking up words they did not know as they encountered them while reading their textbooks, doing online research, or doing experiments.

With regard to effectiveness, teachers rated the dictionaries as either a very valuable (11/17) or a valuable (6/17) way to complement or enrich their instruction. They all indicated that the SLSD and SPSD could be used to accommodate different learning styles. “Students have a choice of how to get information and can work at their own speed.” “Changing the avatar’s appearance, zooming and rotating, and altering the signing speed helps to accommodate different students’ needs and preferences.” “For students who process information more slowly, I could change the speed of the avatar.” “For students who benefit from repetition, I could play the definition over and over.” “Students can work at their own speed to learn signs and what terms mean in their own language and in English and in Spanish.” “Listening to the definitions in English was good for students who are hard of hearing. The Spanish was good for one student.”

Also with regard to effectiveness, 100% (17/17) of teachers responded that the dictionaries enable communication, independence, and access to content. Their comments, as in the examples that follow, offer specifics: “Students have the vocabulary to describe the science they are learning.” “My students struggle to demonstrate their content knowledge, but the dictionary helps them try instead of just giving up.” “Students can access the material on their own. They no longer have to rely solely on the teacher to get vocabulary information.” “They can replay the signing avatar or re-read the definitions over and over to make meaning of the vocabulary on their own.” “The dictionaries give students an avenue for being more independent when trying to understand new concepts.”

Teachers’ and students’ post-use survey data provided insight into the degree to which they were satisfied with the dictionaries. All the teachers (100%) were completely satisfied with the information presented. Approximately three-quarters of the students (78%) were completely satisfied. The remaining 22% were somewhat satisfied. Approximately half of the teachers (53%) and more than three-quarters of the students (81%) were completely satisfied with the accuracy of the signs. More than three-quarters of the teachers (82%) and more than half of the students (54%) were completely satisfied with their understanding of what the avatar signed. The remaining 18% of teachers and 46% of students were somewhat satisfied.

Comments from teachers and students, as in the examples that follow, provided additional insight into their satisfaction with the dictionaries. Teachers wrote: “I like that this is a resource all of my students can use, regardless of what level they are." "They are great! We are using them for all of the science units during the year." Students wrote: "It teaches me how to sign new words." "I understand the meaning." "I like going to all the dictionaries. I want to get the dictionaries for my home." "I love it."

## Conclusions

While results of this research reflect the experiences of students who used the dictionaries and do not include comparison with a group that did not use them, it appears highly likely from the results presented that the SLSD and SPSD, when used as assistive tools, will contribute to giving students in grades 9–12 who are deaf or hard of hearing access to science vocabulary in their own language. Results suggest students will likely be better able to understand the grade-appropriate science content that they are studying. Such access may also enable this population to work more independently to develop a technical life science and physical science vocabulary. Results also indicate that the dictionaries' interactive features promote individualized instruction for a wide range of learners with varying levels of hearing loss and learning challenges. Teachers who used the SLSD and SPSD were able to easily integrate them into their instruction. In addition, the Avatar technology appears to motivate high school students and fire up their curiosity and interest in learning science vocabulary.

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# SOOC: Addressing Varied Learning Needs through Online Professional Learning and UDL

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## Abstract

The typical classroom does not exist - face to face or online. Learner variation is today's reality, in what our students need and consequently what teachers need, and it is primary to effective course design. Learner variability is based in neuroscience and supported by the concept of neuroplasticity, and should drive development of effective instructional design for today's diverse population of learners. Universal Design for Learning (UDL) provides a framework to vary curriculum and instruction by intentional design (National Center on UDL, "What is Universal Design for Learning?"). Emerging from the concept of universal design (Center for Universal Design), and constructivist learning principles (Vygotsky), UDL addresses learner variation in designing goals, assessment, methods, and materials in all learning environments, online, blended, and face to face. The SOOC uses UDL as a primary framework to model and teach UDL principles, to apply UDL in the intentional use of digital applications (apps), and to address research-based weaknesses in the use of MOOCs in education.

## Keywords

Online learning, Universal Design for Learning, open access, professional development.

## Introduction

Universal Design for Learning (UDL) is a framework to support and improve teaching and learning by effectively addressing the widely varied needs of all students from the onset through innovative curriculum design, rather than through retroactive adjustments and accommodations (Rose and Meyer). The term UDL was coined over 30 years ago by the Center for Applied Special Technology (CAST), and over time CAST has built upon the initial UDL concept, moving from its original focus on a medical model intended to address those "in the margins" to focus now on learner variability with the goal of developing expert learners (Meyer, Rose, and Gordon 8-10). UDL has three core principles: 1) Multiple means of engagement to create purposeful, motivated learners; 2) Multiple means of representation to develop resourceful, knowledgeable learners; and 3) Multiple means of action and expression to support strategic, goal-directed learners (Meyer, Rose, and Gordon 90-104). UDL's goal to develop expert learners through the application of these principles and their related guidelines is explained in graphic form (see Fig. 1.). The potential for UDL to be achieved in an online learning environment is high. Engagement, access and expression can be enhanced through the use of varied online digital content and tools.

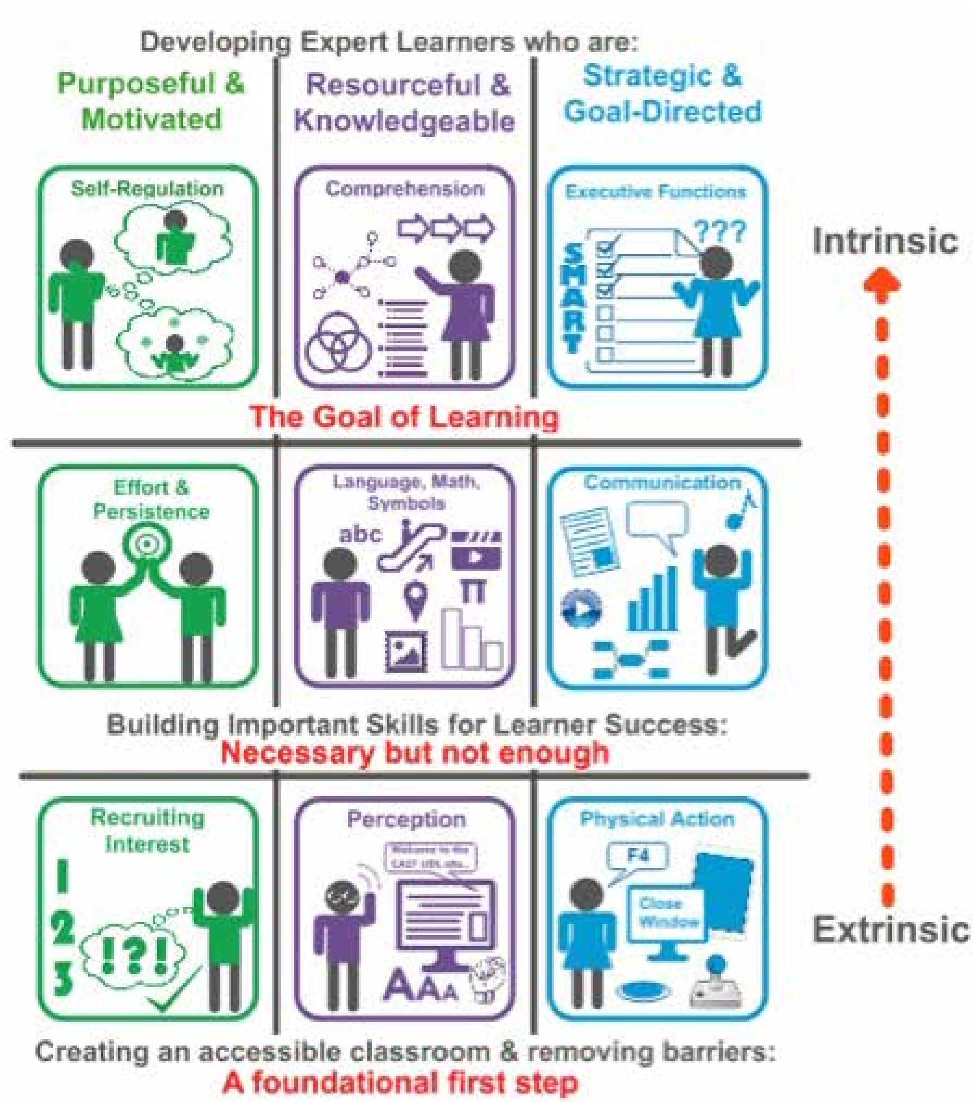


Fig. 1. The Key Goal of UDL: Developing Expert Learners.

*Online Learning and MOOCs*

Technology holds great potential to enrich learning for both teachers and students, but actual technology use in schools is often dull and boring and much less transformative. (Cuban, Kirkpatrick, and Peck). New models for professional learning are needed that incorporate technology tools effectively. One such model is "open pedagogy", which relies on open educational resources (such as videos and podcasts) and emphasizes the learner's network and connections within it (Stacey).

Massive Open Online Courses (MOOCs) are one kind of instructional design through which “open pedagogy” has been made available. MOOCs are designed to deliver free content, are open to anyone, and are often offered without university credit. Millions of citizens from around the world have participated in some sort of MOOC, but the role MOOCs play in effective professional development and their outcomes is still either unknown or not well defined. Studies indicate that while many educators aspire to implement principles of effective online teaching (student directed learning, interactivity & social presence), the reality of MOOCs tends to reduce interactivity, rather than support it (Henry and Thornewill).

Peer assessment, common in MOOCs, is often problematic (Watters). One study at University of Edinburgh showed that participants felt there was no professor 'present' in the course (Parr). The design of MOOCs, often a ‘one size fits all’ model, does not lend itself to support learners who have differing needs and/or disabilities. MOOCs are often replications of traditional content delivery models of education, and their size limits personal choice and options which diverse learners need to make the learning environment work for them.

Concerns regarding MOOCs, opportunities for implementing UDL in online learning environments, the goal of effective teacher professional learning, and technology's ability to vary and support professional learning led the authors to design an alternative model for online professional development. The intent of the model is to deliver instruction in a manner that teaches content about UDL and at the same time models the use of UDL in teaching and learning, using constructivist pedagogy. This model is a SOOC - Small, Short, Supported and Social Open Online Course.

## Discussion

The SOOC uses UDL as a guiding framework, incorporating these goals: 1) Ensure content, resources and interactions are accessible to all participants; 2) Provide descriptive (not prescriptive) learning paths for participants, integrating options, choice, multiple means of representation and of action and expression; 3) Model seamless integration of technology; 4) model the dual role of instructor and participant in a constructivist learning environment; and 5) Support participants' deep understanding of UDL principles through sharing and self-reflection.

UDL principles and guidelines are embedded in instructional design and delivery in two specific areas: course materials and environments (course website, webinars, weekly tasks) and communication and feedback (synchronous sessions, asynchronous instructor & participant postings, digital badges).

*Course Materials and Environments*

The course website was the central location for the SOOC, including the course syllabus, access to videos, images, websites and other resources, and descriptions of weekly tasks offering choice for demonstrating understanding of UDL. The WordPress platform provided flexibility and support for accessibility, using a plugin to provide keyboard accessibility for pull-down menus to meet W3C's Web Content Accessibility Guidelines.

The course was four weeks long, with engaging videos introducing each weekly section. The videos featured experts in the fields of UDL and educational technology, and covered an overview of UDL as well as its three overarching principles. Transcripts were available to participants for alternative representation. After each video, guiding questions highlighted key ideas and concepts to help frame the learning experience. Each week, learners were presented activities to choose from to demonstrate understanding of the key concepts and ideas for that week. The SOOC intentionally optimized individual choice and autonomy in order to emphasize relevance, value and authenticity in task choices (CAST, "UDL Guidelines"). Activities varied in the types of apps and tools learners could use as well as the approaches they could take. Learners were also provided with an open choice to suggest their own task, further optimizing course personalization. Links to all products submitted by the course participants were posted to the course website. Participants were required to submit their task in more than one format, reinforcing the UDL principle of multiple means of representation. By seeing the variety of ways that activities could be completed, the learner's self-efficacy as UDL practitioners was further facilitated and supported.

*Communication and Feedback*

To ensure participants had ample opportunities for support and feedback, and thus ensure the rapid development of a community of practice, a decision was made to limit course enrollment to 80 participants. Each week, the instructors set aside time for virtual office hours when learners could chat with them using the Hangouts feature integrated into Google+. Twitter chats supplemented these Google Hangouts on a different day. At the end of each chat, a Storify archive of the conversation and shared resources was created and posted to the Google+ community for those who missed it.

Participants were encouraged to be reflective of their practice throughout the course. This was accomplished through the intentional design of the task questions and was supported through instructor questions and requests for clarification after participant posts. To further build community, participants were encouraged to provide peer feedback and comment on submitted tasks via the Google Community. Instructors actively participated in the course by completing weekly tasks and reflecting on their learning within the community. As one participant noted, "Their insights and modelling gave a sense of comfort in my own contributions." This served as both motivation and as a model of best practice. Participants recognized the role the instructors' played, stating "I loved that instructors were showing the progression of their own products. This was extremely useful in building a community of practice in a short amount of time."

Digital badging was incorporated in the course to document completion of the tasks and as a tangible recognition system for weekly progress and final completion that was linked to ISTE technology standards. Separate badges were designed for each week of the SOOC and for completion of the full SOOC (see Fig. 2), providing flexible means of recognition for participants' varied involvement.


Fig. 2. Badge Designs for SOOC: UDL & Apps.

## Results

The SOOC was offered twice, in 2014 and 2015, with 53% of participants completing the 2014 course, and 58% of participants completing the 2015 course. Most participants brought some knowledge of UDL with them. However, more people said they applied UDL in their practice than actually understood it. This could be based on a misconception that UDL is just "good teaching" or that providing access to technology is enough. Many participants recognized their knowledge and application of UDL was not as advanced as they initially assumed and were more cautious in their evaluation of their application to practice in the post-survey (see Fig. 3).

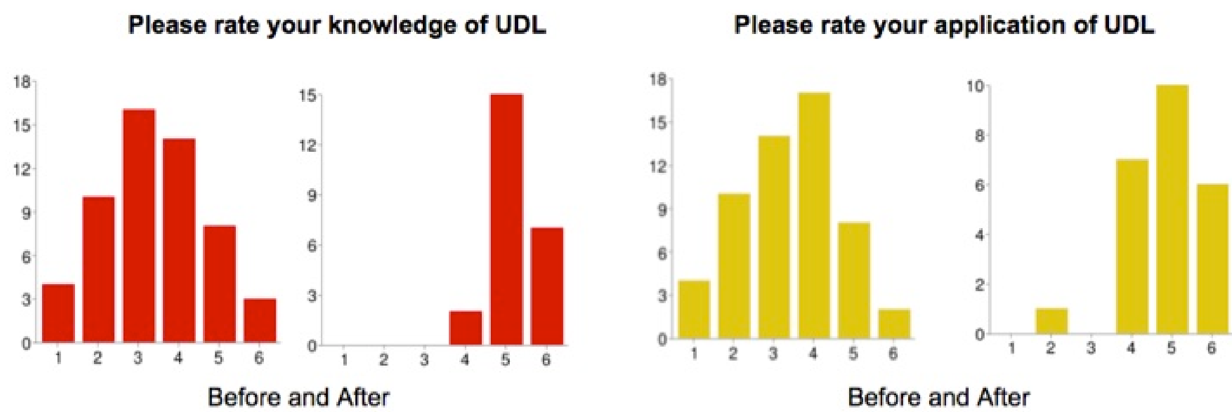


Fig. 3. Participant Knowledge and Application of UDL.

When asked the question: "Looking back on your application of UDL to your practice, what has or will change after taking the SOOC?" participants referenced five categories in their written responses from most to least referenced: 1) They now use UDL as a lens to reexamine their current practice; 2) They have increased awareness of and clarity of UDL principles; 3) They apply UDL intentionally, moving from theory to practice; 4) They will include, explore, and share more apps with fellow teachers; 5) They will advocate for the use of UDL and share their knowledge of UDL with others.

Participants understood the course was designed to serve as both a model of UDL and accessibility, and of how to create engaging online learning spaces. In both versions of the SOOC numerous comments specifically identified the instructors as key to participant engagement in the course and completion of same. Additionally, participants were unanimous in their positive response to instructor presence, feedback and commitment to the SOOC experience, with 91.3% rating instructor comments as very helpful in motivating them to stay engaged. When asked whether they would participate in this type of learning again and whether they would recommend a SOOC to a colleague, 100% said yes.

**Conclusions**

A key to the successful implementation of the SOOC model in both iterations of the course was the instructors' role as not only designers of the learning environment and facilitators of the weekly learning activities, but as lead learners themselves. Learning was made visible through instructors' posts of their own work and their comments to others' submissions in the Google+ community. This modeling of metacognition was cited by participants as a key component of the SOOC that differentiates it from a traditional MOOC design.

From the learner's perspective, the SOOC received overwhelmingly positive feedback. Participants noted that it was a flexible way to learn that met their professional needs. Multiple pathways for learning were evident in the choice of activities learners could select to demonstrate their understanding, in keeping with the UDL principle of multiple means of action and expression. Given this flexibility, each person approached the learning differently and took away something unique, which was intentional within the course.

Unlike traditional MOOCs, students had extensive interactions with the instructors in a variety of settings and modes. The feeling that "there is no teacher" which has been reported by some participants in traditional MOOCS was not evident in this course, possibly explaining the high levels of participation and satisfaction reported by participants. Despite the positive outcomes of this course, the instructors view the SOOC findings as a baseline design that should continue to be refined. Key areas considered for improvement include providing additional options for student participation, further exploration and refinement of badge integration, and a greater focus on researching learning outcomes.

Early enthusiasm for MOOCs as a model for online education has lessened or changed in recent years, but these results suggest that an open online course format holds promise for promoting, enhancing and supporting engaged learning if specific design modifications are made. While MOOCs focus on delivery of content in the most efficient ways possible to the greatest number of learners, the SOOC course model focuses on developing an interactive community of practice, multiple pathways for learning, and ongoing support.

These aspects of the SOOC are consistent with recent literature findings about MOOCs and their effectiveness (or ineffectiveness). The instructors focused on the implementation of best practices in education and accessibility before considering the tools used in this course.

They modeled UDL, which exemplifies the type of technology-enabled learning recommended by Ertmer and Ottenbreit-Leftwich, where the tools are no longer an isolated goal to be achieved separately from pedagogical goals, but are the means by which students engage in relevant and meaningful learning. These findings indicate that this new SOOC model warrants further exploration of its effectiveness for online professional learning, its effectiveness as a vehicle to demonstrate and model UDL implementation, and its appropriateness for modeling how other professional areas can provide engaging online learning opportunities.

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# Globally Defining an Inclusive Education Standard

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## Abstract

This paper identifies the need to establish a global standard of *inclusive* education for those of us with disabilities to meet goal 4 of the Sustainable Development Goals adopted by the United Nations.



## Keywords

K-12 Education, Higher Education, Government.

## Introduction

As we move into the era of a human rights model of disability, (Marcia Rioux) inclusive education has become the goal of many advocates and international organizations, including the United Nations. Goal 4 of the Post 2015 Sustainable Development Goals (SDGs) stipulates that we must: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all."

While the term inclusive education is representative of education for all (leave no one behind), we have yet to define what that term means for those of us with disabilities in a global context.

In many models of education, the terms *accommodated for*, *mainstreamed, special education* and *integrated* education are used interchangeably with inclusive education.

However, *accommodated for*, *mainstreamed, special education* and *integrated* education remain dependent on inserting a person with a disability into an inaccessible learning environment and attempting to *make them fit* (Harman). *Non-inclusive* learning environments create barriers to students with and without disabilities.

This paper establishes the need for a global standard that defines the implementation of inclusive education in developed and developing nations (Global North and Global South).

## Convention on the Rights of People with Disabilities

While the CRPD outlines the need for accommodation when necessary, it fails to provide more guidance and definition to facilitate the creation of a global inclusive education standard. We must also add tertiary education to article 24.

Juxtaposed against the call for inclusive education is the current call for quality education (Education International). Although the need for quality education is referred to primarily for those of us without disabilities, the elements of quality education discussed in a global context can be incorporated into a global inclusive education standard. For example, models of quality education are holistic and bring together safety, psycho-social well-being, access to the built environment, access to learning material (whether that material is physical or digital), a standard for teacher qualifications, and substantive equity (Grima). All are components of inclusive education.

As we move toward establishing a global inclusive education standard, we are faced with several seemingly interchangeable terms: *accommodated for*, *mainstream*, *special education*, *integrated*, *quality* and *inclusive*. Unfortunately, many of these terms have negative connotations for those of us with disabilities.

**The Legacy of Mainstreaming**

Most current articles on mainstreaming acknowledge the legacy of attempts to insert those of us with disabilities into the *regular* classroom, either full or part-time, with little or no supports. Even the contributors to the Wikipedia definition of mainstreaming begin the article by stating that "mainstreaming is not to be confused with inclusive education" (Wikipedia).

The very definition of mainstreaming precludes an inclusive learning environment. The focus of mainstreamed learning is that those of us with disabilities spend only part of the day in a *regular* classroom and are withdrawn for special education for some subjects.

The focus of *accommodated for*, *mainstreame*d, *special education*, and *integrated* education fosters a dependence on external supports for those of us with disabilities. This eradicates accountability of the teacher toward multi-modal teaching techniques, maintains a distance between those of us with and without disabilities, and perpetuates a segregated social model of disability with remnants of the medical model of disability.

In Canada, *mainstreaming* has been replaced by a model of *integrated* education (Statistics Canada). The concept maintains an equal but separate learning environment.

Although some provinces have their own human rights based legislation containing language specific to those of us with disabilities, there are no provincial or national standards defining inclusive education. The focus is on *accommodation for* those of us with disabilities (Government of Ontario).

The term *special education* is discriminatory as it relates specifically to those of us with disabilities and does not include those of us who are gifted or require other types of learning environments (Wikipedia).

If we are committed to inclusive education and learning environments, those of us with disabilities must be accepted as equals with the same rights as other students and teachers. We must begin to leverage technology when available to support learning and inclusion.

## The Role of Technology in Inclusive Education

In an inclusive education model, the focus is not on technology but rather on options for learning. When learning assets are accessible, and students seamlessly use their adaptive technology, a significant barrier to learning is removed.

For example, the use of adapted learning tools such as *Learning Path* (LeaP) by Desire2Learn provides a framework for students to have additional learning material presented to them based on goals and objectives set by the teacher and based on responses to the learning assets presented (Desire2Learn). The focus is on learning the concept, and the technology is a responsive means toward that goal. The technology is not the goal itself.

An inclusive education model must contain clearly identified international guidelines and standards of accessibility for the use of technology in teaching and technology used by those of us with disabilities to access learning material.

A global inclusive education standard must recognize that not every country or region has access to the same level of technology, connectivity and digital learning material. As the availability of technology increases, a global inclusive education standard will assist countries and regions ensure that technology is accessible, and students and teachers with disabilities have access to adaptive technology.

## Creating a Global Inclusive Education Standard

First, we must agree on the elements of inclusive education in the global context. This is a difficult but not impossible task. A priority in creating the global inclusive education standard is the consultation and participation of those of us with disabilities in creating the standard.

In order for us to be successful as a global community in achieving an inclusive education standard by 2030, we must begin moving toward learning environments with all of the following elements:

- Any tool used in any learning environment must be accessible to international guidelines or standards. For web content, applications and apps this means WCAG (Web Content Accessibility Guidelines) and the Authoring Tool Accessibility Guidelines (ATAG). PDF (Portable Document Format) is identified in ISO 14289 (International Standards

Organization). There are international guidelines for captioning and video description, accessible multimedia and other formats.

- Tools used in a learning environment include but are not limited to administrative software, grading software or software used to communicate with parents.
- To promote role models and include those of us with disabilities in the learning environment, we must hire teachers with disabilities.
- Teachers with and without disabilities must receive education that establishes them as inclusive educators who are able to teach those who want to learn. (This may include professional development programs in sign language, Braille, adaptive technology and so forth.)
- The built environment must be accessible to students and teachers with disabilities. This includes sports fields, areas of athletic activity and auditoriums used for physical education.
- A by-product of this component is in providing opportunities for Paralympian's to train and compete locally nationally and internationally.
- Any deliverable/assignment produced by any teacher or student must be created to be accessible. Principles of universal design must be present in all deliverables produced in any learning environment.
- A by-product of this is that graduates with and without disabilities will be more competitive in a global employment environment because employers will not have to train or educate them on established accessibility/inclusive standards.
- Additionally, any funding for any educational project must include language that moves the learning environment toward the global inclusive education standard. This includes monitoring and evaluation protocols that ensure the above mentioned components of inclusive education are implemented in a timely manner.

## Conclusion

In 2016, despite the promotion of *inclusive* education as it pertains to those of us with disabilities, we are no closer to establishing what *inclusive* education means in a global context.

There are exponential benefits to establishing a global inclusive education standard for those of us with and without disabilities. If the SDGs are to be realized by 2030, we need to begin graduating students who are already able to create, design, deploy, and invent products, physical and digital environments that are inclusive/accessible. Moreover, these graduates need to be able to accept those of us with disabilities as part of all professional practices.

Developing a global inclusive education standard creates the infrastructure for a human rights model of disability. It will ensure that those of us with disabilities are an integral part of our communities socially, professionally, and politically.

## Author's Note

In this paper the term "those of us with disabilities" purposely replaces the more generic "people with disabilities" to promote the use of a more inclusive language.

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# Meeting Accessibility Challenges with Web Components

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## Abstract

Web Components comprise a suite of technologies under development by the World Wide Web Consortium (W3C) that together enable standard formats such as Hypertext Markup Language (HTML), and Scalable Vector Graphics (SVG) to be extended with new functionality. Web Components encapsulate presentation and behavior in a reusable fashion that coheres well with the markup languages and development practices of the Web. We briefly review the constituents of Web Component technology - custom elements, the shadow DOM, HTML imports, and the HTML 5 template element. We then argue that Web Components are a general mechanism that can be used to address problems, some of them long-standing, of Web accessibility.

Our argument proceeds via a series of examples that illustrate the utility of Web Components as means of enhancing non-visual access to images, providing spoken and braille alternatives to textual content, and implementing custom interactive controls with features that improve access while bringing to the fore the underlying semantics of the content. Although the design of our Web Components is motivated by educational needs, they and the broader approach to solving accessibility challenges which they exemplify are applicable to the Web as a whole.

## Keywords

Web accessibility, Web components, Web standards.

## Introduction

Although the Web browser has become a progressively more sophisticated programming environment, until recently, it’s predominant markup languages - HTML and SVG - have not been accompanied by an extension mechanism permitting new elements and attributes to be defined to express application or domain-specific concepts. This role is now filled by Web Components, a technology which is presently undergoing standardization by the World Wide Web Consortium, and which browser developers have started to implement.

Web Components support abstraction and modularity in Web applications by allowing the registration of "custom elements" (Glazkov, *Custom Elements*) that can be used in HTML or SVG contexts. A custom element is typically associated with executable code (written in JavaScript) with which the element provides a user interface. This user interface can be implemented via HTML, SVG and CSS. The code and styles comprising the user interface operate in isolation from scripts and CSS rules applicable to the HTML document in which the custom element occurs. This separation is achieved by way of the shadow DOM (Glazkov and Ito), a mechanism for attaching an element hierarchy to a DOM node. This subordinate tree is then isolated from the surrounding document.

A simple mechanism, HTML imports (Glazkov and Morrita) has been proposed to allow Web Component implementations to be included in HTML documents. This proposal, which extends the HTML link element, remains controversial, and it may be superseded by an alternative solution. Authors of Web Components can also take advantage of the template element, already standardized in HTML 5, (Hickson et al. 4.11.3) to supply prebuilt content for manipulation by JavaScript code in constructing the desired user interface. In combination, the technologies briefly introduced here support a high degree of modularity. A custom element, with its associated functionality and styles, comprise a Web Component which, once created, can be used as needed in diverse application scenarios while maintaining isolation from the surrounding context.

As we shall demonstrate via the examples described in the next section of the paper, the emergence of Web Components opens the possibility of devising reusable solutions to problems of Web accessibility that can be integrated into documents and applications in a straightforward and modular fashion. Web Component technology provides markup language extensibility of a kind that complements and enhances the capabilities of the Web browser as a programming environment. The potential benefits that this extensibility brings to addressing the challenge of accessibility are, we contend, considerable. This conclusion is here supported by experiments in the design of innovative Web components that address a range of practical difficulties which current Web standards do not adequately resolve: the provision of alternatives to images that extend beyond textual descriptions, the specification of precise spoken and braille representations of text, and the creation of custom user interface components.

*Web Components for Associating Alternatives with Images*

Standards and practices for making graphical content accessible have focused largely on the use of textual alternatives such as labels and descriptions. This emphasis is reflected in guideline 1.1 of *Web Content Accessibility Guidelines (WCAG) 2.0* (Caldwell et al.), which requires text alternatives to be provided for any "non-text content", including images. Although this requirement serves the needs of users of conventional screen readers, it does not accommodate a larger range of non-visual representations that can provide richer perceptual alternatives to graphical material. Moreover, the needs of users with learning and cognitive disabilities are not taken into consideration, due to a lack of universally applicable measures that are widely accepted as enhancing such users' ability to comprehend graphical content. A more inclusive solution, the Diagrammar, has recently been proposed by the DAISY Consortium (*Resource Directory for the Z39.98-2012 Authoring and Interchange DIAGRAM Description Feature, Version 1.0)* as an XML format designed to facilitate the authoring and exchange of a range of alternatives that may be associated with an image. The supported alternatives include a short and a long description, a tactile graphic (supplied as a reference to an external resource), a tour (i.e., a textual overview) of the tactile graphic, a simplified image and a simplified description. Whereas the last two alternatives are meant to meet the needs of people with learning and cognitive disabilities, the remainder are principally of benefit to users who are blind or who have low vision.

By means of Web Components, the Diagrammar can be implemented directly in HTML as a set of custom elements, preserving the original semantics and making only slight syntactic adjustments. Specifically, the specification requires each custom element to be given a name that contains a hyphen ("-") character, and which avoids names reserved by other specifications. An instance of our dg-content Web components is depicted in figure 1. Unlike the original XML format intended to enable the creation and exchange of documents, a series of Web Components is expected to provide not only syntax but also behavior. In adapting the Diagrammar for use in Web applications, we chose an approach to the design which is inspired by the audio and video elements of HTML 5. If the Boolean controls attribute is set, then the Web Components display a user interface, namely a menu of alternatives to the original image (illustrated in figure 2) from which the user can select. If the controls attribute is not set, the determination of which alternatives to present to the user is the responsibility of the application in which the Web Components occur. This flexibility supports the use of a global configuration option or a profile of the user's access requirements to control the selection of alternatives. Thus, the Web Components are designed to be consistent with the recent paradigm shift in accessibility research and standards toward personalization of user interfaces according to each individual's declared needs and preferences (Nevile; Nevile, Treviranus, and others; Vanderheiden et al.).

```
<dg-content controls>
  <dg-img>
  <img src="imgs/survey.jpg" alt="Image of surveyors working">
 </dg-img>
 <dg-summary show>
  The image depicts two surveyors measuring the angles between
  themselves and a tree.
 </dg-summary>
 <dg-longdesc show="true" overlay="false">Two surveyors, A and P, stand some distance
  apart on the south bank
  of a river, looking at a tree, T, that is on the north bank of the river.
  Points A, P, and T form a triangle. At points A and P, there are two parallel
  sight lines pointing north and forming angles outside of the triangle. At
  point P, angle TPA is 53 degrees. The adjacent angle between PT and the
  northern sight line is 37 degrees. At point A, angle TAP is not labeled,
  and the adjacent angle formed between AT and that northern sight line is
  32 degrees.
 </dg-longdesc>
 <dg-simplifieddesc show="false">
  T, A, and P are the three points on a triangle. Angle TPA is 53 degrees
  with an adjacent angle of 37 degrees. The angle adjacent to angle TAP is 32 degrees.
 </dg-simplifieddesc>
 <dg-tactile show="false" source="imgs/anglesmap.jpg" controls="false">
  <dg-tour>
    Start exploring at the top right.
  </dg-tour>
 </dg-tactile>
</dg-content>
```

Fig. 1. Diagrammar implemented as a web component. The code can be used in line within an HTML application.

# DIAGRAM Content Model in HTML

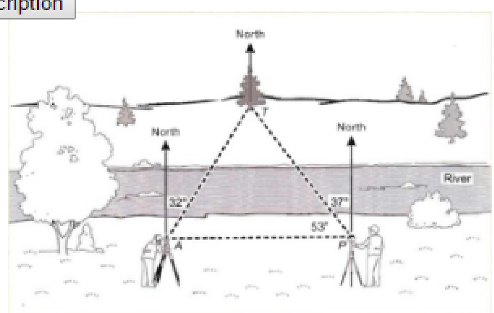
▼ Controlling `<dg-content>` with javascript

Show/Hide Controls | Show/Hide longdesc | Show/Hide Simplified Description | Show/Hide Tactile | Toggle longdesc style

## Survey Diagram

The following image:

Description




The image depicts two surveyors measuring the angles between themselves and a tree.

Two surveyors, A and P, stand some distance apart on the south bank of a river, looking at a tree, T, that is on the north bank of the river. Points A, P, and T form a triangle. At points A and P, there are two parallel sight lines pointing north and forming angles outside of the triangle. At point P, angle TPA is 53 degrees. The adjacent angle between PT and the northern sight line is 37 degrees. At point A, angle TAP is not labeled, and the adjacent angle formed between AT and that northern sight line is 32 degrees.

**Simplified:** T, A, and P are the three points on a triangle. Angle TPA is 53 degrees with an adjacent angle of 37 degrees. The angle adjacent to angle TAP is 32 degrees.

Emboss

**Tour:** Start exploring at the top right.

Can you explain how the distances to T is calculated?

Fig. 2. Diagrammar Content from Figure 1, as rendered in HTML using the Chrome Browser.

*Providing Spoken and Braille Alternatives to Text*

Our second example demonstrates the use of Web Components to meet an immediate need arising from shortcomings in the implementation of standards by assistive technologies. Since current screen readers do not support Speech Synthesis Markup Language (SSML) (Burnett, Shuang, and others), there is no standards-based mechanism available with which a content author can prescribe the pronunciation of a text string, for example a name or a domain-specific term. Although labeling techniques (e.g., the aria-label attribute) can be used as a crude means of substituting a misspelling of a word or an expansion of an abbreviation that improves pronunciation, they incur the disadvantage of imposing the substitution not only on text to speech users, but also, and undesirably, on users of refreshable braille displays. The comprehension of text to speech users is thus improved at the expense of the comprehension of braille users, for whom the misspelling of key terms, for example, runs the risk of impeding understanding of the text.

Until SSML is more widely deployed, this problem can be partially addressed by a set of Web Components, comprising a container, apip-alt, which allows spoken and braille renderings to be specified in their respective child elements (see figure 3). The name is a reference to the Accessible Portable Item Protocol (APIP) specification of the IMS Global Learning Consortium (Accessible Portable Item Protocol (APIP)). The spoken form is a string that can be substituted for the original text; the braille form is given as a string of characters drawn from a block of Unicode code points that correspond to all 256 possible eight-dot braille patterns. In practice, of course, six-dot braille cells would typically be used, as these are the norm in almost all braille encodings. This braille representation takes advantage of the observation that the Unicode braille characters are correctly processed by most screen readers (i.e., the corresponding dot patterns are forwarded to the braille display). As in the preceding example, a controls attribute determines whether the Web Component supplies its own user interface or whether this responsibility belongs to the application. In the resultant rendering shown in figure 4, the control is rendered as a drop down list prior to the displayed text, which enables the user to select their preferred alternate from the list (braille or spoken). The effect of the Web Component is thus to present either the spoken alternative or the braille alternative to the user, while allowing for the possibility of switching between them, thereby supporting the needs of those who rely on both access methods during a single interaction.

```
<h2>Sample Problem</h2>
<p>The following is a math expression:</p>

<apip-alts id="s0" controls="true">
    <apip-display>12<var>x</var><sup>2</sup>
        + 7<var>xy</var> - 10<var>y</var><sup>2</sup>
    </apip-display>
    <apip-spoken id="s1" >
                    Twelve times ex squared, plus seven times ex times
        why, minus ten times why squared
   </apip-spoken>
   <apip-braille id="s2" >
        #12x^2"+7xy-10y^2_4
   </apip-braille>
</apip-alts>

<p>Can you factor this expression?</p>
```

Fig. 3. Prototype apip-alts implemented as a web component. The code can be used in line within an HTML application. The element contains "display text", spoken alternate, and Nemeth versions of a simple equation.

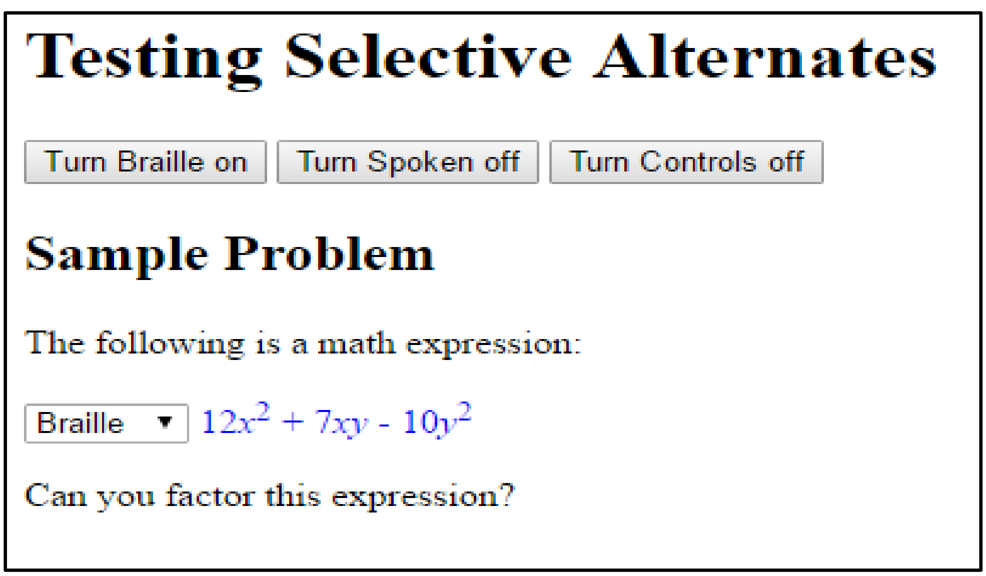



Fig. 4. apip-alts content from Figure 3, as rendered in HTML using the Chrome Browser.

*Designing an Interactive Control as an Accessible Web Component*

The third example was developed to demonstrate the value of Web Components in capturing the semantics of complex user interface controls, while providing intrinsic accessibility by implementing the WAI-ARIA 1.0 attributes required to support screen readers (Craig and Cooper). A set of Web Components was developed that implements the capabilities of the choice element defined in the IMS Global Learning Consortium Question and Test Interoperability (QTI) specification, an XML-based standard for the creation and exchange of interactive assessment items (*IMS Question & Test Interoperability Specification*). The choice element supports both single and multiple selection of options by the user, as well as the automatic shuffling of the choices. To the user, the resulting qti-choice Web Component (see figure 5) and its contents appear as a series of radio buttons (see figure 6), with customary behavior. The advantage to the assessment application author, however, lies in the provision of a modular component that can easily be incorporated into software for delivering tests to users via a Web browser, or even into the test materials themselves, while maintaining the supplied visual presentation, behavior, and accessibility, and preserving the abstract semantics of the original XML format. The visual presentation can readily be modified by application authors who desire to do so.

```
<qti-itemBody>
    <p>Look at the picture of a sign found in Japan.</p>
    <p><img src="images/sign.png" width="25%" alt="Person running toward circular shape."/></p>

    <qti-choiceInteraction responseIdentifier="RESPONSE" shuffle="false" maxChoices="0"
                minChoices="0" orientation="vertical">
        <qti-prompt>What does it indicate to you?</qti-prompt>
        <qti-simpleChoice identifier="ChoiceA">You have reached a safety point.</qti-simpleChoice>
        <qti-simpleChoice identifier="ChoiceB">Watch out for open manhole covers.</qti-simpleChoice>
        <qti-simpleChoice identifier="ChoiceC">Watch out for puddles of water.</qti-simpleChoice>
        <qti-simpleChoice identifier="ChoiceD" fixed="true">None of the above.</qti-simpleChoice>
     </qti-choiceInteraction>
    <qti-submit></qti-submit>
</qti-itemBody>
```

Fig. 5. Prototype QTI Choice Interaction implemented as a web component. The code can be used in line within an HTML application.

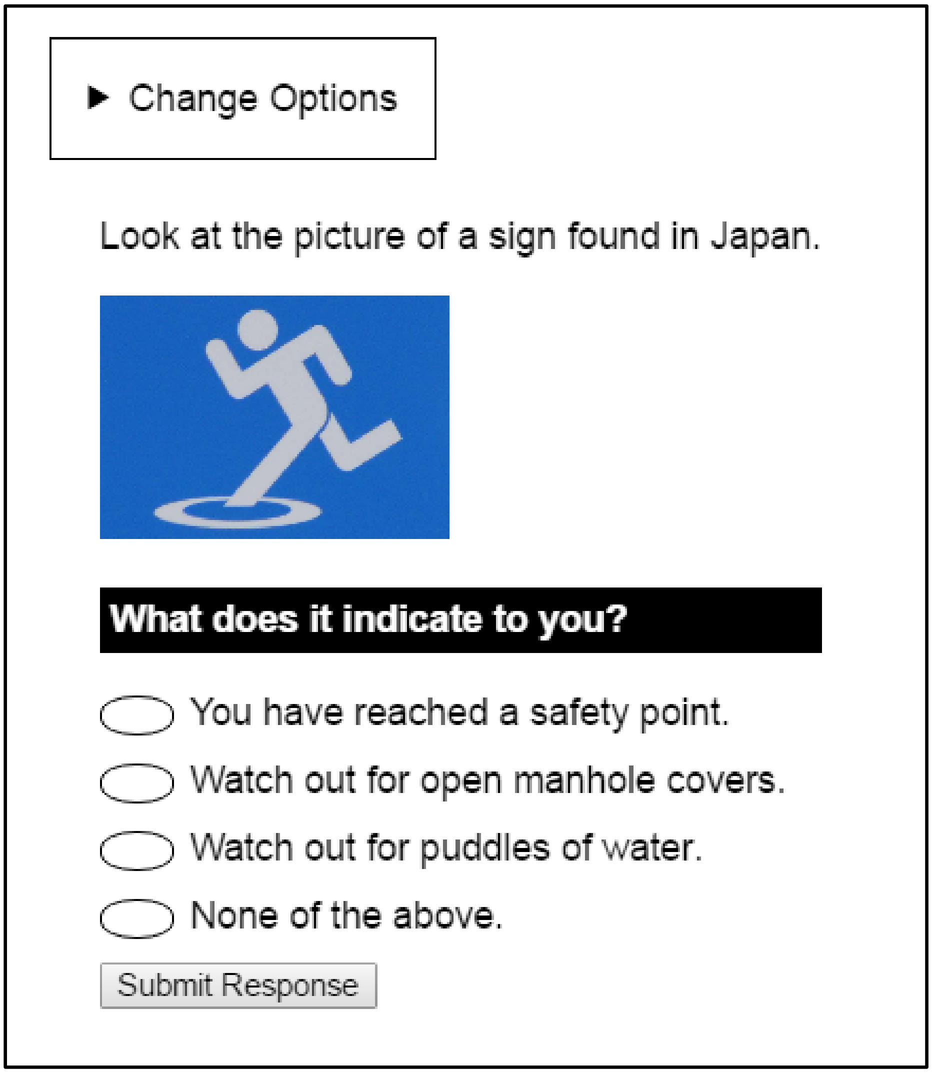



Fig. 6. apip-alts content from Figure 5, as rendered in HTML using the Chrome Browser.

## Discussion

As the preceding examples illustrate, Web Components permit the HTML and SVG markup languages to be extended without requiring any modification of the underlying browser's source code, hitherto the only effective means of associating novel behavior with newly defined elements. The custom elements can be applied without having regard to the details of their implementation: presentation and behavior, including characteristics needed to support accessibility, are safely isolated within the Components themselves. A familiar and expressive markup language interface - that of elements and attributes - is presented to the content author, who is insulated from the internal details of the Web Components, including, crucially, those aspects of their implementation that are needed in order to support accessibility. The semantics of the content are clearly exhibited in the markup by way of appropriate abstractions, a practice made possible by Web Components that may be contrasted with the repurposing of HTML elements, including generic containers such as div and span, as user interface controls, in which the true meaning of the markup is obscured from authors and maintainers of the document or application. Thinking and designing in terms of suitable abstractions and their associated vocabulary is thus encouraged by the introduction of special-purpose elements as Web Components.

**Conclusion**

As our examples show, Web Components provide a versatile, expressive and modular means of bringing abstractions into Web applications, with accompanying user interfaces that address problems of accessibility. Ongoing work by the authors and their collaborators seeks to integrate the "Diagrammar" Web Components into a reading system for electronic books, and to inform the development of future versions of the IMS QTI standard by encouraging support for the use of Web Components as a modular and accessible means of building interactive assessments for delivery via Web technologies.

Our examples explore only a few of the potential ways in which Web Components can be applied to enhancing accessibility. As support for the underlying technologies matures, it will become increasingly feasible to develop and deploy in practice a host of further innovations based on Web Components designed to meet the needs of users with disabilities, and to assist authors in the design of accessible Web applications.

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The Journal on Technology and Persons with Disabilities

# Optimizing Accessibility of Wireless Emergency Alerts: 2015 Survey Findings

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## Abstract

The Wireless Emergency Alert (WEA) system is a free, opt-out, national emergency alerting service that was deployed in 2012 as one component of the Integrated Public Alert and Warning Systems (IPAWS). Since 2012 over 10,000 WEA messages have been transmitted to mobile phones in the U.S. In 2015, a national online survey on WEAs (2015 WEA Survey) was conducted to understand the effectiveness of WEA messages for people with disabilities. The survey collected data on availability, awareness and accessibility of WEA messages, as well as actions taken by the recipient upon receipt. The survey also takes into consideration the type of mobile device used by the respondents. Project researchers hypothesized that greater awareness and exposure to WEA alerts would increase trust and appropriateness of individual responses to alerts. The analysis of the survey data supports the hypothesis. The 2015 WEA national online survey results provided policy and practice insights to improve the intended impact of WEA messages for people with disabilities.

## Keywords

Wireless Emergency Alerts, Accessibility, Emergency Communications, Behavioral Response.

## Introduction

Historically, people with disabilities, older adults, the economically disadvantaged, women, children and immigrants have been disproportionately affected during disasters. In many instances an individual's social and economic vulnerability can seriously impair his or her ability to prepare for a disaster, cope with the aftereffects, and fully recover from the disaster (Tierney 110; Wisner et al. 11). Previous research on support for older adults and people with disabilities in the Southeast United States (with the exception of Florida) has shown that many states' emergency plans do not explicitly include these demographics and the requisite mitigation, preparedness, response and recovery measures that could reduce the impact of their socioeconomic vulnerability (Bennett n.p.). One result of this gap is that communications to people with disabilities are insufficient.

Executive branch and federal agency concern regarding the modernization of the nation's emergency alerting capabilities, and ensuring equal access to emergency alerts and warnings, catalyzed a massive effort to integrate multiple infrastructures and methods used for emergency alerting (broadcast, cellular, internet protocol) into one unified system, the Integrated Public Alert and Warning System (Exec. Order No. 13407 1226, Federal Communications Commission 6), of which Wireless Emergency Alerts (WEAs) are a component. Mandated by Congressional statute (109th Congress, Pub.L. 109-347 n.p), the Federal Communications Commission (FCC) outlined technology neutral rules governing wireless service providers who elect to transmit WEA messages to their subscribers (FCC n.p). WEA represents the first national emergency notification system that was mandated by law to be proactively inclusive of people with disabilities (109th Congress 153), as people with disabilities rely on their mobile devices to receive and to send critical information. Despite the cost, 90% of people with disabilities buy mobile phones to stay informed and connected (Wireless RERC 2). According to a survey of user needs, 82% of 1600 respondents with disabilities stated that wireless devices were increasingly important to them, while 72% of respondents stated that wireless devices were especially important during emergencies (Mueller et al. 45). In light of these observations, the implementation of the WEA service in 2012 necessitated research on how tenets of Pub.L. 109-347 were being applied, with specific inquiry into the use of mobile phones by people with disabilities during emergencies, identifying the device specifications and user needs requirements for effectively alerting this population, and protective actions taken in response to emergency messages.

In 2015, Georgia Institute of Technology researchers conducted a national online survey (2015 WEA Survey) to identify how people with disabilities respond to WEA messages. Project researchers hypothesized that greater awareness and exposure to WEA alerts would increase trust and appropriateness of individual responses to alerts. The analysis of the survey data supports the hypothesis. The 2015 WEA survey collected data on WEA awareness, accessibility, trust and validation of message content, frequency of receipt of WEA messages, actions taken upon receipt, and expectations for future features for the next-generation of WEA (NG-WEA).

*Methodology: Development and Deployment of the 2015 WEA Survey*

The project team conducted evidence-based research on user experiences with actual WEA messages. To accomplish this task, focus group methodology was employed to inform the design of the survey instrument. Using a purposeful sample of individuals belonging to specific disability groups, focus group moderators explored the level of WEA availability, awareness and trust amongst the participants in their use of these tools for receiving emergency alerts, and behavioral responses upon message receipt. The project conducted focus groups composed of people with hearing, vision, mobility/dexterity, and cognitive disabilities. Focus group findings were used to fine tune the on-line survey instrument originally developed by the Wireless RERC in 2012 (the Wireless RERC collected WEA survey November 2013 through March 2014. Updating the 2012 survey allows for some longitudinal comparisons with data collected in the 2015 WEA Survey) and collect data on factors that may impact the effectiveness of WEA messages.

*Sampling*

The survey used convenience sampling to specifically target respondents with a declared disability. Convenience sampling versus fully random sampling was necessary because of the difficulty and cost of selecting individuals with disabilities from the general population. No large, publicly-available databases of people with disabilities and their contact information exist. Consequently, it would be necessary to draw a very large random sample of the general population (at least 20,000) to generate a random subsample of Americans with disabilities. The survey was offered online using Survey Gizmo, over the telephone, and in paper format to people with disabilities, including people who are deaf, hard-of-hearing, blind or had low vision. The survey was also administered using American Sign Language (ASL) for people who are Deaf and primarily conversant in ASL. Deaf Link, Inc., created an ASL video to recruit individuals that primarily communicate via ASL to ensure there was no language barrier in reaching the desired population.

*Analysis*

The results of the survey were analyzed using IBM SPSS, statistical software. This report presents the findings from our initial univariate analysis. We expanded our analysis by closely examining the relationship between two or more variables such as disability, WEA awareness, and behavioral response to WEA in order to understand if greater awareness and exposure to WEA alerts would increase trust and appropriateness of individual responses to alerts. These relationships were examined using Chi-squared analyses of the relative distribution of values between and among discrete variables. Since a model has yet to be generated for how all contributing variables might relate to specific behavioral outcomes, multiple independent testing was used. As a result, significance values reported herein are indications of strengths of relationships, rather than absolute statistical significance. All Chi-squared distribution analyses employed Yates correction for continuity.

*Demographic Profile of Survey Respondents*

To maintain consistency with previous surveys conducted by project personnel, respondents are always asked to self-identify for all categories of disability as identified through the US Census Questionnaire: sensory, speaking, dexterity, mobility and cognitive. The Census questions are, for example, worded "I have difficulty with hearing." In doing so, we also acknowledge that some respondents have more than one disability to report. One thousand three hundred thirty four (1334) people completed the survey; 55% reported having a disability and 45% indicated that they did not have a disability. Figure 1 portrays the type of disability by percentage. The most represented disability amongst survey respondents was hearing (28%). Eighteen percent (18%) self-identified as having a mobility disability; 15% indicated difficulty seeing; 11% reported anxiety; reach and dexterity together represent 11% of respondents; and 4% self-identified as having difficulty speaking.

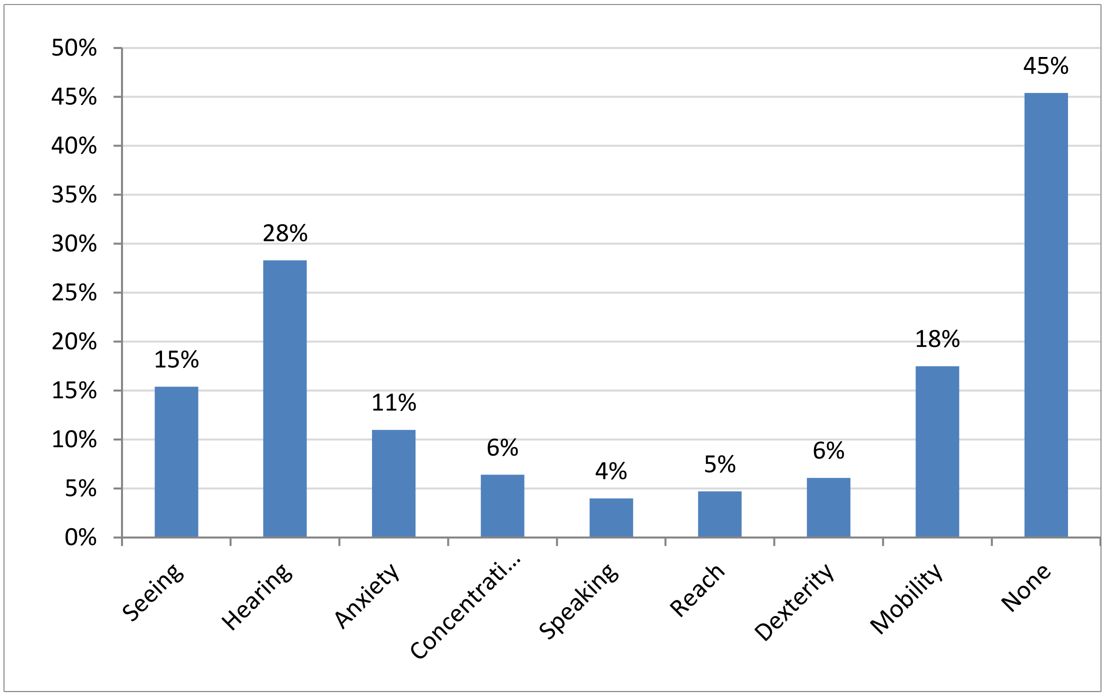


Fig. 1. Type of Disability.

With regard to hearing and vision disabilities, separate questions were asked to determine level of hearing (deaf, hard of hearing, hearing) and level of vision (blind, low vision or sighted). Four percent (4%) of respondents reported being blind, 9% low vision, 10% specified that they were Deaf and 16% hard of hearing (HoH). These numbers include 4% of those not reporting that they had “vision difficulty”(41 respondents) indicating that they were blind or had low vision, as well as 6% of those not reporting “hearing difficulty”, (35 respondents), reporting that they were Deaf or hard of hearing (HOH). In addition, 38% (78 respondents) who reported difficulty with vision, answered that they were “sighted”, while 17% (64 respondents) indicated difficulty with hearing yet were “Hearing.” This indicates confusion with the manner in which the Census questions are worded.

The average age of survey respondents was 51 years old; the oldest was 94 and the youngest was 19 years old. Two percent (2%) of respondents fell in the 18-24 age group; 26% in the 25-43 age group; 49% in the 44-62 age group; and 18% in the 63+ age group (5% of respondents did not answer the question). Sixty one percent (61%) were female and 37% male (2% of respondents did not answer the question).

Caregivers of people with disabilities may face unique challenges during an emergency. There may be issues including egress from the home, sheltering in place, or evacuation. This may be particularly true for families that include persons with severe mobility disabilities. Hence, questions about caregivers and independent living were included in the demographics section of the survey. Sixteen percent (16%) of all respondents indicated they were a caregiver to a person with a disability. Another motivation for including these questions was to collect data on the percentage of respondents with disabilities that live independently. The vast majority of respondents with disabilities (83%) indicated that they do not require caregiver assistance; and in fact 18% of survey respondents with disabilities are caregivers to other persons with disabilities.

## Discussion

As stated, project researchers hypothesized that greater awareness and exposure to WEA alerts would increase trust and appropriateness of individual responses to alerts. The analysis of the survey data showed this to be true. Individuals who were familiar with WEA were more likely to act immediately, less likely to be unsure of what action to take, and less likely to make judgements about whether the emergency alert applied to them.

### *WEA Availability*

Availability of WEA messages depends, in part, on an individual's access to WEA – capable devices. To assess WEA availability to people with disabilities, questions were asked concerning mobile phone ownership in general and the make and model of the respondents' phones, specifically. We found that the vast majority of all respondents (98%) own a mobile phone. Descriptive analysis revealed that respondents with disabilities own mobile phones at a similar rate to their non-disabled cohorts; 96% and 99%, respectively. Chi-square distribution comparison between these rates, however, showed that people without disabilities were 7 times more likely to own a cell phone than people with disabilities ($p < 0.001$). When the data was analyzed by income level there is also some discrepancy. As income increased, so too did the likelihood of mobile phone ownership, with the exception of those in the lower middle-income bracket (Figure 2). People with household incomes between $25,000 and 34,999 were 3.2 times less likely to have a cell phone ($p<0.05$).

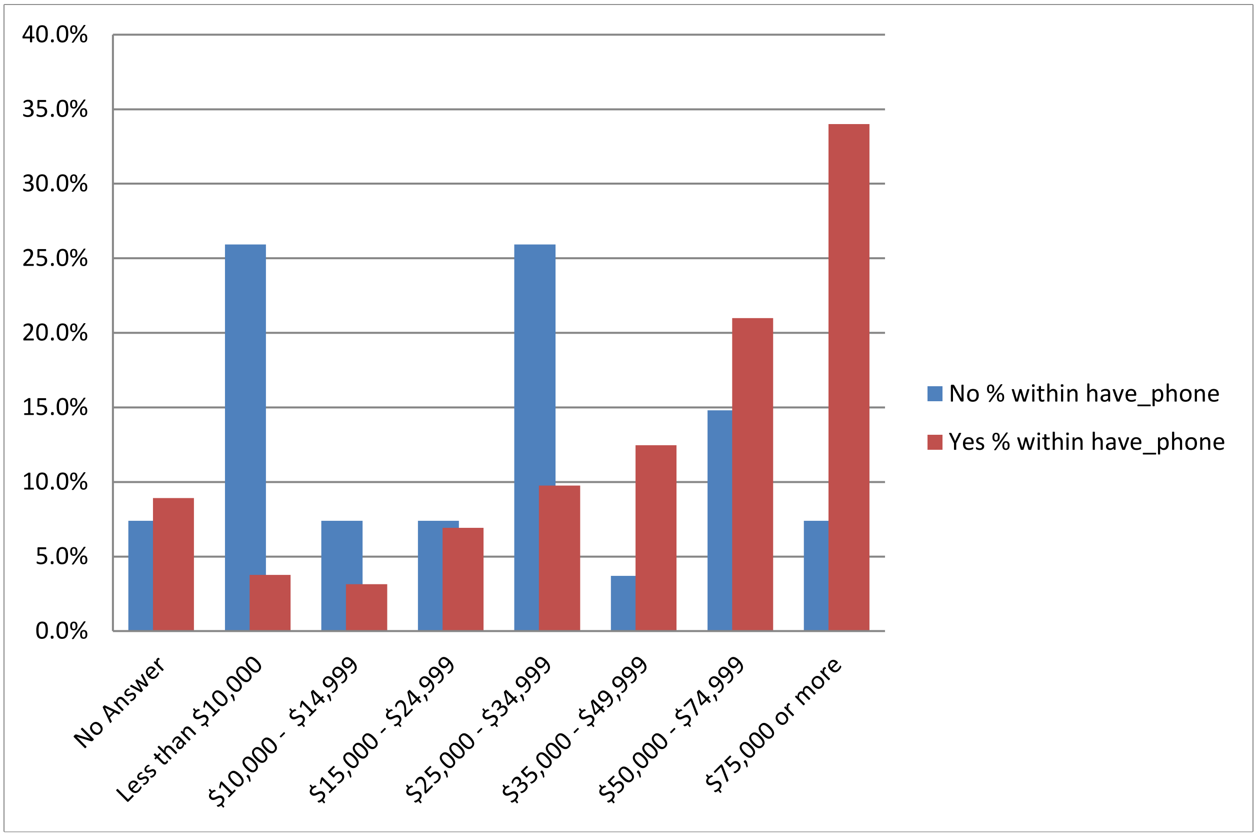


Fig. 2. Mobile Phone Ownership by Income.

An overwhelming majority (82%) of respondents use a touchscreen mobile phone, and a small but significant percentage (9%) use the mobile phone with the most basic numeric keyboard. Respondents, with and without disability, overwhelmingly use the mobile phone products manufactured by Apple, Inc. The reported top four manufacturers: Apple, Samsung, LG and Motorola account for 83% (1,111 respondents) of the total reported mobile products, with the remaining 17% (181 respondents) listing 15 manufacturers, including “other” and “I don’t know.” With the exception of the iPhone 4, the top ten identifiable (reported accurately to reflect make and model) phone models in use by respondents with and without disabilities are all WEA-capable. People with disabilities reported higher ownership of the iPhone 5, 5c, 6Plus and

Samsung Galaxy 4 than did respondents without disabilities. This may indicate that those phone models have the preferred accessibility features for those respondents.

A comparison of respondents with disabilities, compared to those without, revealed a 2% percentage point difference (34% and 36% respectively) in ownership of WEA-capable iPhone models. These data, taken together, indicate that for mobile phone owners, WEA-capable devices, and hence WEA messages, are available to both people with and without disabilities at similar rates. However, since people with disabilities were seven times less likely to own a mobile phone than people without disabilities, there still may be a gap in WEA availability based on the covariates of mobile phone ownership and disability status.

*WEA Awareness*

A majority of all respondents (60%) had heard of WEA prior to this survey. In the 2013-2014 WEA survey data, 59% of all respondents had heard of WEA. This indicates that despite increased WEA-capable phone penetration, WEA awareness levels have remained flat. Figure 3 shows WEA awareness based on disability status. Respondents without disability were twice as likely to report having heard of WEA (69%) than those respondents with disability (53%) ($p<0.01$). Variations in level of WEA awareness by the disability category is as follows: Blind/Low Vision (56%), Anxiety (52%), Mobility (52%), Speaking (51%), Deaf/Hard of Hearing (49%), Concentration (49%), Dexterity (44%), Reach/using hands and arms (41%). These data suggest that there is significant room for growth regarding educating people with disabilities on the availability of WEA. Further, due to the differing awareness levels based on disability type, targeted outreach may be necessary, as well as ensuring that outreach materials and methods are appropriate and accessible to the target population.

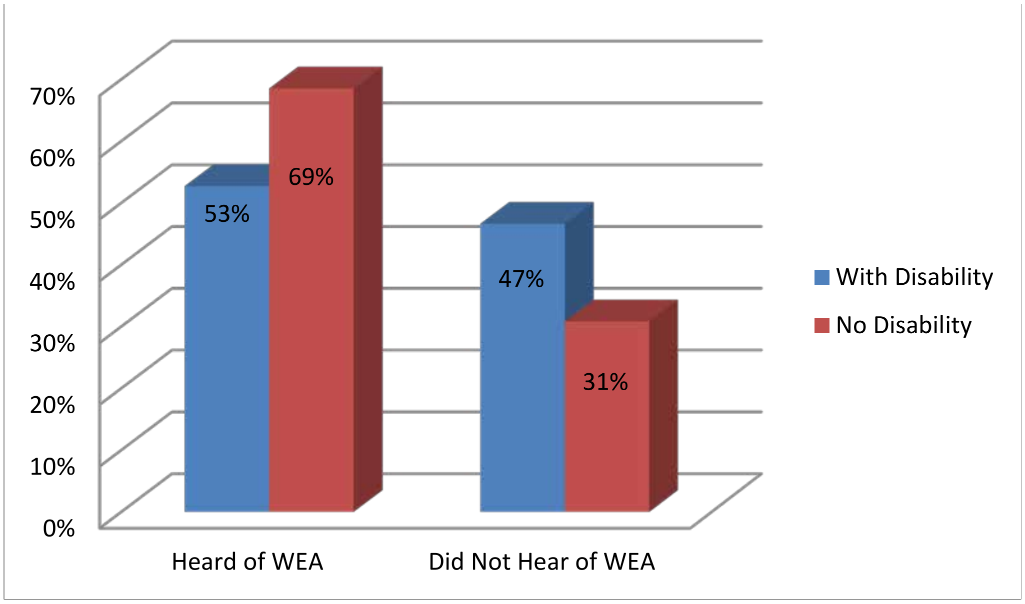


Fig. 3. Prior WEA Knowledge.

*WEA Response*

Behavioral responses were examined based on whether the respondent had been aware of WEA prior to taking the survey. Relative responses to each action are presented below.

The results to the statement, "*I took action immediately based on the information in the alert.*" indicated that those who were previously aware of WEA were slightly more likely to take immediate action after receipt of a WEA message than respondents who were unaware of WEA ($p < 0.01$). Figure 4 shows that 56% of respondents with prior WEA knowledge indicated that they agree or strongly agree with the above quoted statement, while 39% of respondents without prior WEA knowledge agree or strongly agree.

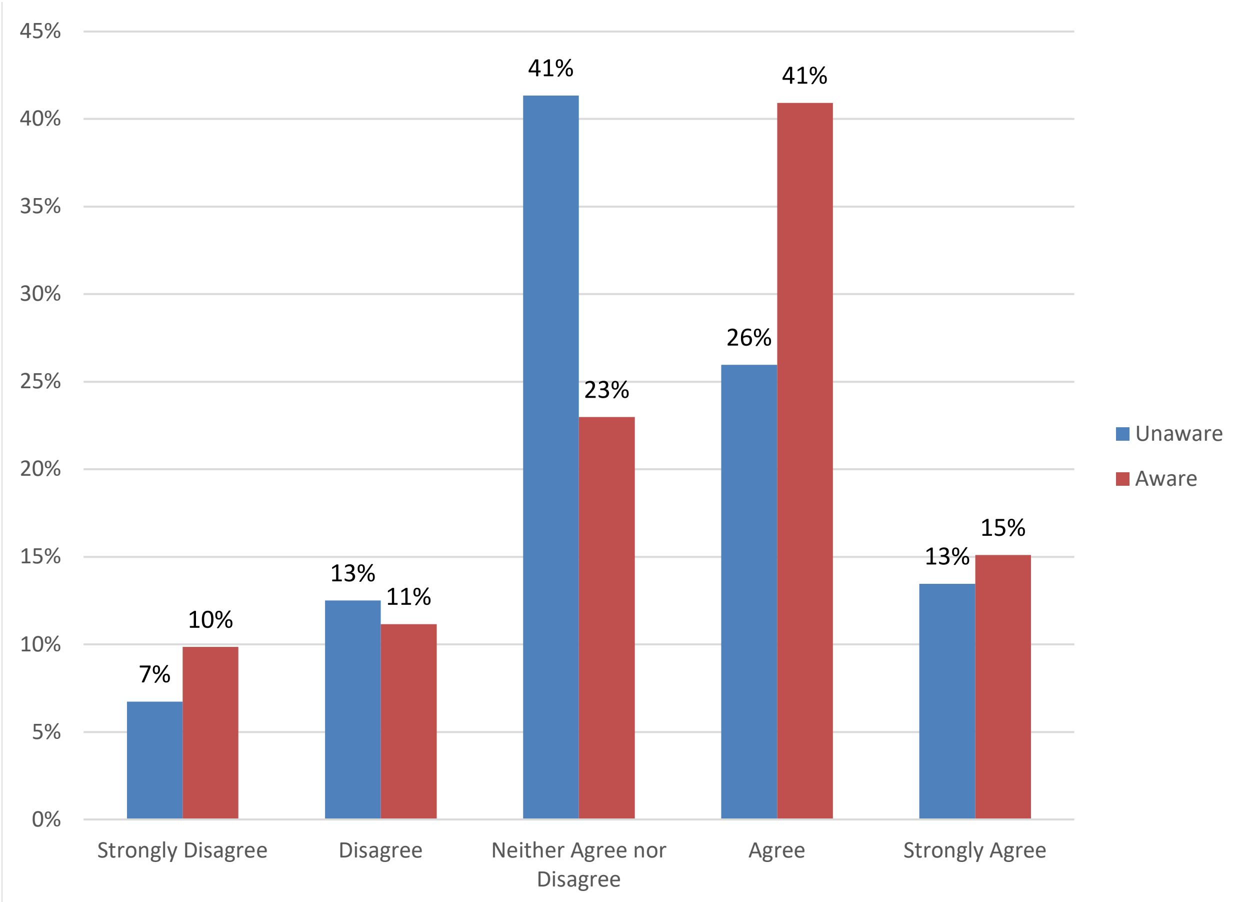


Fig. 4. Took Immediate Action (by awareness of WEA).

Whether respondents believed that the nearest emergency was near them varied based on whether they had prior knowledge of WEA ($p<.01$). Forty-eight percent (48%) of those who had prior knowledge of WEA strongly agree or agree that they did not take action because the emergency was not near them. This compares to 55% of respondents who did not have prior knowledge of WEA. Similarly, 33% of respondents who had prior knowledge of WEA disagreed or strongly disagreed with this statement, while only 21% who were not aware of WEA did. This is significant as it indicates that individuals make more of their own judgement call about a pending emergency when they are unfamiliar with the mechanism that notifies them.

Regarding the content of the message, respondents who were not familiar with WEA were more likely to be uncertain of what action should be taken. Ten percent (10%) of those familiar with WEA strongly agreed or agreed with the statement that "I did not take action because I was unsure of what action I should take;" while 16% without WEA knowledge agreed or strongly agreed with the statement. Sixty-seven percent (67%) of those with prior WEA knowledge indicated that they were more comfortable by disagreeing or strongly disagreeing with the statement, as compared to 51% of those without prior WEA knowledge.

**Conclusions**

Project researchers hypothesized that greater awareness and exposure to WEA alerts would increase trust and appropriateness of individual responses to alerts. The analysis of the survey data confirmed the hypothesis. Individuals who were familiar with WEA were more likely to act immediately, less likely to be unsure of what action to take, and less likely to make judgements about whether the emergency alert applied to them. As a result, federal government stakeholders, such as the FCC, FEMA and DHS, should increase efforts to educate the public on WEA. The recommended interventions to improve awareness of and response to WEA messages can be measured by the level of awareness of the availability of WEA, the extent to which WEA-enabled devices are diffused amongst the population of people with disabilities and behavioral response to the messages is favorable. It is thus imperative that WEA messages and the devices on which they are received be optimized for accessibility. Finally, analysis of the demographic data showed that the majority of respondents with disabilities are able to live independently. Emergency managers need to anticipate that people with disabilities will likely not have caregivers assisting them in their response to emergencies. Thus the content of their preparedness and response materials should not only be accessible, but include disability specific directions that will enable people with differing capabilities to independently take protective actions for themselves and their families.

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# Accessible Button Arrangements of Touchscreen Interfaces for Visually Impaired Users

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## Abstract

Regardless of the improvements of accessibility functions on touchscreen computers, they have some problems using touchscreen interfaces including smartphones and tablets. The reason includes the arrangements of accessible objects may differ in users' visual conditions because the manipulations under screen readers are different from those without screen readers, the characteristics of object arrangements on the touchscreen computers for the visually impaired remain unclear. In this paper, our objective is to clarify the accessible button arrangement features in smartphones for users with visual impairments. We studied these characteristics by evaluating reaction times and error rates in a memory experiment of a single button from some arranged buttons in a smartphone for visually impaired people under a screen reader condition. As a result, the performance of reaction time on a button selecting task with a single button increased as the number of buttons increased; buttons aligned more two-dimensional than one-dimensional allocations.

## Keywords

Visually impaired people, touchscreen computers, accessible button arrangements.

## Introduction

Touchscreen interfaces, such as smartphones and tablets, have recently become popular in the sighted people because of intuitive manipulation and high customizability. Most of these interfaces ensure accessibility for people with visual impairments via screen magnification software and screen reader functions such as VoiceOver (Apple iOS) and TalkBack (Google Android). As a result of the improvement of the accessibility functions, the accessibility environment for visually impaired people is gradually improving.

Regardless of these improvements, individuals with visual impairments have problems using touchscreen computers, since the manipulations with accessibility software differ from those of manipulation by sighted people. As a result, specialized learning materials and lecture courses for touchscreen computers are insufficient. The reasons include insufficient accessibility support of third-party applications, as with non-compliant screen reading and non-optimized buttons and these arrangements. These situations result from inadequate touchscreen application design guidelines for visually impaired people and a lack of clarity regarding of the conditions of touchscreen computer usage and a spatiotemporal manipulation. To ensure that accessible touchscreen computers for the visually impaired will become prevalent, it is necessary to investigate the specific interaction conditions between users with visual impairments and touchscreen computers.

In this study, our final objective is to embody the application guideline of touchscreen interfaces, such as smartphones and tablet computers. We mainly aim in this paper to clarify the accessible button arrangement characteristics in smartphones for visually impaired users. Our hypothesis is that the usability of 1- and 2-dimensional button arrangements under screen readers' conditions are not different in the case of a small number of buttons, but different in the case of a large number of buttons in visually impaired users.

## Related work

The improvement of accessibility for the visually impaired is due to the researches and improvements in user interface (UI) designs. Recently, studies on the UIs of touchscreen computers for visually impaired people have been increasing. These studies can be classified into three main types: presentation methods to users, manipulation methods for users, and investigations of usage conditions. The presentation methods include auditory and/or tactile presentments for sensory substitution and display of additional information, using sound or speech (Ferati, Mannheimer, and Bolchini 9-16; Kennel, 51-56; Ross, and Blasch 193-200) stable guided tactile feedback (El-Glaly et al. 245-253; McGookin, Brewster, and Jiang 298-307) and dynamic tactile feedback (Benedito et al. 379-380; Yatani and Truong, 111-120; Yatani, Gergle, and Truong 661-670). The manipulation methods include pie menu applications tuned for easily browsing and selecting objects (Banovic et al. 120-129) and a slide rule that allows a user to select and input by a combination of continuous slide gestures (Kane, Bigham, and Wobbrock 73-80). The investigations include usability evaluations of objects such as buttons and icons as well as gestures for interacting with a touchscreen computer while using accessibility applications (Bragdon et al. 403-412; Kane et al. 273-282; Kane, Wobbrock, and Ladner 413-422). In addition to these investigations, some researchers have evaluated text input methods for screen readers (Bonner et al. 409-426; Southern et al. 317-326). Some of these results may now be reflected in touchscreen computer screen readers such as VoiceOver.

Apple provides an application design guideline for visually impaired iOS users (iOS Human Interface Guidelines). Applications developed along this guideline are accessible to visually impaired people using VoiceOver. Leporini et al. and Wong et al. reported on the usage situations for Italian and American visually impaired users using VoiceOver, respectively (Leporini, Buzzi and Buzzi 339-348; Wong and Tan, 646-650). Montague et al. investigated user situations for those with visual and motor impairments (Montague, Hanson, and Cobley 151-158). Kane reported preferable gestures in some cases by American visually impaired people (Kane, Wobbrock, and Ladner 413-422). They proposed guidelines for touchscreen interfaces for visually impaired users based on their results. Oliveira et al. presented the different demands about the various text entry methods of touchscreen display in visually impaired people (Oliveira et al. 179-186).Miura et al. investigated touchscreen computers usage and interaction situations for the Japanese visually impaired population (Miura et al. “Usages and Needs of Current Touchscreen Interfaces in Japanese Visually Impaired People” 2,927-2,932; Miura et al. Accessible Single Button Characteristics of Touchscreen Interfaces Under Screen readers in People with Visual Impairments” 369-376).

In summary, the application design guidelines and usage conditions for visually impaired users are being clarified and are now more specific. However, quantitative evidence for creating accessible interfaces are not sufficient, and particularly there is little knowledge regarding accessible button arrangements for visually impaired people. Clarifying these arrangements can enable UI developers to design accessible interfaces for beginners and experts with visual impairments.

## Experiment

### *Participants*

Ten visually impaired people (mean age: 24.6 ± 5.3) comprising five and five individuals with congenital total and partial visual impairments participated in this experiment. Nine of them had their own smartphones and used them over a year. Eight of the owners started to trace from the edge of the upper left while one of them from the edge of the upper right. All of the participants with total visual impairment had manipulated under screen reader functions including VoiceOver over three years while one of the participants with partial visual impairment had used a screen reader, but three of them had experienced to use VoiceOver over two years. Seven of them were right-handed while others were left-handed.

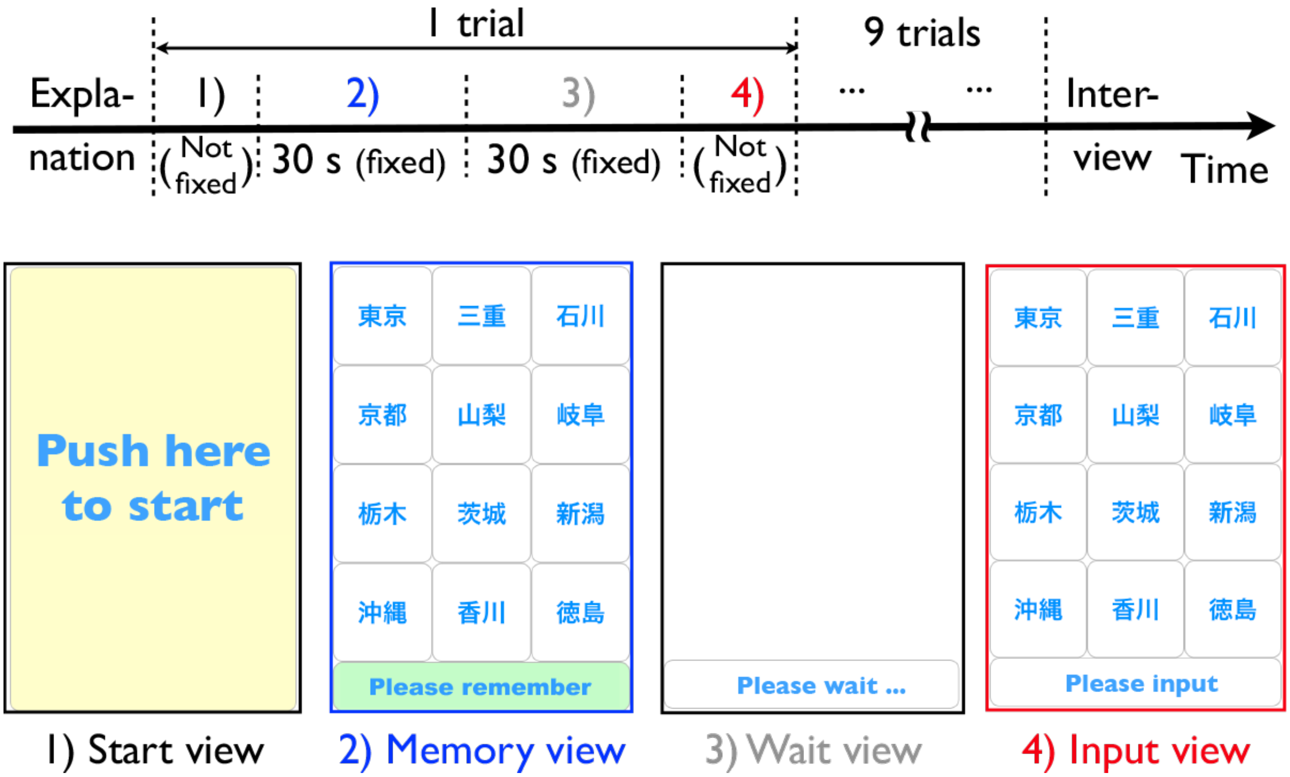


Fig. 1. Upper: Time protocol of the experiment. Lower: Overview of the experimental application.

*Method*

**Experimental application**

In this experiment, we developed an experimental application for a smartphone, and then discussed the differences of reaction time and error rate by the number of buttons and these arrangements. The experimental time protocol and overview of the application are shown in the upper and lower part of Fig. 1, respectively. This application presents 1) start view, 2) memory view, 3) wait view, and 4) input view successively. The development environment was Xcode 5.1.1 on Mac OS X 10.8.5, and we implemented to Apple iPhone 5s (OS: iOS 7.1 or 8.1). The contents of buttons were randomly generated from 47 prefectures in Japan (these are common in Japanese adults), and were read aurally by VoiceOver function when a user traces on the surface of a button. The application also presented the view transitions with implemented voices and sounds to a user for informing them to the transitions.

### Procedure

The experimental procedure is explained along with the time protocol shown in the upper part of Fig. 1. First, the participants asked to hold the smartphone with their non-dominant hand and manipulate with their dominant hand. In this smartphone, the VoiceOver function was activated. Second, they were asked to tap the surface of 1) start view, and then watch 2) memory view 30 seconds. In this case, “tap” means double tap or split tap after tracing the touchscreen surface; these gestures correspond to a single tap, and are mainly used in the manipulation mode under screen readers including VoiceOver. At that time, the participants were asked to remember button arrangements. The condition of button arrangements were fifteen: three conditions of four buttons (4 × 1, 2 × 2, and 1 × 4 (vertically × horizontally)), six conditions of twelve buttons (12 × 1, 6 × 2, 4 × 3, 3 × 4, 2 × 6, and 1 × 12), and six conditions of twenty buttons (20 × 1, 10 × 2, 5 × 4, 4 × 5, 2 × 10, and 1 × 20), respectively. The reason that we selected these numbers of buttons is that four is the least square number that can check the difference of one- and two-dimensional arrangements, twelve and twenty are the number of buttons presented in Japanese character input methods.

In 3) wait view that was presented 30 seconds to the participants, they were asked to leave their manipulation hands from the screen. After the transition to 4) input view, they entered the recalled button as quick as they could. This procedure repeated ten times for each button arrangement. The participants did this task 200 times, and then were interviewed the difficult condition to memory and the strategy to memory and manipulate.

The experiment was carried out in a silent room for suppressing acoustic noise level and making the participants listen to VoiceOver’s voices correctly. In addition, for checking the memorability without visual information, screen curtain mode was used to prevent some participants from watching the button arrangements.

### Evaluation items

Regarding evaluations, the application was implemented to log a user’s manipulations, including the reaction time to select a button, the positions touched by fingers, and the kinds of touch events. The interview items after the experiment were comprised by followings:

- Usual manipulation method (5 items): Holding and manipulating hands of a smartphone. Whether hold or put on the device while using it. Use experiences (years) of touchscreen computers and screen readers installed on them. Current smartphones used. Familiar gestures.

- Manipulation in this experiment (6 items): Easy and difficult button arrangements in each number of buttons. The easy-to-tap shape of a button. Strategy to trace and find buttons. Method to remember buttons. Subjective strains in each number of buttons. Free answers.

## Results and Discussion

Figures 2 and 3 show the reaction time and the error rates of the button selections by partially and totally visually impaired participants in each button arrangement condition, respectively. The error bars in Fig. 2 represents standard errors. According to the result of 3-way analyses of variance (ANOVA), there were significant main effects of participants' visual conditions, numbers of buttons, and button arrangements ($p < .01$). The results of Tukey honestly significant differences (HSD) test indicated that there were significant differences in all combinations of numbers of buttons, in the totally visually impaired group ($p < .01$). However, in the partially visually impaired group, though there were also significance in 4 and 12, 4 and 20 button conditions ($p < .01$), no significant difference were observed between 12 and 20 button conditions ($p = .49$). According to the interview comments by the participants, they felt mentally overloaded as buttons increased, and these overloads were reported by mainly the participants who liked two-dimensional button allocations and mainly included people with partial visual impairments. Moreover, as the buttons increased, some of them changed the style to remember buttons, from linguistically to spatially or the reverse order. These strategy changes were mainly observed in the participants with partially visual impairments. This difference may be because they usually get information from screen reader and visual cues, and they are accustomed to switching which they rely on, visual or auditory senses. On the other hand, according to the results of 2-way ANOVA for combinations of the years of experience in touchscreen computers with the reaction time or the correct rates, there were no significant main effects and interactions between these two combinations ($p > .10$).

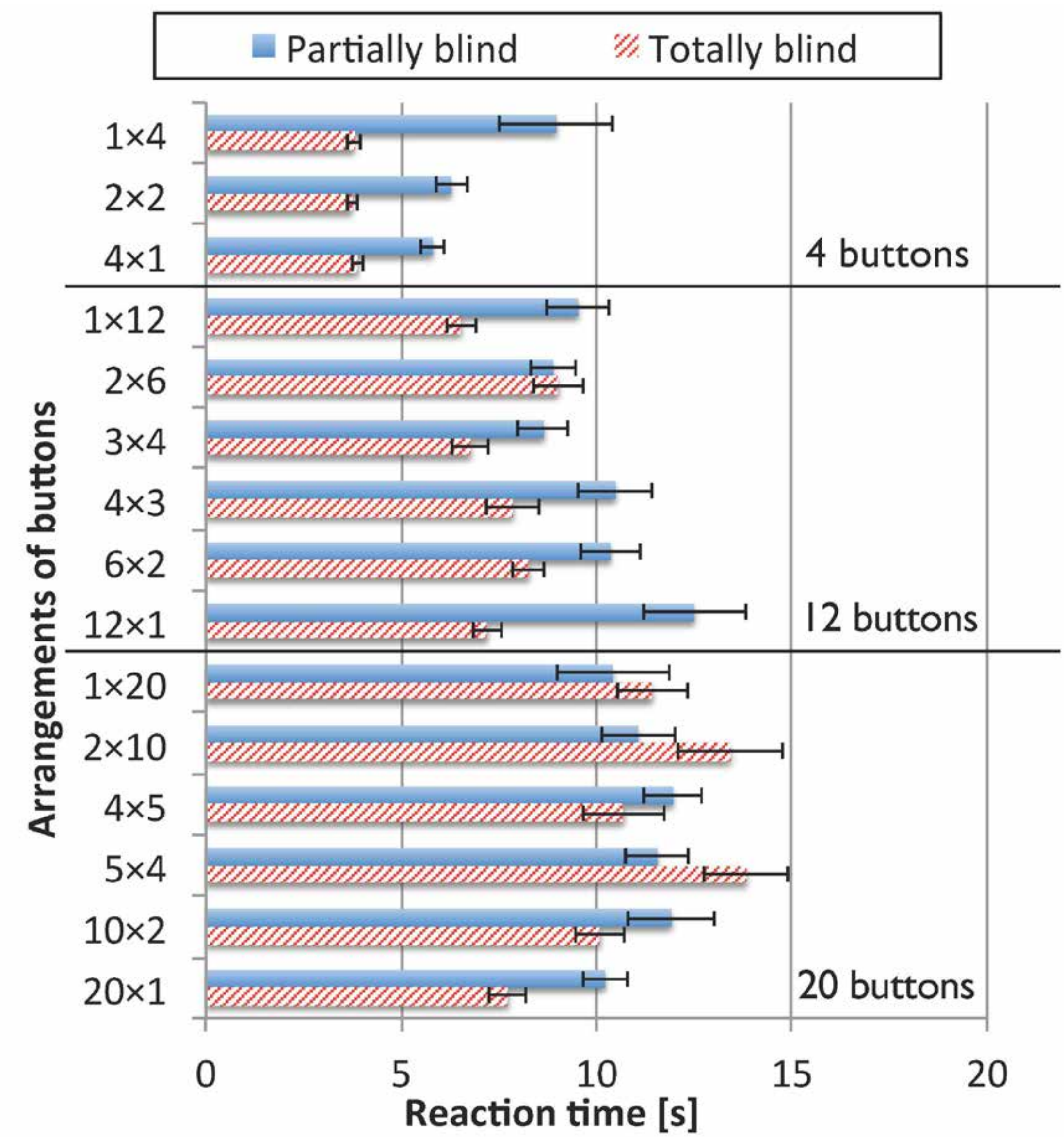


Fig. 2. Reaction time of button selection in each button arrangement condition.

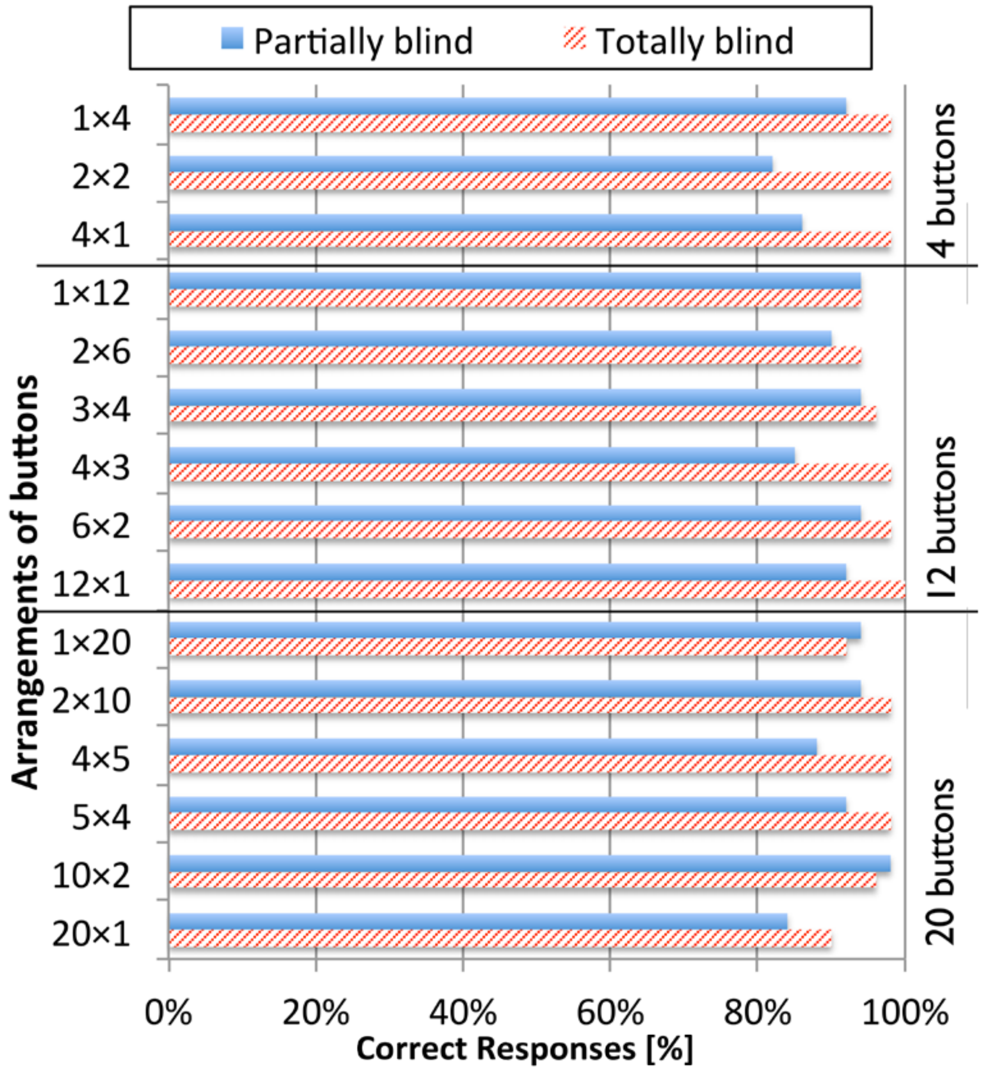


Fig. 3. Correct rates of button selection in each button arrangement condition.

In the button arrangements of 1 × 4, 1 × 12, 12 × 1, and 20 × 1, the participants with total visual impairments reacted significantly faster (Tukey HSD: $p < 0.05$). However, in the other conditions, no significant difference was observed between the two. These results may be because of the participants with partial visual impairments were less used to tracing buttons that were allocated vertically or horizontally. According to the comments of the participants with partial visual impairments, they sometimes confused to remember the button locations in these button arrangements conditions and often felt the difficulty trace the target button, particularly in the 20 × 1 condition. Besides, the results of subjective strains in each button arrangements indicated that the number of the participants who preferred two-dimensional button arrangements increased as the number of buttons increased. These results show the opposite tendency from the reaction time, but the similar tendency to the error rates.

From these results, the guideline of button arrangements in this study can be summarized as follows:

- One-dimensional button arrangements bring a user with visual impairments, particularly totally visually impaired users to a speedy manipulation experience.
- Two-dimensional button arrangements enable a user with visual impairments, especially partially visually impaired users, to robust manipulation experience.

This tendency becomes stronger as the number of buttons increases. Also, even individuals with total blindness also feel troublesome to use 1-D button arrangement with large number of buttons.

## Conclusions

In order to clarify the accessible button arrangement characteristics in smartphones under a screen reader condition for visually impaired users, we qualitatively evaluated reaction times and error rates in a memory experiment of a single button from some arranged buttons. The results indicated that performance of reaction time on the button selecting task with a single button increased as the number of buttons increased; buttons aligned more similar to two-dimensional than one-dimensional allocations. However, error rates were generally lower in the case of two-dimensional button arrangements, especially in partially visual impaired users.

From these results, we summarized a design implication of button arrangement for visually impaired touchscreen users like one-dimensional button arrangements bring users with total blindness to a fast manipulation experience while two-dimensional button arrangements enable users with partial visual impairments to robust manipulation experience.

Our future work includes an evaluation of button arrangements with more numbers of buttons whose size are varied, and a proposal of a comprehensive design guideline of touchscreen interface for visually impaired users.

## Acknowledgements

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# Eyetracking Metrics Related to Subjective Assessments of ASL Animations

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## Abstract

Analysis of eyetracking data can serve as an alternative method of evaluation when assessing the quality of computer-synthesized animations of American Sign Language (ASL), technology which can make information accessible to people who are deaf or hard-of-hearing, who may have lower levels of written language literacy. In this work, we build and evaluate the efficacy of descriptive models of subjective scores that native signers assign to ASL animations, based on eye-tracking metrics.

## Keywords

Eye-Tracking, Sign Language, Animation.

## Introduction

Automatic synthesis of sign language animations can increase information accessibility for people who are deaf and use signing as a primary means of communication. In the US, this population is estimated to be over half a million (Mitchell et al. 328-329). Standardized testing has revealed that many US deaf adults have lower levels of English reading literacy (Traxler), and thus complexity in the reading level of the text on websites or media can be too high. Linguistically accurate and natural-looking animations of American Sign Language (ASL) that are automatically synthesized from an easy-to-update script would make it easier to add ASL content to websites and media.

Researchers must regularly evaluate whether animations are grammatically correct and understandable, often through participation of signers, e.g. (Gibet et al. 18-23; Kipp et al. 107-114; Schnepp et al. 250). We have previously proposed the use of eyetracking to evaluate participants' reactions to animations *without obtrusively directing their attention to any particular aspect of the animation* (Kacorri, Harper, and Huenerfauth, Comparing; Kacorri, Harper, and Huenerfauth, Measuring 549-559). In this work, through multiple regression analysis on data from a user study, we identify relationships between (a) eyetracking metrics defined on recorded eye movements of participants watching ASL animations and (b) the subjective scores on grammaticality, understandability, and naturalness that participants assigned to those animations.

## Discussion

### *Eyetracking and Sign Language Animations*

As discussed in (Kacorri, Lu, and Huenerfauth, 514-516; Huenerfauth and Kacorri), in the context of research on incorporating new capabilities into ASL animation technology, it is difficult to design experimental stimuli and questions to measure participants' comprehension of information content specifically conveyed by some new feature of an animation.

To address this concern, we examined research using eyetracking to unobtrusively probe where participants are looking during an experiment, which can allow researchers to infer the cognitive strategies of those users, e.g. (Jacob and Karn). In fact, researchers have used eyetracking with participants who are deaf to investigate comprehension of *videos* of humans performing sign language (Cavendar et al.; Muir and Richardson; Emmorey et al.), but not of sign language *animations*. In our prior work (Kacorri, Harper, and Huenerfauth, Comparing; Kacorri, Harper, and Huenerfauth, Measuring), we examined whether these eyetracking methods could be adapted to the evaluation of sign language animations. However, in this earlier work, we examined one-to-one correlation relationships between the evaluation scores that participants assigned to the stimuli (video and animations) and specific eyetracking metrics. In this paper we focus on sign language animations only, and we systematically investigate the contribution of *multiple metrics* in indicating the subjective responses that native signers assign to ASL animations via multiple regression modeling.

### *User Study and Collected Data*

**Participants.** Eleven ASL signers were recruited using ads posted on New York City Deaf community websites: 4 men and 7 women of ages 24-44 (average age 33.4). Seven learned ASL since birth, three prior to age 4, and one learned ASL at age 8 (attending schools for the deaf with instruction in ASL until age 18 and continuing to use ASL at home and work).

**Experiment.** Participants viewed 21 short stories in ASL performed by an animated character, created by a native ASL signer using the VCom3D (2015) SignSmith animation tool; we previously shared these stimuli with the research community (Huenerfauth and Kacorri). The video size, resolution, and frame-rate for all stimuli were identical. During the study, after viewing a story, participants responded to 1-to-10 scalar-response questions about their subjective impression of the animation. All questions were presented onscreen (embedded in the stimuli interface) as HTML forms to minimize possible loss of tracking accuracy due to head movements of participants between the screen and a paper questionnaire on a tabletop. The following English question text was shown onscreen:

(a) Good ASL grammar? (10=Perfect, 1=Bad)

(b) Easy to understand? (10=Clear, 1=Confusing)

(c) Natural? (10=Moves like person, 1=Like robot)

An initial sample animation familiarized the participants with the experiment and the eye tracking system. All of the instructions and interactions were conducted in ASL; subjective questions were explained in ASL. Some introductory information about the study was conveyed via a video recording of a native ASL signer. As discussed in (Kacorri, Harper, and Huenerfauth, Comparing), participants were seated in front of an Applied Science Labs D6 desktop-mounted eye-tracker, which sat below a 19-inch computer screen at a typical viewing distance.

**Eyetracking Metrics.** We recorded eye-tracking data while the participant viewed each animation, and then participants answered the questionnaire. Since eyetrackers occasionally lose the tracking of the participant's eye (e.g., if the participant rubbed their face with their hand), we needed to filter out any eye-tracking data in which there was a loss of tracking accuracy, as discussed in (Kacorri, Harper, and Huenerfauth, Comparing). For analysis, we defined 4 areas of interest in our stimuli: the virtual signer's head/face, body (including hands), upper face, and lower face; eye fixations elsewhere were coded as "off." Based on these areas of interest, we describe a participant's eye movements during each animation with 28 eyetracking metrics.

**Table 1. Eyetracking Metrics**

| Category | Eyetracking Metrics |
|---|---|
| Total Fixation Time: *duration when the eyes are on this area of interest* | BodyTotalFixTime, UpperFaceTotalFixTime, LowerFaceTotalFixTime, FaceTotalFixTime |
| Proportional Fixation Time: *percentage of time with the eyes on this area of interest* | PercentFaceFix, PercentUpperFaceFix, PercentLowerFaceFix |
| Proportional Fixation Time (discounting "Off" time): *same as above, but the fixation time spent "off" is not included in denominator* | PercentFaceFixNoOff, PercentUpperFaceFixNoOff, PercentLowerFaceFixNoOff |
| Transitions: *count of the movements of the eyes from one area of interest to another* | NumFaceToBody, NumBodyToFace, NumBodyToOff, NumOffToBody, UpperFaceToBody, LowerFaceToBody, UpperFaceToLowerFace, LowerFaceToUpperFace, BodyToUpperFace, BodyToLowerFace, OffToUpperFace, |
| Proportional Transitions: *same as above, but normalized by the total time duration of the stimulus* | NormFaceToFromHands, NormUpperFaceToFromHands, NormLowerFaceToFromHands, NormUpperFaceToFromLowerFace |
| Overall: *counts of transitions or length of the eye movement trail* | NumTotalTran, TotalDetailedTrans, NormTrailDistance |

*Results and Analysis*

The goal of our analysis is to examine how eye movements of participants relate to their responses to subjective questions about ASL animations. In addition, we wanted to know which eyetracking metrics best capture variance in score for each of the subjective questions evaluating the grammar, understandability, naturalness of the animations. We therefore used multiple regression to analyze the data. Our independent variables included all of the eyetracking metrics, listed in the above table. We trained a separate model for each of our dependent variables (Grammar, Understand, and Natural).

Since we have calculated many eyetracking variables, it was important to explore combinations of variables in a systematic manner. We used the 'leaps' package (Lumley) to build models of all possible subsets of features to identify the model with the highest adjusted R-squared value, i.e. the percentage of total variability accounted for by the model.

For a meaningful interpretation of the relative contribution of each of the eyetracking metrics, we calculated the relative importance of each independent variable in the Grammar, Understand, and Natural models, using the Linderman-Merenda-Gold (LMG) metric (Lindeman, Merenda, Gold), using the 'relaimpo' package (Grömping). This analysis assigns an R-squared percent contribution to each correlated variable obtained from all possible orderings of the variables in the regression model. Higher bars in Figures 1-3 indicate that the metric had greater importance in the model. We employed bootstrap to estimate the variability of the obtained relative importance value, to determine 95% confidence intervals (whiskers in the graphs). Importance values may be considered significant when whiskers do not cross the zero line in the graph. As illustrated by Figures 1-3, we see that the eyemetrics relating to the 'Head/Face' area of interest features prominently in many of the best models.

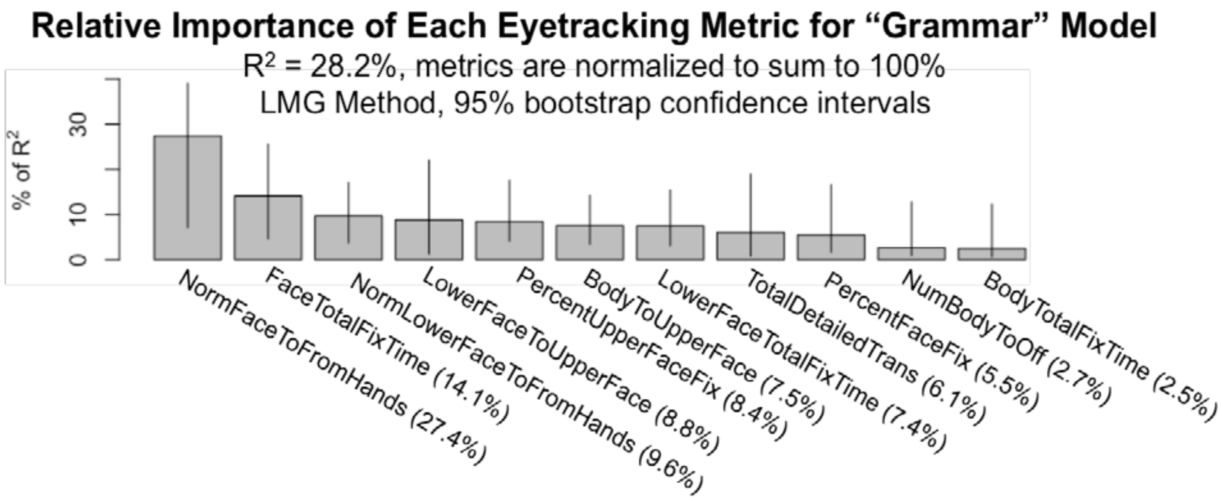


Fig. 1. Relative importance of each eyetracking metric in the model with the highest R-squared value (28.2%) for the "Grammar" subjective response score; the most important metrics include: NormFaceToFromHands and FaceTotalFixTime.

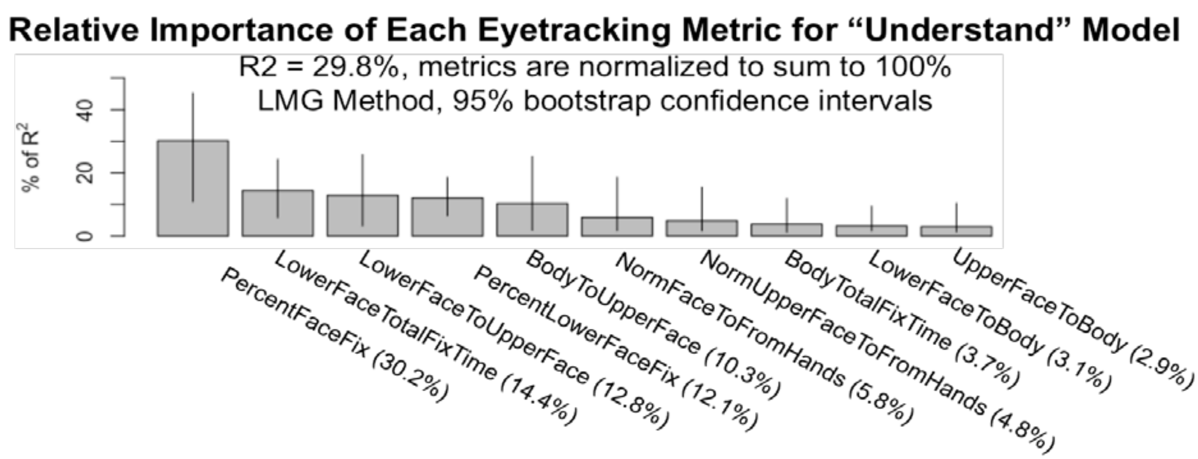


Fig. 2. Relative importance of metrics in the model with highest R-squared value (29.83%) of the "Understand" subjective response score; the most important metrics include: PercentFaceFix and LowerFaceTotalFixTime.

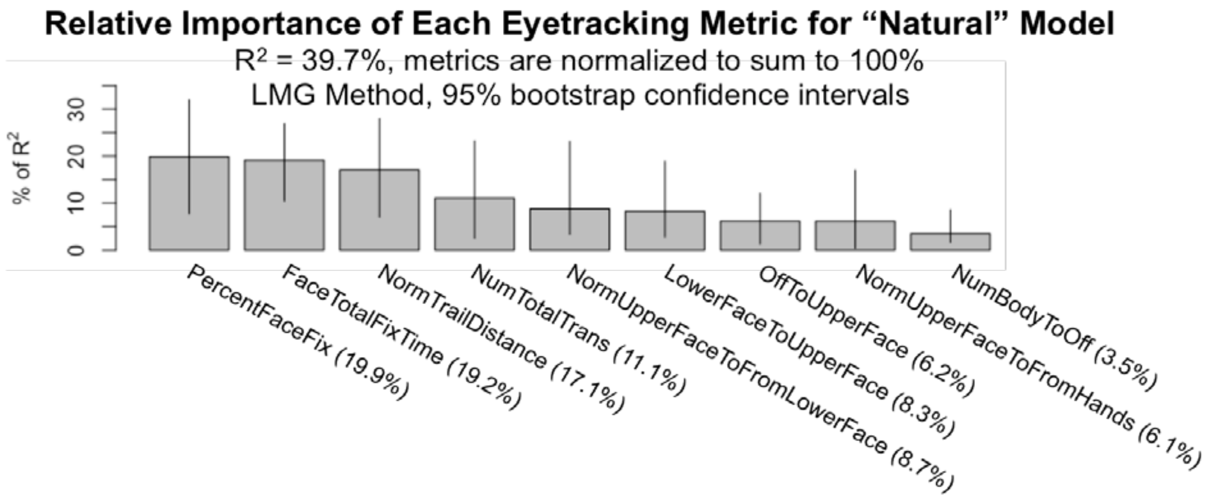


Fig. 3. Relative importance of each eyetracking metric in the model with the highest R-squared value (39.7%) for the "Natural" subjective response score; the most important metrics include: PercentFaceFix and FaceTotalFixTime.

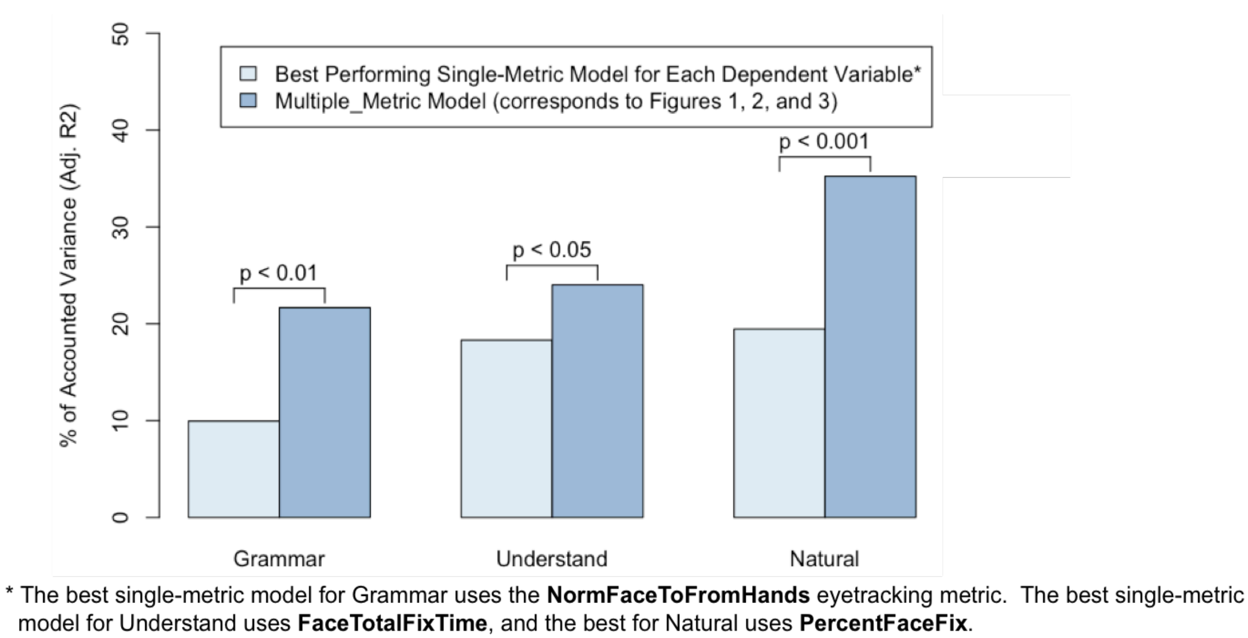


Fig. 4. Comparison of the best multiple-metric regression model and best single-metric regression model for each of the subjective response scores.

In order to determine whether these multiple-metric models outperformed single-metric models (as we had explored in earlier work), for each of the subjective scores we build a model using a single eyetracking metric (chosen by ‘leaps’ as the one yielding the highest adjusted R-squared value). As shown in Figure 4, we found that in each case, the single-metric model accounts for significantly less variance than the multiple-metrics model (ANOVA, $p<0.05$).

## Conclusions

We have offered guidance on which eyetracking metrics can be used to predict ASL signers’ subjective judgments about the grammaticality, understandability, and naturalness of sign language animations. Future researchers who need to unobtrusively collect subjective judgments about sign language animations can use regression models based on these metrics.

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# Analysis of Player Preference in Networked Audio Games

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## Abstract

Different types of games have been made accessible to people with visual impairments (VI) by creating audio enhanced versions of the games. This paper analyzes a website created and run by several of the authors (rsgames.org) that offers 17 different free to play audio games. The results of this analysis may help to understand the types of games played by people with VI and may provide an indication of what kinds of games should be made in the future and what types of features should be present in games. A survey of 55 active users showed that background music and having played the non-digital version of the game the top reasons for enjoying the audio version of the game.

## Keywords

Audio games, blind, visually impaired, accessible gaming, non-visual games.

## Introduction

A person who is blind can play many commercial games. Games that utilize standard dice are playable without modifications as the dice themselves contain tactile information that uniquely identifies each side of the die. Commercial video games have been modified to use enhanced audio and tactile feedback in order for them to be played by a person who is blind (Allman 2009, Morelli "VI Tennis" 2010, Morelli "VI Bowling" 2010, Yuan 2008). Board games may need modifications, or may need to be rebuilt from scratch in order to be playable by people who are blind (Corday 1980, Wang 2006). This paper looks specifically at board, dice, and card games that were made accessible to a person who is blind by converting them to audio only networked computer games. An Internet site was created in 2009 and different games have been added to the site periodically. This paper is organized as follows. First the gaming site is described, then the available games are described, then usage statistics and the results of player surveys are revealed, next a discussion on the statistics is performed, and then the paper is concluded.

Rsgames.org was started in 2009 in an effort to curtail the lack of games accessible to blind and low vision players around the world. It was originally started simply as a Monopoly server/client, the client at the time only available for Windows. It has since grown into a multiplatform system accommodating anywhere from 60 to 100 plus simultaneous global connections. Utilizing a central server, storing user authentication and game data in an SQL database, with a client for Windows, Mac OS X and Linux, sight impaired players can play a variety of popular board and card games.

A custom library, called Accessible Output, allows the client to hook into the APIs of numerous commercial, free and open-source screen-reading technologies. Additionally, it permits the game's output to be directed to a Braille display. There are 19,136 registered players on the site. In a period of 28 days (04/01/2015-04/29/2015), there was an average of 5.896 new accounts created per day. It averages 1,500 unique visitors a week. The architecture has one central server where all the game data (sounds, code etc.) is stored. The single client then connects to the server and retrieves the data for each game. In this way, when a new title is released, only the new sounds for that particular game must be downloaded to the user's machine; nothing else is done client-side.

## Discussion

Rsgames.org contains 17 game titles available. The titles available for play are: 1000 Miles, Apples to Apples, Battleship, Bingo, BlackJack, Cards Against Humanity, Dreidel, Farkel, I doubt it, Monopoly, Pig, Rummy, Shut The Box, Toss Up, Uno, Yatzee and Zombie Dice. Several of the games allowed for players to play against other players, or against bots if no other players were available for immediate play. Those games include 1000 Miles, I Doubt It, Monopoly, Pig, Toss Up, Uno and Zombie Dice. A more detailed description of the most popular games (Table 1) including an analysis of the accessibility of the original games and modifications to make them more VI accessible follows.

### *Uno*

Uno (Mattell Games Uno 2016) is a popular card game where players take turns and attempt to lose all of their cards. Players hold cards in their hands and try to match either the color of the card, or the value of the card with the card on the top of the discard pile. If the player is unable to match either the color or value, the player must pick up a new card and add it the cards he is holding. In addition to standard cards with numbered values, players may also pick up action cards such as cards that reverse the direction of play (clockwise to counter-clockwise) or instruct a player to skip the turn. Players with VI can enjoy this game by playing with a sighted peer who will announce the color and number of the cards the player is holding. There are also special prints of the cards that contain braille in addition to the standard graphics that will assist players with VI.

The audio game version can be played with real people or by adding bots. The game begins by announcing the color and value of all cards held by the player and the top card in the discard pile. The player only knows about the number of cards held by his opponents. Up and down arrows cycle through the cards in the player's hand and the option to draw a new card. As the game is played, the number of cards remaining in the opponents' hands is not announced. The top card in the discard pile is only read at the start of the player's turn, which may make it difficult for the player to decide what card to place if he missed that audio cue.

### *Farkel*

Farkle (Legendary Games 2016) is a dice game for two or more players where players alternate throwing six dice and achieving a score. After each throw, a player must set aside one or more scoring dice that were just rolled. If the player cannot set any dice aside, he has *farkled* - his turn is over and he must pass the dice to the next player. Prior to passing the dice, his combination of thrown dice are assigned a score and that becomes his score for that round. Players add their score for a particular round to their total score and play continues until on player reaches a predetermined point total such as 10,000 points.

The audio game features background music and follows the rules of Farkel. Players roll 6 dice, and are then given a list of the valid moves. Players can choose any of those moves, or end their turn. Players hear everything about their opponents turn.

### *1000 Miles*

1000 Miles (Parker Brothers Mille Bornes 2016), also known as Mille Bornes, is a multiplayer card game where players compete against each other attempting to be the first player to achieve 1000 miles. Players are given distance cards, hazard cards, remedy cards, and safety cards. Players can penalize other players by placing hazard cards, overcome hazards by placing remedy or safety cards, and make progress towards the final goal by placing distance cards but only if there are no hazards on the player. When a player reaches 1000 miles in distance cards, the game is over and each player's cards in play are totaled to create a score. The player with the highest score wins the game. Like other card games described here, a special deck of cards can be created or purchased that enhances the cards with braille in order assist a person with VI.

The audio game features up beat rock music as the background music. Using the default settings, players play for 5000 miles, but this value can be changed in the settings. Players can use the arrow keys to highlight their cards and hear a description for each card. They can also select to draw a card or discard a card. There is no option to get the status of the opponents other than to listen to the narration of what takes place during their turns. This multiplayer game allows the use of bots.

*Yahtzee*

Yahtzee (Milton Bradley Company 2016) is a popular dice game for one or more players. The game of Yahtzee consists of players rolling 5 die with the hopes of creating combinations. Different combinations pay out different point values, for example rolling three of a kind can earn the player 17 points, while rolling four of a kind will earn the player 24 points. On a given turn a player can roll the dice up to three times. The player is required to roll all dice on the first roll of a turn, and on the remaining two rolls the player may choose to only roll a subset of the dice. After thirteen rounds, the player with the most points is declared the winner. As with all dice games, players with VI can feel the tactile information contained on a standard die. The rest of the dice games listed below are assumed to be able to be played this way unless otherwise noted.

The audio game features similar jazzy background music and dice rolling sounds. Players roll the dice to see who goes first. On the player's turn, he can roll the dice or view the score card of his or any of his opponents. As players roll dice, the status of the game is audibly announced including the values of all dice rolled, and what dice were kept. Players use the arrow keys to highlight different dice, and then use the space bar to select the dice for a re-roll. When the player is satisfied with the status of the dice, he chooses to score.

**Table 1. Percentage of Games Played, Menu Order, and Release date.**

| Title | % | Order | Release |
|---|---|---|---|
| 1000 Miles | 11.49 | 5 | 6/19/11 |
| Apples to Apples | 1.16 | 8 | 12/20/11 |
| Battleship | 2.20 | 6 | 6/16/11 |
| Bingo | 1.43 | 12 | 7/31/13 |
| Black Jack | 2.15 | 3 | 12/25/10 |
| C.A. Humanity | 2.72 | 16 | 9/1/14 |

| Title | % | Order | Release |
|---|---|---|---|
| Dreidel | 0.52 | 13 | 11/27/13 |
| Farkel | 20.15 | 9 | 12/20/12 |
| I Doubt It | 1.14 | 15 | 12/20/13 |
| Monopoly | 8.32 | 1 | 12/20/09 |
| Pig | 2.90 | 11 | 3/17/13 |
| Rummy | 4.23 | 10 | 12/20/12 |
| Shut the Box | 1.39 | 7 | 4/14/12 |
| Toss Up | 4.36 | 17 | 12/20/14 |
| Uno | 24.03 | 2 | 8/30/10 |
| Yatzee | 11.81 | 4 | 12/20/10 |
| Zombie Dice | 1.56 | 14 | 12/20/13 |

Data was collected from the website over the time period of 3/29/2015 through 5/4/2015 to analyze player behavior. The data collected is for every game that is started, not every game that was played to completion. In all 52,850 games were started in total comprised of the individual 17 game titles. The average number of games started per title was 3157 (SD=3711). The individual break down of games played per title is shown in Table 1. The responses from the survey about preferred games are in line with the actual game play statistics.

More than 44% of all games played were either Farkel or Uno. Why are these games favored when compared to the other games? One possible reason could be that they are easier to access when logging into the site. When players first login, they are presented with a list of games, and that list of games is always in the same order. Games at the end of the list may receive less play because it is harder for players to find them. Uno is the second game in the list, while Farkel is located in the middle of the list at position 9. The first 8 games on the list sorted by order in the menu contain 61% of the play, while the last 9 games on the list contain 39% of the play.

**Table 2. Avg. Game Rating (1 poor, 5 great) and percentage of respondents who have played the non-digital version of the game**

| Title | Rating | Played % (Non-Digital) |
|---|---|---|
| 1000 Miles | 4.13 | 15.38 |
| Apples to Apples | 3.62 | 17.31 |
| Battleship | 3.67 | 53.85 |
| Bingo | 3.33 | 84.62 |
| Black Jack | 3.49 | 59.62 |
| C.A. Humanity | 3.58 | 11.54 |
| Dreidel | 2.34 | 7.69 |
| Farkel | 4.57 | 21.15 |
| I Doubt It | 3.27 | 13.46 |
| Monopoly | 4.13 | 88.46 |
| Pig | 3.16 | 13.46 |
| Rummy | 3.47 | 26.92 |
| Shut the Box | 3.08 | 19.23 |
| Toss Up | 3.22 | 7.69 |
| Uno | 4.38 | 73.08 |
| Yatzee | 3.98 | 51.92 |
| Zombie Dice | 3.16 | 5.77 |

Another possibility could be that older games receive more play. Games that have been on the site longer could be more familiar to the players and as a result they may get more play. 62% of the games played came from games that were in the first 8 games to be released (4/14/12 and before) while 38% of the games played came from the 9 games that were released after 4/4/12. Although overall preference is given to games that have been around for a while and games that are in the first half of the list, these are not stand out statistics as Farkel, whose play makes up over 20% of all play, is located in the latter half of both of these lists.

In order to try to figure out what makes a better audio game, 55 active users were surveyed about why they play the audio games on this site. When players log in to the site they are presented with a message of the day. A message was posted that asked players to voluntarily and anonymously take a survey about the games contained on the site. The statistics used from these surveys were taken from the first 55 respondents.

Players were asked to rank each game from 1-5, where 1 is a poor game and 5 is a great game. The results of this player survey are shown in Table 2. Falling in line with the usage statistics, players preferred to play Farkel and Uno over all the other games. One reason that people preferred these games could be that they prefer these games because players are familiar with the game play from playing the non-digital version of the game. Surveyed players were asked whether or not they have played the non-digital version of the game. The most popular games players had played as a non-digital version were Monopoly (88.46%) followed by Bingo (84.62%). Uno came in third place at 73.08% and Farkel ended up in 8th place with 21.15% of players having played the non-digital version of the game. By these numbers it appears as though familiarity of the game by playing the non-digital version of the game does not have any effect on the rating given to the audio computer game.

**Table 3. What game features are most important?**

| Category | Average Rating |
|---|---|
| Background Music | 4.44 |
| Played Non-Digital Version | 3.59 |
| Game Sounds | 3.52 |
| Social Features | 3.48 |
| Works with Screen Reader | 2.56 |
| Playability | 2.42 |

Surveyed players were asked about different features of games that they felt were most important when playing audio computer games (Table 3). Most important was background music, followed by playing the non-digital version of the game and game sounds. It may be considered surprising that background music was rated more important than works with a screen reader. The games are playable using the built in audio cues without using a 3rd party screen reader. That may explain why the screen reader importance was ranked so low.

**Table 4. How often do you play games on this site?**

| Category | Percentage |
|---|---|
| Several Times A Day | 16.36 |
| Once a Day | 1.82 |
| Several Times a Week | 25.45 |
| Once a Week | 10.91 |
| Several Times a Month | 25.45 |
| Once a Month | 5.45 |
| Several Times a Year | 10.91 |
| Once a Year | 0.00 |

Table 4 shows self-reported values for frequency of play and Table 5 shows self-reported average duration for each game play session. Most players spend between 30 minutes and 2 hours during one gaming session and log in several times a month to several times a week. Based on these results, it is suggested that new audio games contain great background music with an average play session time of 1 hour, and players will expect to play the game on a regular basis.

**Table 5. How long is your average play session?**

| Category | Percentage |
|---|---:|
| < 10 Min | 0.00 |
| >10 Min and < 30 Min | 18.18 |
| >30 Min and < 1 Hour | 30.91 |
| > 1 Hour and < 2 Hours | 334.55 |
| > 2 Hours | 14.55 |

## Conclusions

This paper presented an analysis of games and player behavior on an online audio computer game site. Players found background music and familiarity with the non-digital version of the game as the most important features of computer audio games. It was also discovered that most players spend between 30 minutes and 2 hours per play session, which indicates game play time should be within that range. Although no significant trends were discovered, the data presented here and collected from primarily blind players, is important to take into consideration when creating new games for people who are blind.

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PERSONS WITH
DISABILITIES

# Real-time Synchronous Slideshow Presentation Access Technology for the Blind

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## Abstract

This research has developed a prototype software package called SPARC (Slideshow Presentation Access with Real-time Communication) that enables people with blindness or visual impairments to have synchronous access to slideshow presentation made with Microsoft Office PowerPoint, using cloud computing as a core Internet of Things (IoT) technology. The SPARC consists of three inter-related system components: a presenter add-in, a cloud service, and a user terminal application program. Once the slideshow starts, the presenter add-in automatically analyzes the current slide and convert it into accessible text format. Then, it publishes the converted text to the SPARC cloud service along with some metadata including a slide number, information on slide layout, and non-textual object properties in the current slide. The SPARC cloud service is a message-oriented middleware empowered by IoT technology and enables real-time communication between the presenter and the audience. The SPARC user terminal software is an application program that receives the slide information from the cloud service and displays it on user's assistive devices. In the lab trial where there were one computer on the presenter side and five different devices on the audience side, it was demonstrated that all the audience-side devices had successful real-time access to the current slide information synchronized with the active presentation on the presenter compute without any missing data and perceptible delays.

## Keywords

Information Accessibility, Presentation, Internet of Things, PowerPoint.

## Introduction

Since the year of 1987 when the first release of slide presentation software showed up in the world, the use of the presentation software, such as Microsoft PowerPoint and Apple’s Keynote, has been a primary way to efficiently provide information to participants in many different settings including professional (work-related), education, entertainment, and general communication. Although there are no compelling results to prove or disprove that the use of slide presentation software is more effective for learner retention than traditional lectures (Savoy, Proctor and Salvendy), it is supposed to help both the presenters and the audiences. For the presenters, the use of presentation software can save a lot of time, who otherwise would have used other types of visual aid (e.g., hand-drawn, mechanically typeset slides, blackboards, whiteboards, and/or overhead projections). For the participants, its use can make their learning experience enriched by allowing them to have the information in more diverse formats (e.g., text, images, sound, movies, and other objects) with a variety of visual effects. Among presenters world-wide, the slideshow presentation software is used at an estimated frequency of 350 times per second (Parks).

However, people who are blind or visually impaired consistently find that it is impossible or difficult to have access to the information presented in forms of slideshow presentation. The total number of 7,327,800 adults (non-institutionalized, male or female, range of age 16 through 75+) with all education levels in the United States was reported to have a visual disability in 2013 (Erickson, Lee and von Schrader). According to the Annual Report 2014 published by American Printing House for the Blind, 60,393 legally blind children were enrolled in elementary and high school in the U.S, who are eligible to receive free reading matter in Braille, large print, or audio format (APH). Some presenters provide the alternative format of their presentation slides to the learners with vision issues in advance, so that they can read them through with their screen readers or Braille note-takers. However, it cannot meet their needs appropriately without providing real-time synchronous access to the information currently displayed on the public screen through their assistive reading technologies. In order to address this issue, this research has developed a prototype software package called SPARC (Slideshow Presentation Access with Real-time Communication) that enables people with blindness or visual impairments to have synchronous access to slideshow presentation made with Microsoft Office PowerPoint, which has at least 95% of the presentation software market share with installations on at least 1 billion computers (Parks), using cloud computing as a core Internet of Things (IoT) technology (Fig. 1).

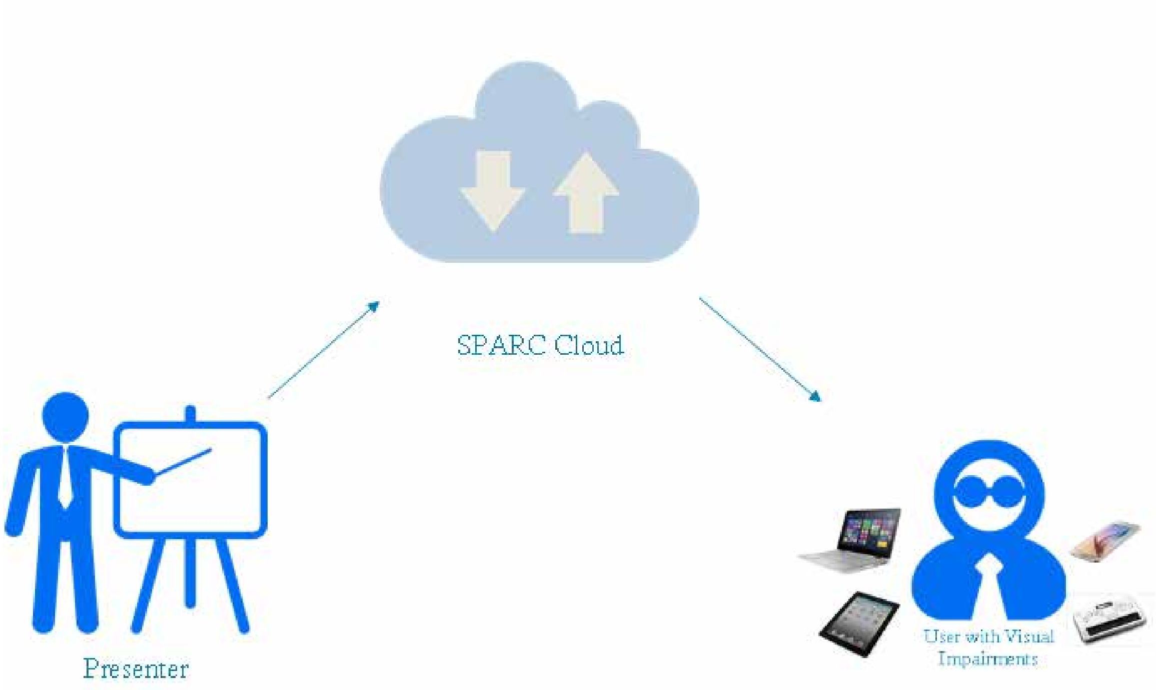


Fig. 1. SPARC Conceptual Diagram.

**SPARC (Slideshow Presentation Access with Real-time Communication)**

The SPARC consists of three inter-related system components: a presenter add-in, a cloud service, and a user terminal application program. As shown in Fig. 2, the presenter add-in is a supplemental software program that provides custom accessibility features to Microsoft Office PowerPoint. It has been implemented with VSTO (Visual Studio Tools for Office) provided by Microsoft. VSTO provides 2 types of project templates: document-level customizations and VSTO Add-ins. Document-level customizations consist of an assembly that is associated with a single document. The assembly is loaded when the associated document is opened. Features in the customizations that the developer creates are available only when the associated document is open. VSTO Add-ins consist of an assembly that is associated with a Microsoft Office PowerPoint application. Features in VSTO Add-ins that developers create are available to the application itself, regardless of which documents are open. The VSTO Add-in not only runs automatically when the associated application is started, but users can also load VSTO Add-ins after the application is already running. The SPARC presenter add-in is based on a VSTO Add-In.

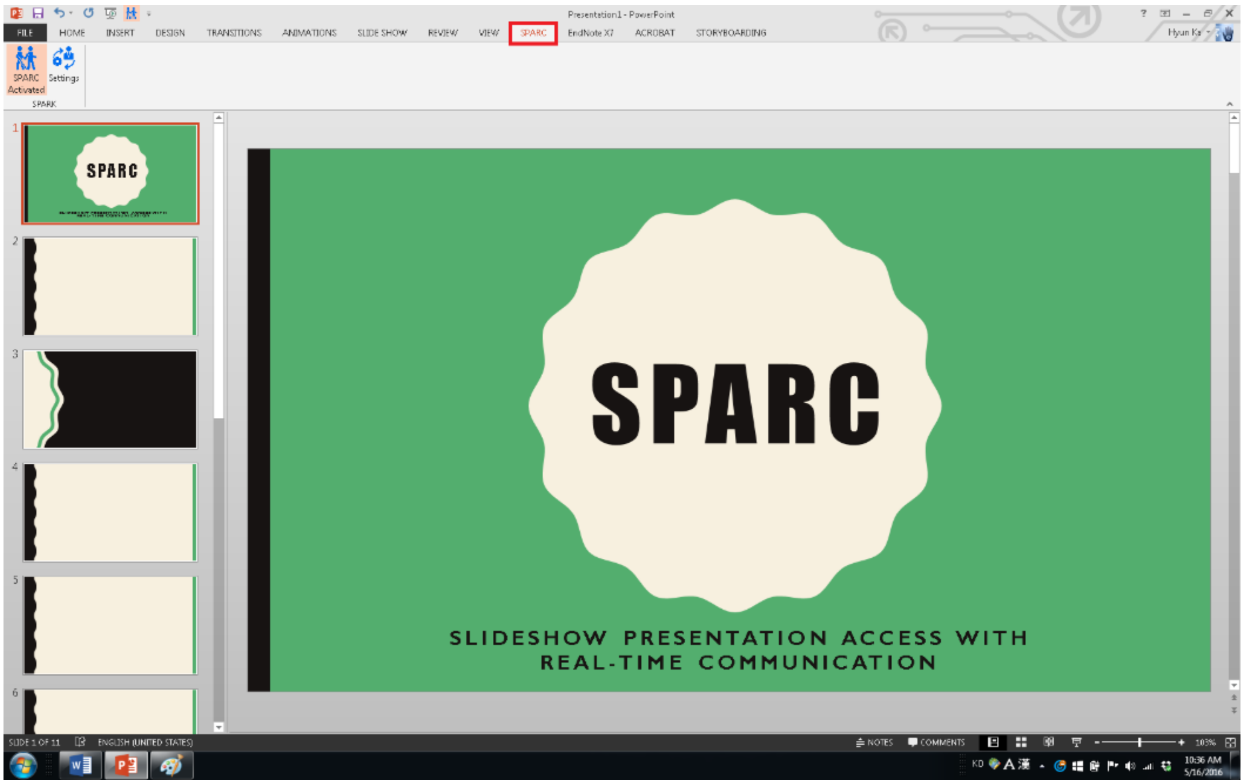


Fig. 2. SPARC Presenter Add-in.

When a presenter opens Microsoft PowerPoint program and activates the presenter add-in, a dialog box pops up and asks the presenter to name the current slideshow presentation, which should be shared with the audiences with visual impairments who are using the user terminal application. Once the slideshow starts, the presenter add-in automatically analyzes the current slide and convert it into accessible text format, based on PowerPoint Document Object Model provided by Essential Studio (Henry). The PowerPoint Document Object Model that represents the entire presentation with a hierarchical tree structure (Fig. 3). Each node in the tree corresponds to an element used in the PowerPoint presentation file, as shown in Table 1. Once Current slide information has been converted, the presenter add-in au publishes the converted text to the SPARC cloud service along with some metadata including a slide number, information on slide layout, and non-textual object properties in the current slide. Whenever the presenter gives a new command to or navigates the active presentation, the SPARC add-in automatically recognizes the command/navigation event and publishes the updated information to the cloud service.

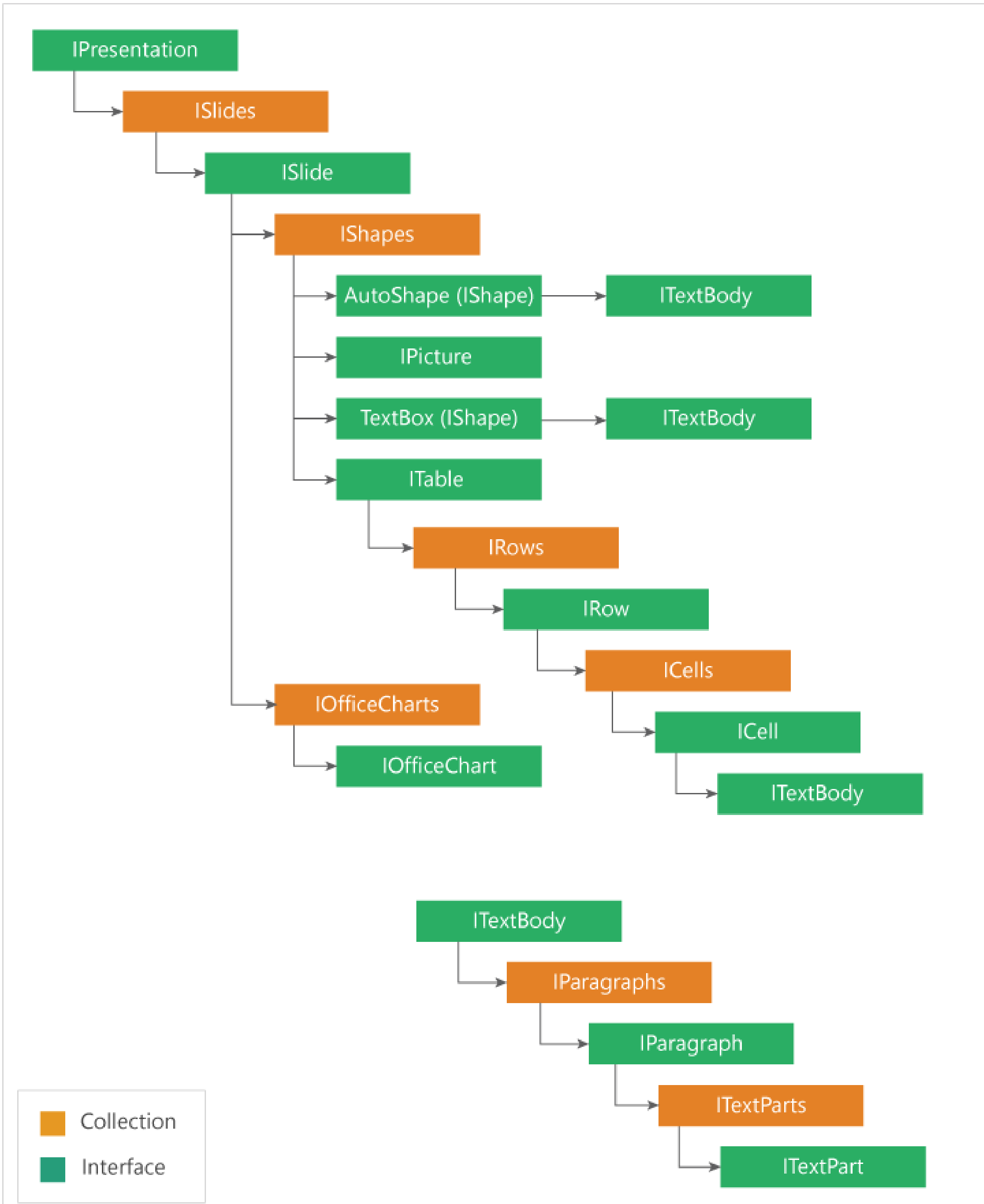


Fig. 3. PowerPoint Document Object Model.

**Table 1. PowerPoint Document Object Model**

| Element | Explanation |
|---|---|
| **IPresentation** | It represents an entire PowerPoint presentation file. This presentation instance contains the slide collections present in the PowerPoint presentation file. |
| **ISlide** | It represents a single slide within a PowerPoint presentation, which in turn contains a collection of shapes. All the elements present within a slide are enclosed in a shape. |
| **IOfficeChart** | It represents a chart present within a slide. |
| **ITable** | It represents a table within a slide. A table instance contains a collection of rows. |
| **IRow** | It represents a single row in a table. Each row contains a collection of cells. |
| **ICell** | It represents a single cell within a row. A cell contains an instance of ITextBody. |
| **ITextBody** | It represents a container for textual content. It can contain a collection of paragraphs. |
| **IParagraph** | It represents a paragraph. Paragraphs can only be added into text boxes and auto-shapes. A paragraph contains a collection of text parts. |
| **ITextPart** | It is similar to <span> in HTML. An instance of ITextPart holds textual content of similar character-level formatting. |
| **IPicture** | It represents a picture or image in a slide. |

The SPARC cloud service is a message-oriented middleware designed to empower Internet of Things and real-time communication between the presenter (publisher) and the audience (subscriber), using publish/subscribe model which allows any number of publishers to communicate with any number of subscribers anonymously in real-time (An et al.). The developed cloud service is implemented based on Google Cloud Pub/Sub Platform. The SPARC cloud service provides a rich set of API (application programming interface) supporting a standard representational state transfer (REST) interface (Fielding and Taylor), WebSockets and MQTT, so that different types of platforms and devices can be connected and communicate seamlessly.

The SPARC user terminal software is an application program that receives the published slide information and displays it on user's devices. The current user terminal software was implemented based on a cross platform open source .NET framework called Mono (Mono). It is compatible with PC/Macintosh operating systems, iOS/Android smartphones and tablets, and network accessible Windows CE based Braille note-takers. When a user opens the SPARC user terminal application software, it asks to enter the slideshow presentation name shared by the presenter. Once the presentation name is given, the terminal software automatically subscribes to the active presentation via the SPARC cloud service and get and displays the current slide information in real time on the user's device.

## Discussion

In the lab trial where there were one computer on the presenter side and five different devices (Windows and Macintosh laptops, IOS and Android tablets, and a Braille note-taker produced by HIMS International) on the audience side, it was demonstrated that all the audience-side devices had successful real-time access to the current slide information synchronized with the active presentation on the presenter computer, which consisted of 11 slides with different slide layouts (Fig. 4), without any missing data and perceptible delays.

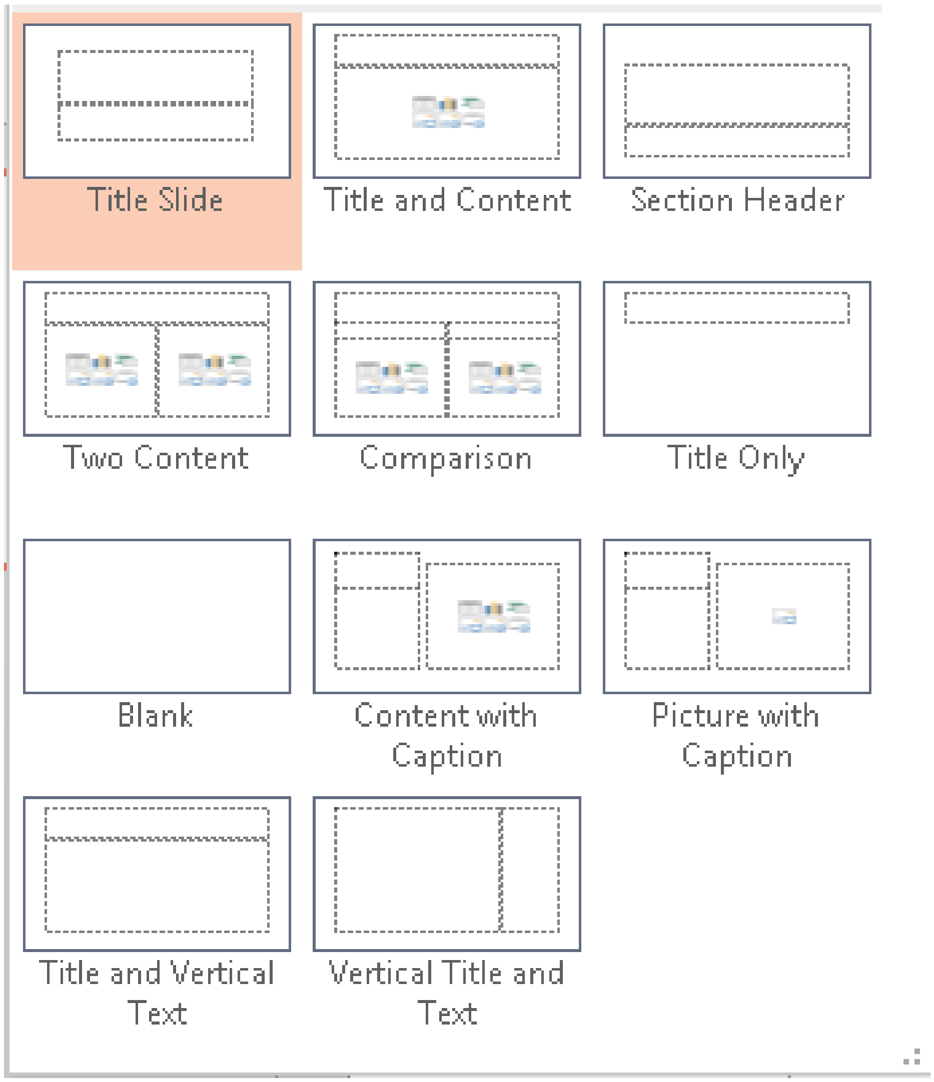


Fig. 4. 11 different slide layouts.

Although the SPARC demonstrated real-time synchronous access to the current slide information synchronized with the active presentation made with Microsoft Office PowerPoint, More refinement should be considered, because the evaluation conducted in this research were based on the 11 different slide layouts provided by Microsoft, which are recommended to use as templates for the screen reader users. Thus, for the slideshow presentation which does not use these standard templates, it is necessary for the SPARC to automatically detect the nonstandard slide, intelligently infer the missing information and convert it into accessible format. While testing with a wide range of custom slide formats, we are refining the software algorithm of the presenter add-in, applying a number of machine learning algorithms. In addition, we are planning on holding multi-round focus groups with participants, who belong to end-user and key stakeholder population, to get their perceptions, opinions, and attitudes toward the refined SPARC and to guide future directions.

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# Wireless Technology Use by People with Disabilities: A National Survey

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## Abstract

Access to and use of mobile wireless consumer technology (i.e., mobile devices like cellphones and tablets, software and services) has become critical to social and economic participation, especially for people with disabilities who already face additional barriers. This article presents data from the Survey of User Needs (SUN) conducted by the Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC) from June 21, 2015 through April 14, 2016. The SUN focuses on patterns of use, preferences and unmet needs for wireless technology among people with disabilities. Data are presented on the overall adoption rates, preferred platforms (cellphone, smartphone, and tablet), wireline (landline) use, and wireless use by disability type. Comparative analysis of adoption rates between people with disabilities and the general population is presented. Additionally, data from the 2012-2013 SUN are presented for comparison with the 2015-2016 data. The potential impact of demographic variables (age, income and education) and type of disability on wireless technology use is also analyzed. Response data show that people with disabilities own and use wireless technology at rates similar to the general population, but substantial variation exists in ownership of various types of wireless devices depending on disability type and other demographic variables.

## Keywords

Technology, disability, cellphone, smartphone, tablet, accessibility.

## Introduction

Access and use of mobile consumer information and communication technology (ICT) has become essential to independent living, employment and social participation. The ubiquity of technology in society and its increasing power and sophistication – especially the mobile kind – has made it ever more critical for communications, information access, entertainment, navigation/wayfinding, shopping, banking, and health monitoring. Data from the CTIA-The Wireless Association show over 355 million wireless service subscriptions in the United States (2015). The Pew Research Center's survey data show a steadily rising rate of cellphone ownership among the general population of American adults in recent years, from 73% in 2006 to 92% in 2015, with current smartphone ownership at 68%, and tablet computer ownership at 45% of American adults (2015).

Advances in consumer technology have created new opportunities for people with disabilities: to augment or assist communication, aid vision, aid memory, guide navigation outside the home, automate and monitor events inside of the home, monitor health, support emergency communications and location finding, provide information on the go, and socialize. Despite these new opportunities, the rapid rate of technological innovation risks leaving people with disabilities behind, or undoing hard-won advances in accessibility as new generations of technology are introduced (Wentz and Lazar 2016; Schroeder and Burton, 2010).

This article presents findings from the Survey of User Needs (SUN), a large, multi-year survey on use and usability of mainstream consumer wireless technology by people with disabilities conducted by the Rehabilitation Engineering Research Center for Wireless Technologies (Wireless RERC). Established in 2001, the Wireless RERC is funded by the National Institute on Disability, Independent Living and Rehabilitation Research (NIDILRR) within the U.S. Department of Health and Human Services. Now in its third cycle of funding, the RERC is a partnership between the Georgia Institute of Technology and Shepherd Center, a rehabilitation hospital in Atlanta specializing in rehabilitation for spinal cord and brain injury.

Most of the data presented here were collected for the 2015-2016 version of the survey. Some comparisons will be made to data collected for the 2012-2013 survey in order to uncover possible trends in technology ownership in recent years. This article is a follow-up to the article published in this journal based on the authors' presentation at the 2013 International Conference on Technology and Persons with Disability (Morris et al. 2014). Additional survey data from the Pew Research Center is presented for comparison with the general population. This article is intended as a broad review of a considerable body of survey data that addresses some core issues and questions (listed below) related to disability and technology access:

1. Disability or digital divide (Kessler Foundation/NOD 2010; Horrigan 2010) – Do people with disabilities use wireless technologies at lower rates than the general population?
2. Functional divide (Morris and Mueller 2016; Morris and Mueller 2014) – Do people with specific disabilities own or use more sophisticated types of wireless devices more than people with different disabilities?
3. Wireless substitution (Blumberg and Luke 2015) – Do income and age of people with disabilities affect the use of wireline technology in the home? Do people with disabilities have wireline service in the more at the same rate as the general population?
4. Income divide (Morris et al. 2014) – Among people with disabilities, do those with higher incomes use more advanced wireless technology than those with lower incomes?
5. Age divide (Morris, Mueller, and Jones 2010) – Do younger adults with disabilities use more advanced technology than older individuals with disabilities?

This analysis is critical to understanding the state of mobile wireless accessibility for people with disabilities in general and for those with specific disability types. It provides the beginnings of a nuanced view of technology access by analyzing the impact of demographic and other factors. Additionally, it provides important detail on the accessibility of mobile wireless technology, which is increasingly essential to independent living and social participation.

Originally launched in 2002, the SUN has been updated over the years to keep up with the rapid pace of technological change. Over 7000 people with all types of disabilities have completed the SUN since 2002. Now in its 5$^{th}$ version (SUN 5) this unique nationwide survey on wireless technology use by people with all types of disabilities has come to be an important reference for the wireless industry, government regulators, people with disabilities and advocates, and other researchers. The results presented in this paper focus on the most recent version of the SUN updated and launched in June 2015. Participants were recruited across the eight general disability categories listed in Table 1. These are based on the categories used by the American Community Survey (ACS), augmented with categories adapted from the National Health Interview Survey (NHIS) for a more robust listing of functional limitations (Ruggles, et al., 2015; CDC/National Center on Health Statistics, 2014). The SUN 5 questionnaire permits finer segmentation of respondents by disability sub-types (e.g., blindness as a subtype of difficulty seeing, using a wheelchair as a subtype of difficulty walking). A total of 1008 people responded to the survey, with 845 reporting having at least one of the eight general functional disability types listed in Table 1. Females constituted 56% of the respondents. The relatively high mean age of 53 years is partly attributable to the exclusion of minors under the age of 18 due to the greater challenges of conducting research with vulnerable populations.

**Table 1. Survey of User Needs Sample by Disability Type (%)***

| **Disability Type** | **2012-2013 Respondents** | **2015-2016 Respondents** |
|---|---|---|
| Difficulty walking or climbing stairs | 39% | 43% |
| Difficulty hearing** | 36% | 48% |
| Difficulty seeing** | 29% | 22% |
| Difficulty using hands or fingers | 26% | 25% |
| Difficulty concentrating, remembering, deciding | 24% | 21% |
| Frequent worry, nervousness, or anxiety | 20% | 22% |
| Difficulty using arms | 17% | 21% |
| Difficulty speaking so people can understand me | 14% | 17% |

*Respondents were asked to indicate all disability types that apply to them. Many respondents noted more than one disability type.

**Respondents were asked separately to indicate level of impairment with difficulty hearing, including hard of hearing (26% in 2012-2013 and 32% in 2015-2016) and deaf (10% in 2012-2013 and 11% in 2015-2016); or seeing, including low vision (15% in 2012-2013 and 12% in 2015-2016) and blind (11% in 2012-2013 and 6% in 2015-2016). However, some did not answer the subsequent question, causing the percentages of level of impairment to add to a sum lower than for the general functional difficulty (seeing or hearing).

Recruitment of participants relied on convenience sampling. Participants completed the survey via web, phone and in-person interviews, and on paper. For analyses that included all respondents with disabilities the sample was weighted, an established technique for correcting potential sampling biases (Yansaneh, 2003). The SUN sample was weighted by annual household income in order to minimize possible sampling biases in favor of wealthier, more educated respondents. Target household income distribution was calculated for respondents with disabilities in the 2014 ACS, the most recent available. Weights were calculated to make the income distribution in the SUN sample match that of the much larger ACS sample. The same procedure was conducted for analysis of the 2012-2013 SUN data, using the 2011 ACS sample.

**Discussion**

This article comprises two main areas of analysis: 1) analysis of responses for all eight disability categories taken together to assess the impact of demographic variables on mobile wireless technology ownership and use; and 2) analysis of responses by each disability category to identify differences in ownership and use between and among disability types. General trends related to overall ownership rates and ownership of specific types of devices (basic or “feature” phone, smartphone, tablet) are examined. Additionally, response data on wireless substitution (discontinuing wireline service, or “cutting the cord”, in favor of wireless-only communications) are examined as a way of understanding the degree to which people with disabilities rely on mobile wireless technology and how that compares to the general population.

Table 2 shows aggregate ownership rates of three types of devices (basic cellphone, smartphone and tablet) for all SUN respondents with a disability and the general population in surveyed by the Pew Research Center. Overall, recent SUN respondents with disabilities own or use cellphones (basic cellphones and smartphones) at a substantially lower rate (82%) than the general population (92%) as measured by the Pew Research Center. Adding SUN respondents who own a tablet raises the ownership rate to 92%. The Pew data do not show the percentage owning any of the three types of devices. Ownership rates for cellphones and tablets for SUN respondents with disabilities have been relatively flat since the 2012-2013 survey; changes in ownership and use rates likely reflect in part sample variation. Over the same period there seems to be a moderate increase of ownership/use by the general population.

**Table 2. Do you own or use a wireless device? (All respondents with a disability, % yes)**

| | SUN 2012-13 | Pew 2012 | SUN 2015-16 | Pew 2014 |
|---|---|---|---|---|
| Cellphone, smartphone or tablet ownership | 91% | -- | 92% | -- |
| Cellphone or smartphone ownership | 84% | 87% | 82% | 92% |

*Source:* Pew Research Center (n.d.). Device Ownership over Time. Accessed online, http://www.pewinternet.org/data-trend/mobile/device-ownership/, May 9, 2016.

Table 3 shows the disaggregated ownership rates for each of the three types of devices for the SUN and Pew samples since 2012. In this period ownership of smart devices has grown considerably for both samples, with corresponding declines in the ownership of basic cellphones. For the earlier period, SUN respondents reported a substantially higher rate of smartphone ownership than the Pew sample (54% versus 45%). This gap narrowed to a small difference (71% and 68%) in the recent period as adoption rates for both groups grew to high levels. Tablet ownership rates are the same or similar for both samples in both periods, with SUN respondents reporting slightly higher adoption rates than the Pew sample in the recent period (50% and 45%).

**Table 3. What type of device(s) do you own or use? (All respondents with a disability, %)**

| | SUN 2012-13 | Pew 2012 | SUN 2015-16 | Pew 2015 |
|---|---|---|---|---|
| Basic cellphone (e.g., Motorola Razr, Pantech Breeze, Nokia 6350) | 31% | 42% | 13% | 24% |
| Smartphone (e.g., iPhone, Android phone, BlackBerry, Windows phone) | 54% | 45% | 71% | 68% |
| Tablet (e.g., iPad, Kindle Fire, Galaxy Tab, Google Nexus) | 31% | 31% | 50% | 45% |

*Source:* Pew Research Center (n.d.). Device Ownership over Time. Accessed online, http://www.pewinternet.org/data-trend/mobile/device-ownership/, May 9, 2016.

The 2015-2016 SUN data show strong evidence of an income divide in wireless device ownership among people with disabilities. It is expected that people with higher incomes are more likely to own more expensive devices, which are used with correspondingly more expensive service plans (for cellphones and smartphones). Table 4 shows a strong relationship between income and *not owning* a wireless device (first data column) or *owning* a basic cellphone (second data column). Lower-income respondents with disabilities are more likely to either not own a wireless device at all, or own a basic cellphone. Consistent with this pattern, respondents with lower incomes are much less likely to own smartphones and tablets.

Table 4 also shows the percentage of SUN respondents with a disability who own a wireline phone in the home – an indicator of the degree to which people depend on wireless phone communications. According to data from the National Health Interview Survey conducted by the U.S. Centers for Disease Control and Prevention (CDC) individuals in the general population with lower incomes are less likely to own a wireline phone. This pattern is evident among SUN respondents with disabilities. However, the effect is strongest among the lowest and highest income ranges shown in Table 4. Overall, approximately 48% of adults in the general population did not have a working wireline phone in the home in 2015, a figure that has climbed steadily since 2003 (Blumberg and Luke, 2016). Among SUN respondents with disabilities that figure is approximately 36%. These lower rates of wireless substitution among people with disabilities might reflect specific accessibility needs, perhaps for people who are deaf or hard of hearing who might need a landline for teletype or captioning services, or who prefer the sound quality of a wireline phone. Also, people with severe motor limitations or speech limitations might find landline phones more durability or accessibility.

**Table 4. Wireless and Wireline Use by Income (All respondents with a disability, %)**

| Annual household income | No wireless device | Basic cellphone | Smartphone | Tablet | Wireline |
|---|---|---|---|---|---|
| Less than $10,000 | 8% | 22% | 47% | 33% | 53% |
| $10,000-$14,999 | 3% | 15% | 65% | 51% | 66% |
| $15,000-$24,999 | 3% | 18% | 59% | 43% | 58% |
| $25,000-$34,999 | 1% | 12% | 67% | 46% | 67% |
| $35,000-$49,999 | 1% | 14% | 71% | 52% | 68% |
| $50,000-$74,999 | 1% | 7% | 82% | 51% | 65% |

| Annual household income | No wireless device | Basic cellphone | Smartphone | Tablet | Wireline |
|---|---|---|---|---|---|
| $75,000 or more | 1% | 8% | 86% | 63% | 74% |

Table 5 shows the same wireless and wireline options in the column headings as table 4, but here the row labels contain age ranges beginning with 18-30 years and ending with over-70 years. It is expected that there would be an age divide by which younger respondents with disabilities would be less likely *not* to have a wireless device and less likely to have a basic cellphone than older respondents. Instead, younger respondents as earlier adopters would be more likely to own sophisticated devices like smartphones and tablets. The data in Table 5 generally support these aspects of an age divide, with the exception of not owning a wireless device. There is little difference between age cohorts in *non-ownership* of wireless devices. As expected, younger respondents are less likely to own a basic cellphone. The pattern of smartphone ownership is generally flat across all age groups (between 71% and 77%) with the exception of the oldest age group over 70 years of age, which reports much lower smartphone ownership. This flattening of smartphone ownership likely reflects the broad adoption of smartphone technology among people with disabilities and society in general. Tablet ownership skews somewhat toward younger age cohorts, with the exception of the youngest group of 18-30 years, who may have financial constraints limiting the ability to purchase a tablet. Finally, consistent with the CDC's data, wireline ownership is much lower among younger respondents.

**Table 5. Wireless and Wireline Use by Age (All respondents with a disability, %)**

| | No wireless device | Basic cellphone | Smartphone | Tablet | Wireline |
|---|---|---|---|---|---|
| 18-30 | 1% | 7% | 71% | 39% | 40% |
| 31-40 | 3% | 8% | 77% | 58% | 57% |
| 41-50 | 1% | 9% | 75% | 56% | 57% |
| 51-60 | 3% | 16% | 72% | 50% | 68% |
| 61-70 | 3% | 16% | 72% | 48% | 77% |
| Over 70 years old | 1% | 20% | 55% | 39% | 84% |

The analysis above for all respondents with disabilities reveals some important trends, particularly in comparison to the general population. However, a more complete understanding requires analysis of wireless device ownership by disability. Table 6 shows wireless device and wireline ownership for the eight disability types listed in Table 1. Table 7 shows the same technology options, but with the respondents who reported having visual or hearing loss disaggregated by level of functional loss: low vision and blind, and hard or hearing and deaf.

**Table 6. Wireless and Wireline Use by Disability Type (%)**

| | No device | Basic phone | Smartphone | Tablet | Wireline |
|---|---|---|---|---|---|
| Cognitive | 0% | 13% | 72% | 50% | 58% |
| Anxiety | 3% | 14% | 67% | 52% | 56% |
| Seeing | 0% | 14% | 73% | 45% | 69% |
| Hearing | 2% | 12% | 74% | 56% | 71% |
| Speaking | 4% | 11% | 59% | 49% | 61% |
| Using arms | 5% | 17% | 59% | 42% | 71% |
| Using hands and fingers | 4% | 16% | 59% | 45% | 67% |
| Walking, climbing stairs | 3% | 16% | 64% | 46% | 65% |

Disability type differs from income and age as a variable in that there is no natural order or progression of the values, except perhaps low vision and blind, and separately hard or hearing and deaf (Table 7). Consequently, it is not possible to analyze trends across the eight general disability categories as in previous tables. Still, some specific values stand out. First, those who reported having difficulty speaking or difficulty using arms, hands and fingers have the highest rates of not having a wireless device, but still at very low levels (4% or 5%). Additionally, those with physical limitations (using arms, hands, fingers, and ambulating) reported the highest rates of basic cellphone ownership (16% or 17%), perhaps because the direct action of physical keys on these devices may provide more control. These interfaces may produce less slippage of fingers for these users and provide physical feedback of key activation. Simple cellphones also may provide greater durability when dropped.

Notably, respondents with hearing and vision, as well as cognitive, limitations were substantially more likely to own smartphones. Those with hearing limitations also were most like to own a tablet and have home wireline service. Those with limited sight were among the least likely to own tablets, but reported among the highest rate of home wireline service. Overall, these results likely reflect in part the ownership patterns of blind and deaf respondents, who are regarded as most enthusiastic technology adopters. There are also notable distinctions between the two vision loss groups and the two hearing loss groups (Table 7). Deaf respondents show much higher rates of smartphone (80% versus 71%) and tablet ownership (63% versus 53%) than hard of hearing respondents, and much lower rates of basic phone (6% and 15%) and wireline ownership (58% and 74%). This is understandable since people who are deaf have more complex communication needs which often cannot be satisfied by basic cellphones or wireline phones.

**Table 7. Wireless and Wireline Use by Disability Type (Vision or hearing limitations)**

| | No wireless device | Basic phone | Smart phone | Tablet | Wireline |
|---|---|---|---|---|---|
| Low vision | 2% | 17% | 68% | 47% | 68% |
| Blind | 0% | 9% | 82% | 39% | 77% |
| Hard of hearing | 2% | 15% | 71% | 53% | 74% |
| Deaf | 2% | 6% | 80% | 63% | 58% |

Similar differences are noted for blind and low vision respondents, with blind respondents much more likely than low vision respondents to own a smartphone (82% versus 68%) and wireline phone service (77% versus 68%), and less likely to own a basic phone (9% and 17%). Low vision respondents, however, are more likely to own a tablet (47% versus 39% for blind respondents, probably because tablets are more visually engaging than smartphones.

## Conclusions

The survey results presented here lead to two general conclusions. First, as a group, people with all types of disabilities use wireless devices (basic phones, smartphones and tablets) at a high rate, although at a lower rate than the general population. They use cellphones overall at a substantially lower rate (82% versus 92%). But, they use smartphones and tablets at somewhat higher rates. Additionally, they are "cutting the cord" of wireline phone service at a slower rate than the general population. These results indicate that the notion of a disability divide between people with disabilities and the general population overlooks important details. Technology access for people with disabilities is more complicated and variable, and it involves the complex interplay of age and income (just as for the general population) and, perhaps most importantly, type of disability or functional limitation. Among people with disabilities there is evidence of an income divide (higher incomes are associated with use of more sophisticated technology) and an age divide (higher age is associated with use of less sophisticated technology). These divides also characterize the general population.

The second conclusion is that substantial differences in technology ownership and use are evident between and among people with different disabilities. The various platforms – basic cellphones, smartphones, tablets (and even wireline phones) – offer different interfaces and capabilities that are utilized at varying rates by people with differing levels and types of abilities, whether it is seeing, hearing, using hands, etc. Each of these platforms offers access and barriers depending on the specific functional loss of potential users with disabilities. Challenges and barriers to access and use persist, and hard won gains can be quickly lost with successive versions and generations of technology (Wentz and Lazar 2016). Furthermore, emerging mobile technologies such as wearables will pose new challenges to access and usability.

**Acknowledgement**

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# Touchscreen Accessibility in Self-Service Terminals

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## Abstract

Touchscreens are becoming a ubiquitous method for interacting with technology, including self-service terminals (SSTs). However, they can pose significant accessibility issues for people with disabilities. The lack of tactile features can be particularly problematic for people with visual impairment. Furthermore, there are additional technical requirements aimed at ensuring the security and privacy of the information processed by SSTs, especially on automated teller machines (ATMs) when entering the Personal Identification Number (PIN). These technical requirements mean that very limited feedback can be given to the user about the options available or the input entered. To explore ways of making touchscreen-based ATMs accessible for everyone, a research project was initiated. After an iterative development process in collaboration with a multidisciplinary team of interaction designers, industrial designers, accessibility and usability specialists, expert evaluators from the Royal National Institute of Blind People (RNIB) in the UK and two rounds of usability testing with people with visual impairment, a solution was found. This paper reports the results of this research project: an input method that allows people with visual impairment to use the touchscreen to interact with an ATM independently, including entering their PIN in complete privacy.

## Keywords

Self-service technology, ATM, touchscreen, visual impairment, privacy.

## Introduction

Self-service technology is becoming more widespread and increasing in importance (Castro et al). One of the biggest benefits of self-service is the convenience and availability of services to anyone, anywhere, anytime (Barnes et al). On the other hand, this is also one of the main challenges of making self-service accessible. Self-service terminals (SSTs), such as ATMs (automated teller machines), supermarket self-checkouts and airport check-ins, must be accessible to anyone, without training or assistive technologies.

More and more often, the primary method of interacting with an SST is via a touchscreen. This trend has been evident for the last decade, and shows no sign of diminishing (Couts). For example, a survey in 2004 of 18-34 year olds in the US found that 82% had used a touchscreen at a self-checkout system, and 70% had used a touchscreen at an ATM. The majority of respondents (89%) reported that they expected touchscreens to become the standard way of interacting with SSTs. (Penn & Berland) However, touchscreens can pose significant accessibility challenges, particularly for people with visual impairments. Although great progress has been made to improve touchscreen accessibility on personal mobile devices, there are additional challenges in the self-service context (Jokisuu et al). There are also strict legal and regulatory requirements to ensure both the accessibility and security of the self-service transaction (e.g. Department of Justice; PCI).

In this paper, we present our research into making touchscreen interaction on SSTs accessible to people with visual impairment, particularly when entering private information, such as a Personal Identification Number (PIN).

## Usability Tests

### *Exploring Gestures Test*

To investigate the possibilities of using touchscreen gestures on SSTs, three early concepts were created by a team of usability specialists and interaction designers (reported in Jokisuu et al). These three concepts were developed to test the experience of entering a PIN using gestures only. The concepts were evaluated in an expert review by assistive technology evaluators from RNIB (Royal National Institute of Blind People) and two visually impaired users. Based on the expert review, two of these concepts were developed further and two additional concepts created to be tested in more detail with users with visual impairment.

The four PIN entry concepts included in the test were:

Visual tallies: swiping up and down anywhere on the screen the number of times corresponding to the number you want entered.

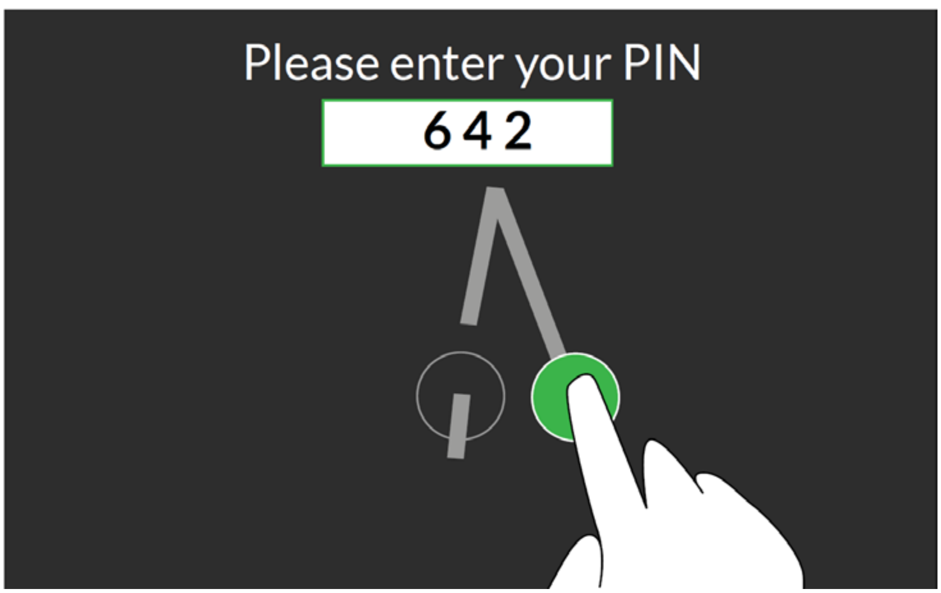


Fig. 1. Concept A for PIN entry: Visual tallies.

Multi-finger multi-tap: either touching and holding on the screen the number of fingers you want entered, or tap repeatedly with one or multiple fingers the number of times you want entered, e.g. two taps with two fingers to enter 4.

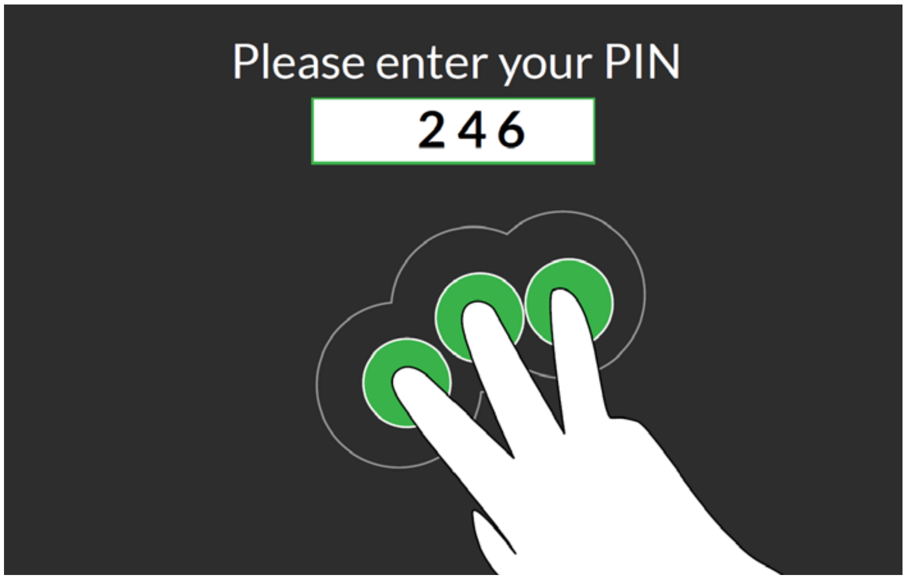


Fig. 2. Concept B for PIN entry: Multi-finger multi-tap.

Tactile markers: A plastic strip with tactile features affixed to the bottom of the screen to guide the finger onto the correct target area on the screen.

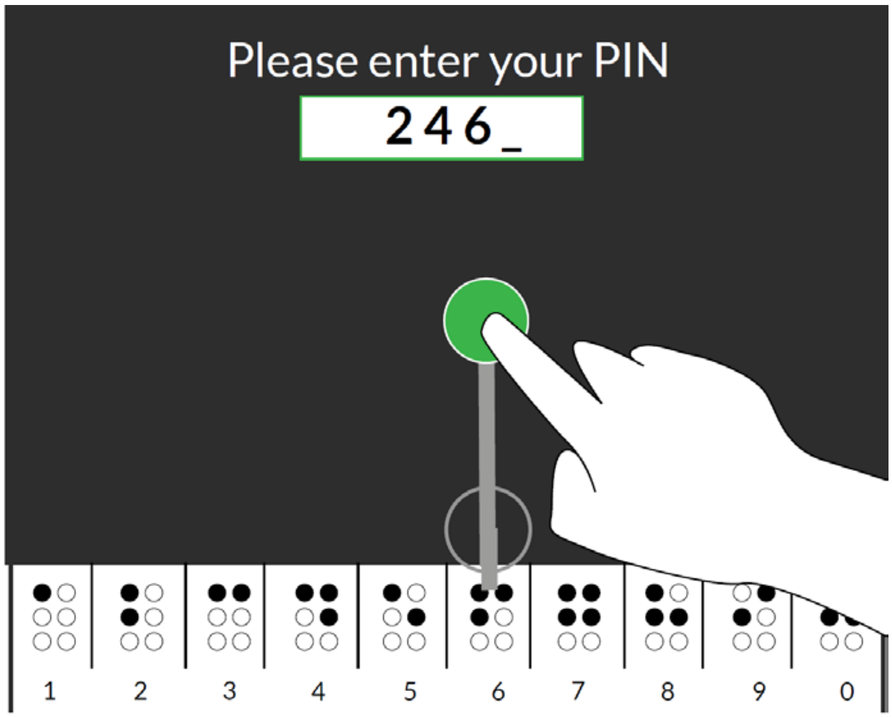


Fig. 3. Concept C for PIN entry: Tactile markers.

Multi-finger tap & hold: touching and holding on the screen the number of fingers you want entered.

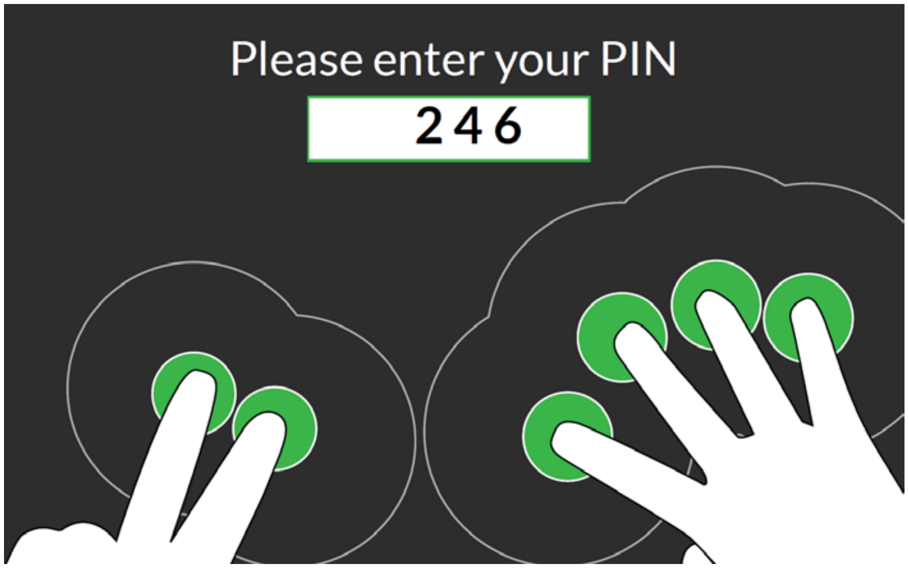


Fig. 4. Concept D for PIN entry: Multi-finger tap & hold.

Concept D for PIN entry: Multi-finger tap & hold. There are specific technical requirements for PIN entry to ensure the PIN remains private and secure (see PCI for details). These requirements mean that no individual numbers or user input can be vocalized.

In addition to the PIN entry task, two other tasks were included in the test: task 2 was to select a specific option in an on-screen menu, and task 3 was to enter the word “SAVE” using an on-screen keyboard. To test these tasks, three concepts were developed:

A) Talking fingers: moving the finger on the screen to hear the menu option/alphabetic character in focus vocalized, then double-tap to select. Options were arranged in a fixed grid in the center of the screen.

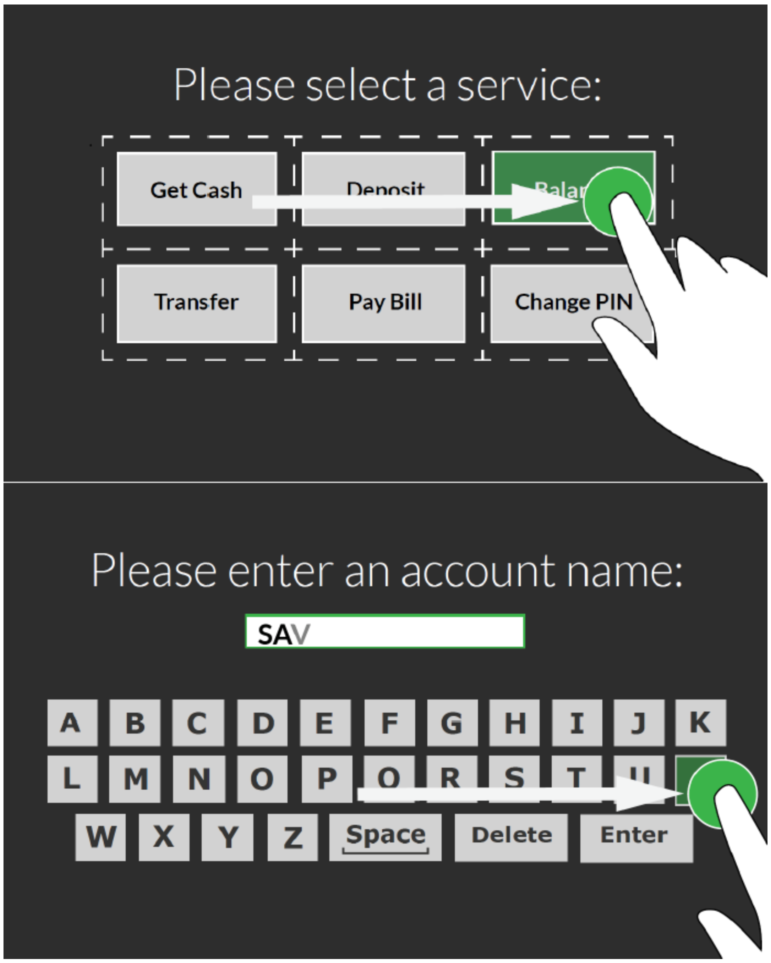


Fig. 5. Concept A for menu selection and text entry: Talking fingers.

Virtual grid: swiping left or right, up or down anywhere on the screen to cycle through the menu options/alphabetic characters, double-tap to select.

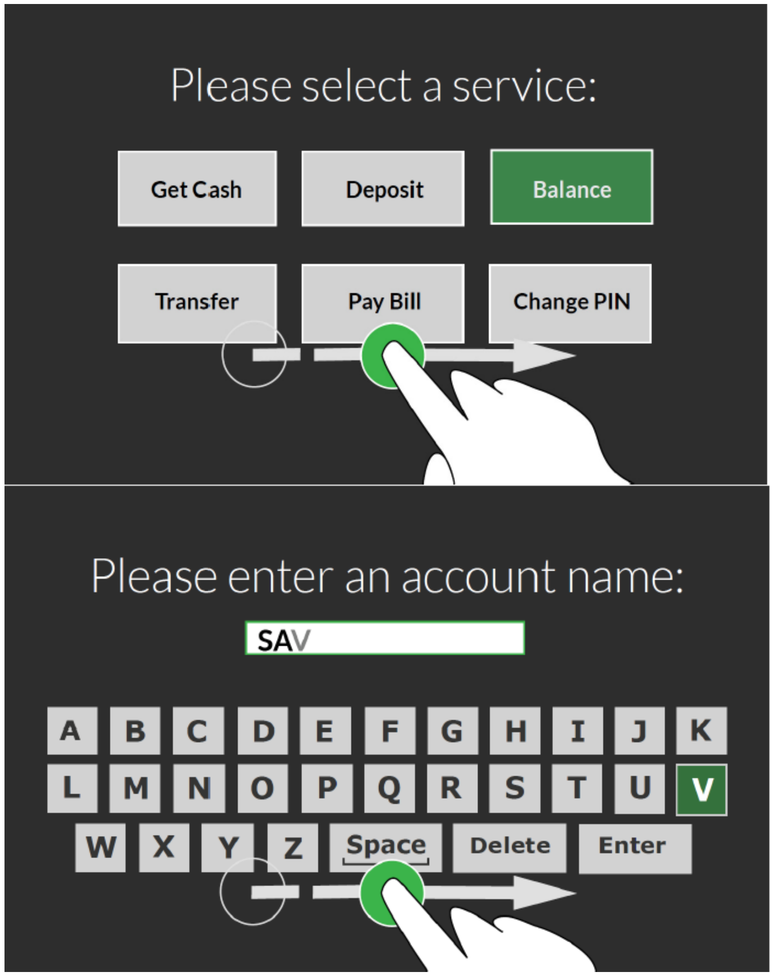


Fig. 6. Concept B for menu selection and text entry: Virtual grid.

Slider: sliding a finger horizontally along the bottom of the screen to hear each menu option/alphabetic character in turn, double-tap to select.

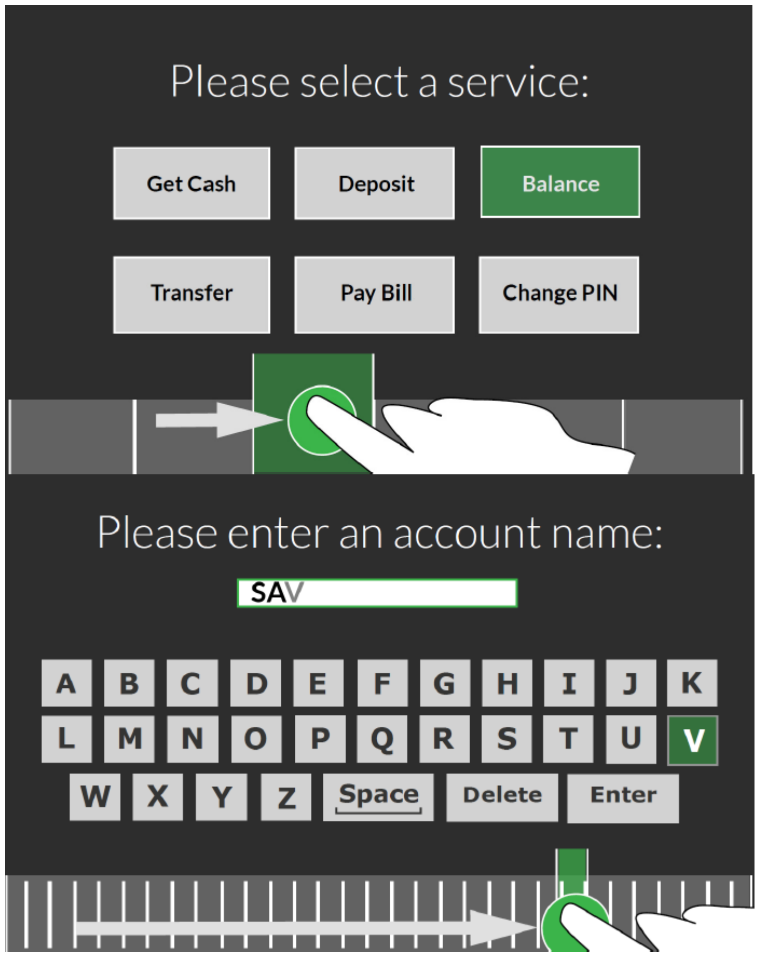


Fig. 7. Concept C for menu selection and text entry: Slider.

A total of 49 people (27 women and 22 men) with varying levels of visual impairment (9 were partially sighted, 22 were blind with some useful residual vision and 18 were blind without any useful residual vision) took part in the usability test. They were recruited through RNIB. The evaluation was a repeated measures design, and the order in which the concepts were used was counterbalanced to reduce any learning effect. The test equipment consisted of a 10” touchscreen attached to a pedestal to simulate the screen size, height and angle of a finished ATM. The touchscreen used was the actual 10” touchscreen from the ATM that was intended to first use this accessibility method, giving a high level of ecological validity to the evaluation. Before starting the test, the participants were given an introductory tour and time to explore the test equipment to help orientate themselves. Each concept was accompanied by a pre-recorded audio guidance describing how to enter a PIN, which the participants were able to listen multiple times if needed. During the test, no practice was allowed, but if a participant seemed to struggle with a concept, the facilitator intervened and gave additional instructions. After using each concept, the participants were asked to rate on a 5-point Likert scale: 1) how easy it was to understand the audio instructions; 2) how easy it was to perform the touchscreen gestures required to complete the task; 3) how confident they would be to use an ATM with that interaction method; and 4) specifically about the PIN entry concepts, how private it felt.

*Exploring Gestures Results*

Entering the PIN was extremely challenging. Due to the security rules around PIN entry, no feedback identifying individual numbers could be vocalized. Participants tended to understand the concepts, but made errors in entering the numbers, and were unaware of these errors until informed. Of the four concepts tested, Concept B "Multi-finger multi-tap" and Concept C "Tactile markers" were rated the easiest to use, and the participants felt the most confident using them. All four concepts were thought to be less private than a traditional ATM PIN pad. The average ratings for each concept are shown in Table 1.

**Table 1. Participants' subjective ratings for each of the four PIN entry concepts in the first usability test (average rating on a scale of 1 = very negative to 5 = very positive).**

| | **A. Visual tallies** | **B. Multi-finger Multi-tap** | **C. Tactile markers** | **D. Multi-finger Tap+Hold** |
|---|---|---|---|---|
| Ease of understanding the audio instructions | 3.44 | 3.29 | 3.49 | 4.08 |
| Ease of performing the gestures | 3.4 | 4 | 3.75 | 3.35 |
| Confident to use independently | 3.32 | 3.76 | 3.88 | 3.61 |
| Privacy compared with traditional ATM | 2.59 | 2.7 | 2.74 | 2.48 |

**Table 2. Participants' subjective ratings for each of three concepts in the menu selection task (average rating on a scale of 1 = very negative to 5 = very positive).**

| | A. Talking fingers | B. Virtual grid | C. Slider |
|---|---|---|---|
| Ease of understanding the audio instructions | 4.15 | 4.08 | 4.19 |
| Ease of performing the gestures | 4.02 | 4.27 | 4.4 |
| Confident to use independently | 4.47 | 4.25 | 4.47 |

Due to the significant difficulties in entering the PIN, it was evident that the PIN entry concepts needed to be improved. Concept C with the tactile markers was selected for further development. An added benefit of this solution was that it also provided a fixed tactile reference point to help users maintain their spatial orientation on the touchscreen, whereas all the other PIN entry concepts relied on gestures only.

Participants found tasks 2 and 3, i.e. the menu selection and text entry tasks, easier than the PIN entry task, primarily because they were able to hear the options and their input vocalized. There was no clear preference for any one concept but Concept C "Slider" was rated highly for the menu selection task, and Concept A "Talking fingers" and Concept C "Slider" for the text entry task. Average ratings for the menu selection task are shown in Table 2 and for the text entry task in Table 3.

**Table 3. Participants' subjective ratings for each of the three concepts in the text entry task (average rating on a scale of 1 = very negative to 5 = very positive).**

| | A. Talking fingers | B. Virtual grid | C. Slider |
|---|---|---|---|
| Ease of understanding the audio instructions | 4.11 | 3.57 | 4.06 |
| Ease of performing the gestures | 3.41 | 2.85 | 3.4 |
| Confident to use independently | 3.82 | 3.24 | 3.72 |

*Improving PIN Entry Test*

Several variations of the “Tactile markers” concept were created to refine the tactile features that would help identify the numbers and the Cancel and Enter functions. Different raised and recessed features were investigated to help differentiate between the numbers, along with different shapes to guide the finger to the correct target area on the screen. These concepts were again reviewed with RNIB evaluators. Based on their feedback, two variants were selected to be tested with users in the next usability test.

6. Tactile strip with grooves to guide the finger to the correct target area on the screen. There were 12 grooves: one for each number, a shorter groove for Cancel and Clear and another shorter groove for Enter.

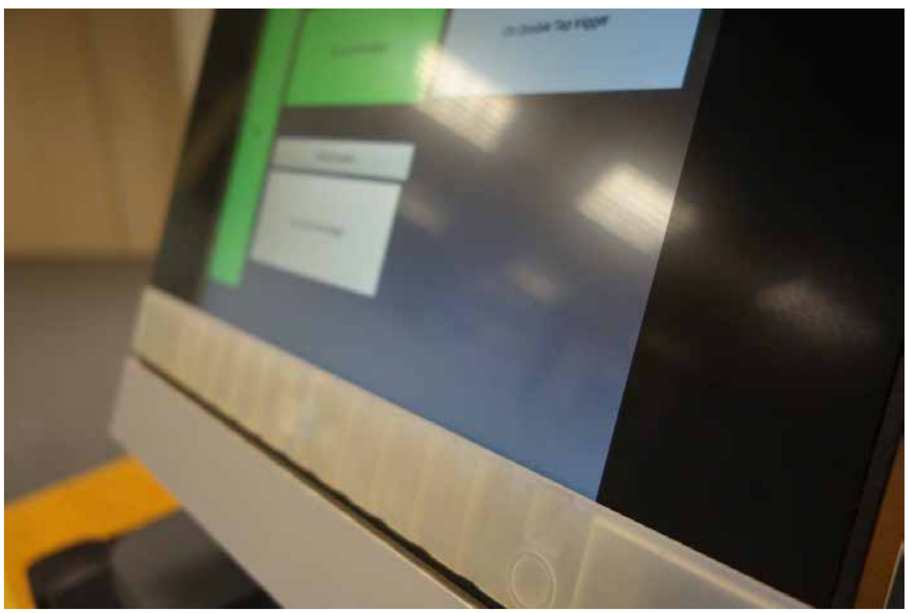

Fig. 8. Concept 1 for PIN entry: Tactile strip with grooves.

7. Tactile strip with holes, similar to the previous concept but each groove also had a hole overlapping the touchscreen to tactilely indicate the target area on the screen.

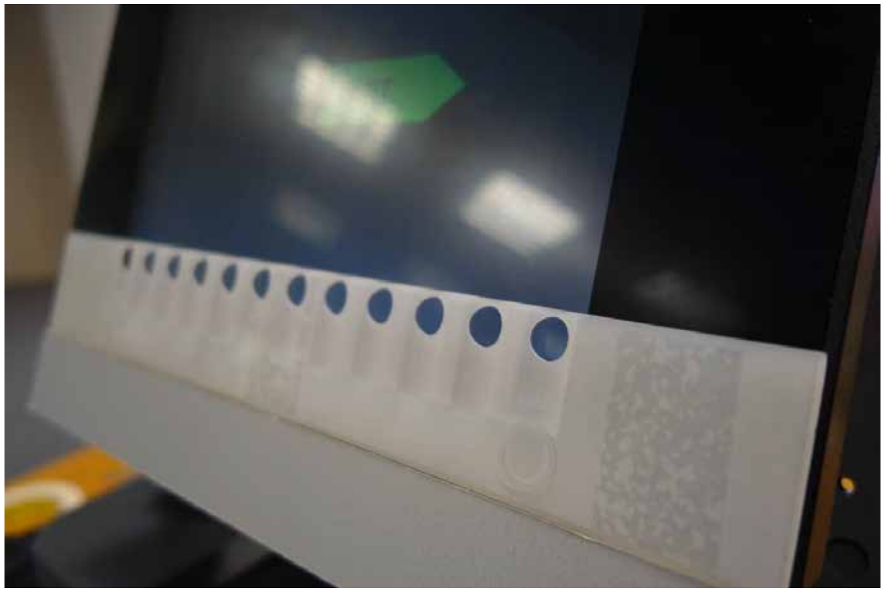

Fig. 9. Concept 2 for PIN entry: Tactile strip with holes.

An alternative to this interaction method would be for the touchscreen itself to provide tactile feedback in response to touches and gestures. In order to investigate the suitability of this type of haptic feedback in SSTs, a prototype of a haptic touchscreen was included in the test as a third concept:

8. Haptic touchscreen: The layout was similar to a traditional ATM PIN pad, with a subtle pulse when a finger was on a number key, a stronger pulse on the 5 key and the function keys “Cancel”, “Clear” and “Enter” vocalized when the finger was on them. To select a key, the user was expected to press down without lifting their finger.


Fig. 10. Concept 3 for PIN entry: Haptic touchscreen.

9. A traditional ATM PIN pad with physical keys was included in the test to enable comparison with the tactile strip concepts and the haptic touchscreen.


Fig. 11. Concept 4 for PIN entry: Traditional ATM PIN pad.

In the second usability test, all participants were asked to enter a PIN using all four concepts (in counterbalanced order to minimize any learning effect). We had 40 participants (23 men and 17 women) with varying levels of visual impairment: 3 were partially sighted, 15 were blind with some useful residual vision, and 21 were blind without any useful residual vision. When asked about their experience of using ATMs, 17 said they used an ATM independently. There were 3 participants who had never used an ATM and a further 8 who said they did not regularly use an ATM but had tried in the past. When asked about their experience of using personal mobile devices with touchscreens, 18 used a smartphone, 10 used both a smartphone and a tablet, and 12 did not use touchscreen-based mobile devices.

*Improving PIN Entry Results*

Both of the tactile strips (Concepts 1 and 2) worked well: only nine participants failed to enter their PIN using them. With Concept 1 (the tactile strip with grooves) 28 of the participants managed to enter the PIN correctly on the first attempt and a further 3 on the second attempt. With Concept 2, 17 managed to enter the PIN correctly on the first attempt, and 14 on the second attempt. On the other hand, the haptic touchscreen was found to be very difficult to use: 21 participants failed to enter the correct PIN, 12 managed it on the first attempt and a further 7 on the second attempt. In contrast, with the traditional ATM PIN pad 37 of the participants managed to enter the PIN successfully on first attempt, a further 2 on the second attempt, and one participant failed to enter the PIN correctly.

Similar to the first usability test, the participants were asked to rate on a 5-point scale: 1) how easy it was to understand the audio instructions; 2) how easy it was to enter the PIN; and 3) how confident they would be to use an ATM with that PIN entry method, both without any practice and with practice. The average ratings are shown in Table 4.

**Table 4. Participants' subjective ratings for each of the four concepts in the second usability test (average rating on a scale of 1 = very negative to 5 = very positive).**

| | **Tactile strip with grooves** | **Tactile strip with holes** | **Haptic touchscreen** | **Traditional ATM PIN pad** |
|---|---|---|---|---|
| Ease of understanding the audio instructions | 4.65 | 4.65 | 4.52 | N/A |
| Ease of entering the PIN | 4.23 | 4.2 | 2.15 | 4.7 |
| Confident to use without practice | 4.22 | 4.28 | 2.38 | 4.8 |
| Confident to use with practice | 4.68 | 4.78 | 3.28 | 4.95 |

Comparing the ratings for the two tactile strip concepts with the ratings for the traditional ATM PIN pad (shown in Table 5), the tactile strips were rated equally easy to use and the participants felt confident that they would be able to enter their PIN as easily as with the traditional ATM PIN pad. The haptics concept was rated significantly more difficult than any of the other concepts, and participants were not as confident that they would be able to use it on their own.

**Table 5. Comparing the participants' ratings for the ease of PIN entry (using Friedman's ANOVA).**

| | **Tactile strip with grooves** | **Tactile strip with holes** | **Haptic touchscreen** | **Traditional ATM PIN pad** |
|---|---|---|---|---|
| Tactile strip with grooves | - | | | |
| Tactile strip with holes | $\chi^2_F(3)=.1$, $p=1.000$ | - | | |
| Haptic touchscreen | $\chi^2_F(3)=1.5$, $p=.000$ | $\chi^2_F(3)=1.4$, $p=.000$ | - | |
| Traditional ATM PIN pad | $\chi^2_F(3)=-0.5$, $p=.5$ | $\chi^2_F(3)=-0.6$, $p=.226$ | $\chi^2_F(3)=-2.0$, $p=.000$ | - |

## Discussion

Based on the first usability test, it was clear that entering the PIN using touchscreen gestures only was extremely challenging. The lack of auditory feedback made it difficult to identify the appropriate number to be entered. It was also difficult to know when a mistake had been made and how it could be corrected. Furthermore, the lack of any tactile reference points on the touchscreen added to the challenge. However, it was positive to discover that the other two tasks, in which it was possible to vocalize on-screen content, were easier to complete.

As shown by these results, the audio instructions and all auditory feedback are very important. They need to be carefully implemented, particularly the sequence and amount of information given to the user. Not everyone will know how to use a touchscreen and perform gestures such as double-taps and swipes. This creates additional challenges for providing instructions that accommodate both first-time users and the more experienced ones.

It is encouraging to note that by refining the tactile features of the first Tactile markers concept and then testing it again with users, a clear improvement could be seen in the participants' ratings. The tactile strips of the second test were rated considerably easier to use, and the majority of participants were able to successfully enter their PIN. Based on our research, it is also evident that the haptics-based touchscreen is not suitable for use on SSTs – yet. This may change in the future as the technologies to create different tactile sensations evolve.

## Conclusions

SSTs have certain characteristics which make them unique in terms of their requirements for accessibility. Anyone must be able to walk up to an ATM and be able to use it without training or assistive technologies. As the user could be anyone, we cannot make assumptions about their prior knowledge and experience. Even for those users who have experience of touchscreen interaction, the self-service environment creates challenges. There is very little time to learn a new interface and master a new interaction method when standing at an ATM. Touchscreen gestures familiar from personal mobile devices cannot necessarily be transferred to an ATM. The bigger screen of an ATM will make it difficult to maintain orientation while navigating the interface. There are also often concerns over privacy and security as the user is required to handle personal and sensitive information in a public place.

Future work will continue to address these issues and improve this initial solution. What the results of this study confirm is that it is possible to make a touchscreen-only ATM accessible for users with visual impairment, allowing them to interact with an ATM independently, including entering their PIN in complete privacy.

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# Communicating with People with Profound Intellectual Disabilities Using Brain Computer Interface

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## Abstract

People with profound Intellectual Disability (ID) have difficulties expressing their needs due to their limited communication skills. These skills are usually limited to gestures and vocalizations many of which so idiosyncratic that can only be interpreted correctly by their caregivers/parents often with a large gap between their interpretations. In this paper we explore the application of Brain Computer Interface (BCI) in designing a methodology to interpret the mental state of these individuals during interaction within their environment, focusing on the phenomenon of "surprise" in interaction. We report on our progress towards predicting the participants' reactions to expected and unexpected events by classifying their brain activities monitored by electroencephalography (EEG signals). This study takes a major step forward towards improving the communication skills with individuals with ID in particular with those outside their family circle.

## Keywords

Intellectual Disabilities, Brain Computer Interfaces, Communication Systems, EEG signals.

**Introduction**

People with ID comprise a wide range of individuals with different cognitive abilities and while there are great individual differences, they can be categorized based on their communication skills. Introduced by McLean et al. and widely shared in the literature (James McLean and Lee Snyder-McLean) this population is categorized to the following three groups: *perlocutionary, Illocutionary* and *locutionary communicators.* Perlocutionary communicators are the individuals that do not intentionally signal other people but their intentional behavior has a meaning being interpreted by their parents and caregivers. Illocutionary communicators express a communicative intent by using different nonverbal forms of behaviors such as gestures and vocalization and *locutionary communicators* are able to use symbols to communicate their intentions and needs. These individuals use many idiosyncratic gestures and vocalization, which cannot be easily ruled out as unintentional (Iacono, Carter and Hook). Number of studies explored the modalities and functions of such behaviors that can be considered communication attempts but there are still ongoing researches on the issue of defining and recognizing intentionality in behavior and communication (Brady et al.; Carter and Iacono; Ogletree, Wetherby and Westling; Wetherby et al.; McLean et al.).

Several augmentative and alternative communication systems are designed to help the ID population communicate better (Ogletree et al.; Romski and Sevcik; Hourcade et al.). Figure 1 shows a typical communication system where a subjects' behavior is being observed and interpreted by the facilitator and then responded appropriately. These methods can be roughly divided to aided and unaided systems. One core principle of the intervention systems for perlocutionary communicators is to try to interpret the idiosyncratic behaviors as potential communication attempts and respond to it until those behaviors are being intentionally generated by the communicator to create the same response (Ogletree et al.; McLean et al.). Another core principle is to practice routines and then introduce unexpected changes in the routine to see the individual's reaction and provide opportunities for initiating a communication attempt. These methods rely heavily on the caregivers' and therapists' interpretation of the ID population behavior. Caregivers have to be attuned to correctly interpret the unconventional gestures and vocalizations and respond to it appropriately, given the multiple possible interpretations (Carter and Iacono) it is valuable to reduce the risk of mistaken interpretations.

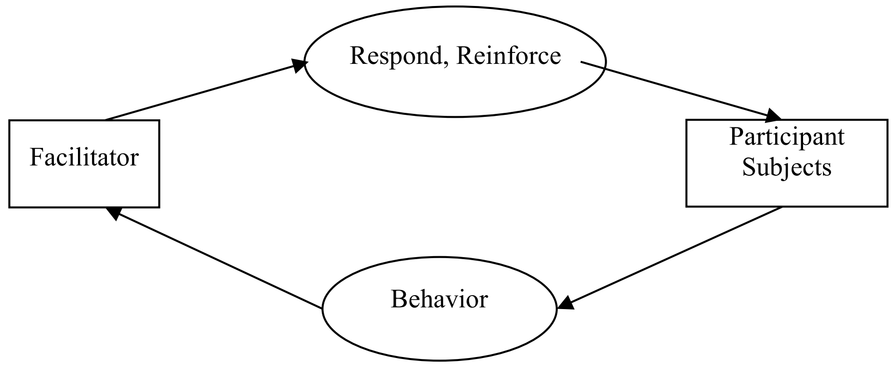


Fig. 1. Communication System.

Therefore, the focus of this study is to gain better understandings of the intentions of perlocutionary communicators by directly using their brain activations to identify the markers that signal intentional state during an interaction. We focus on “surprise”, when one side observes an unexpected event. With cognitively typical individuals, one can recognize the behavioral correlates of mental state of surprise in their reaction; but with person with ID, idiosyncrasy of the behavior would hinder the correct interpretation their behavior and mental state. In addition, one would not know whether the practiced routines of teaching (e.g. symbolic communications) are actually working, if we cannot after all test, whether what follows after the subject points to some symbols is expected from their point of views.

Electrophysiological measures have been widely used and studied for individuals with ID, mainly for the purpose of medical diagnosis and treatments (Boyd, Harden and Patton). Many studies have also explored the EEG correlates of development of cognitive skills in young typical and atypical toddlers (Mundy, Card and Fox; Henderson et al.). Our study takes a different route and explores the effectiveness and usability of Brain Computer Interface (BCI) methods in communication with people with severe to profound ID using interactive environment and activities to record EEG signals corresponding to perceiving unexpected events in different situations. We train the classifiers based on recorded data to predict the moments that the person is surprised during interaction in order to show that using the classifiers to detect surprise would help the caregivers to better communicate with the individual with ID.

## Case Report

The participant of the study was a 20 years old female diagnosed with Angelman Syndrome (AS). AS is a neuro-genetic disorder characterized by Severe/Profound Mental Retardation and epileptic seizures. AS was first recognized by Harry Angelman and is believed to be caused by the lack of maternal copy of the UBE-3A gene expression on chromosome 15 (Kishino, Lalande and Wagstaff) and is associated with unique behavioral and physical features (Dan). Some of these features present in our subject are profound mental disabilities, lack of speech, sialorrhea, hyperactivity, puppet-like gait, etc. She does not seem to have visual impairment and her motor skills are not perfect but good enough that she can reach and grab even very small objects (i.e. peanut) after few attempts. She has been (with some AAC intervention) taught to use a communication device called TANGO, but from our observation she was not able to use that device at all. She more likely sees the devices as a toy or an interesting/colorful box but she does not use it in any purposeful way. We believe that she cannot communicate intentionally although she makes many gestures and vocalizations that one cannot confidently rule out as not having communicative intents so we conclude that she is a higher functioning perlocutionary communicator.

## Method

In this study, we have used the Emotiv Epoch EEG headset. It has 14 channels with the international 10-20 system placement (See Fig. 2). Given the condition of our participant, wireless connection and relatively easy setup were the main reasons for selecting this EEG headset. We conducted our experiments in a classroom setting where only the participant, authors and support specialist were present in the room.

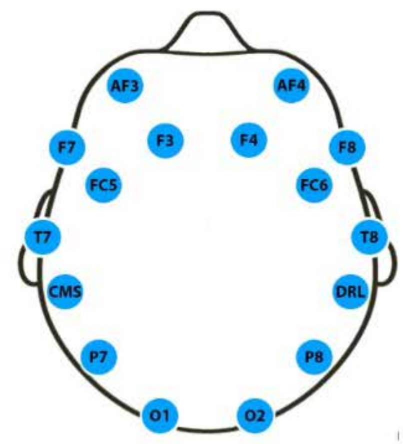


Fig. 2. Electrode placement on the scalp in EEG headset.

*Brain-Computer Interface*

"A brain computer interface (BCI) is a communication system in which messages or commands to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles" (Wolpaw et al.). So BCI systems have been developed to enable the users to control and communicate directly by controlling their brain activities when they cannot do it using brain's normal output pathways. Most BCI systems are based on variety of different electrophysiological signals such as Mu rhythm, P300 potentials and slow cortical potentials (Wolpaw et al.). Fig. 2 shows a schematic of a BCI system where EEG signals are processed for a specific BCI application. An important component of BCI systems, also shown in Figure 3, is the feedback of the system to the user. It means that both the user and the BCI should continually adapt to each other to guarantee a reasonable performance.

But the fact that the users must learn to intentionally manipulate their brain waves, with the purpose of communicating with their environment hampers the usability of these devices for people with ID. Our application needs a BCI system such that it does not require subject training and allows online detection of subject's mental state (Krusienski et al.). Our study follows the recent work on online predicting of mental state without subject training by (Wang, Guan and Zhang). In that study, participants were presented a sequence of portraits and the authors proposed a model to predict from the EEG signals if the person is looking at a familiar face (rare event) in a sequence of mostly unknown faces (prevalent event). Our approach includes predicting from the EEG recordings of the subject's brain, if in a routine of expected events, a situation is unexpected. We report the usability and efficiency of our method after formulating the problem in a form of machine learning classifier model and the communicative behavior of our subject.

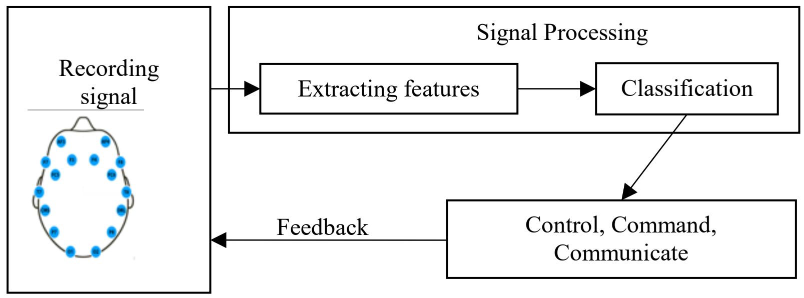


Fig. 3. Brain Computer interface.

*Expected vs. Unexpected Events*

Every time our subject heard the sound of the bag of snacks, she immediately moved her attention to where the sound came from; she got excited and started to salivate. So it was evident that she knew the sound and associated it with the coming snack (or a joyful experience). This is an example of expected and unexpected that has a very clear and obvious behavioral correlates. She expected to get a snack after hearing that sound or seeing the snack bag. But what if we give her a not very interesting toy? Would she ignore the toy because in this case the power of pursuing the goal is very strong?

One of the common communication interventions is to work with simple boards with two switches, where they get different rewards for pressing different buttons. The purpose of such interventions could be teaching cause and effect. But what we have not seen in the literature is methodologies to verify if these causal relationships are actually being learnt.  We are using the notion of *Expected vs. Unexpected* to explore a practical example of such methodology, we call "expected" and "unexpected" to be two states of mind. Figure 4 shows how we modified the model shown in figure 1. Now the facilitator has access not only to the behavior but also to the estimated mental state of the subject.

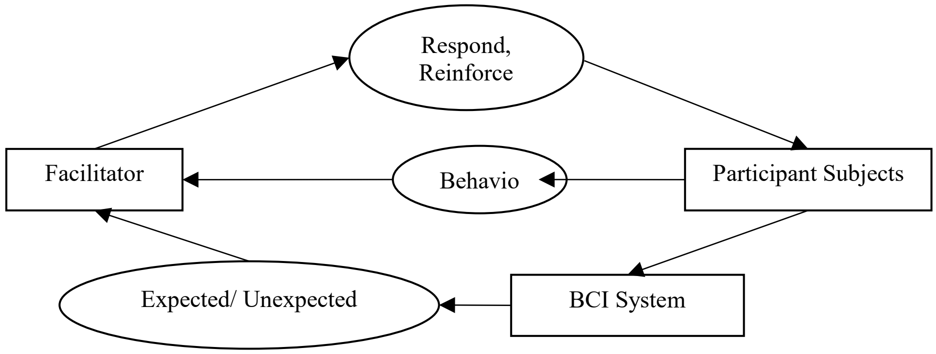


Fig. 4. Improved communication system using BCI system.

## Results

In this study we have used a machine learning classification approach to map a set of inputs to a discrete set of classes. The inputs are the EEG signals from 14 channels and the two outputs classes are the expected and unexpected states/situations. We aim to predict at an instance during interaction if the subject is observing expected or unexpected event by using a training data set consisting of a set of EEG signals and the corresponding labels (e.g. expected and unexpected). We have used the classification method proposed in Lage-Castellanose et al. study (Lage-Castellanos et al.; Blankertz et al.). Due to The highly noisy signal from EEG, a low pass filter was applied on input signals prior to segmenting the EEG signals to 300 ms windows to extract the features from the raw EEG data using fast fourier transformation (Polat and Güneş). By using those features, we trained support vector machines classifier for two output classes consisting "expected" and "unexpected" (Krusienski et al.; Wang, Guan and Zhang).

For training and validating of the model, we created a training set consisting of several input signal-label pairs. To create this set, we considered only those activities that the behavioral correlates of unexpected situations are very visible in them (for example the snack bag task discussed earlier) to distinguish two outputs with confidence. We created a training set of size 80; 55 expected and 25 unexpected events and used cross validation to test the algorithm. Our model was able to predict the mental state in 69 % of the cases, which is much higher than the chance level cases.

**Table 1. The reported benefit of the new communication framework.**

| | ***Session 1*** | ***Session 2*** | ***Session 3*** |
|---|---|---|---|
| *Facilitator 1* | 1.5 | 1.7 | 2 |
| *Facilitator 2* | 1.7 | 2.1 | 2.2 |

In the next step, we performed the evaluation of the algorithm in a real-time communication setting as shown in figure 4, where a facilitator observes both the behavior and the models estimate of the subject's mental state while engaging in an interaction. Two facilitators worked three sessions of 20 minutes with the subject in this setting. We asked the facilitators to report on a scale how much they thought the new setting helped their interaction with the participant (1:no help to 3: significant help). Table 1 shows that employing the BCI system provided more information about the mental state of the subject, to the facilitators and they found that knowledge helpful.

## Discussion and Conclusion

The goal of this study was to explore BCI techniques to facilitate communication between individuals with ID and others, as it would increase the independent living of these individuals. Vos et al. proposed a method to interpret the well-beings and emotional state of persons with ID using some physiological measures such as heart rate and breathing time. The person with ID is not aware or conscious that their well-being or mental state is being read using another device but the bottom line is that they are becoming more independent of their caregivers/parents as the only people that can read their inner states. It would also give them an opportunity to communicate with more people whom they do not know very well so they can generalize their communication skills.

In this paper we have discussed that Brain Computer Interface (BCI) can be a great area to explore for designing new communication systems for people with ID. Subject of our study was an individual with very limited capabilities in expressing her needs and feelings intentionally. Given the prevalence of idiosyncrasy in this population, we have discussed the need for communication devices that can help to estimate the intentions/mental state without using the behavioral correlates. An EEG based BCI model was presented for predicting the instances that the participant observes or experiences surprising or unexpected instances. Our model performed well when predicting these instances that supports our claim on how it can be used in communication intervention settings to inform the facilitator the subject's mental state. Future works will try to improve the performance of the model by exploring different classification and feature extractions algorithms as new algorithms are being proposed. Also considering other common and informative mental states would be a very interesting direction for future works.

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# Innovative Affordances for Blind Smartphone Users: A Qualitative Study

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## Abstract

Blindness imposes various functional limitations on the blind and visually impaired (BVI) individuals. Anecdotal evidence suggests that BVI use their smartphones in various innovative ways to overcome those limitations. We conduct a qualitative field study with three BVI participants to understand how they use their smartphones to overcome their functional limitations in the personal and professional contexts. We use the lens of theory of affordances to analysis the BVI participants' use of smartphones. Affordances emerge from the contextually situated interaction between users and technologies to achieve specific objectives. Our analysis reveals many meaningful affordances which can be systematically incorporated in the smartphone design to enable BVI to overcome some of their functional limitations.

## Keywords

Affordances, smartphone, assistive technology, blindness.

## Introduction

Many visual impairments have specific effects on the blind and visually impaired (BVI) individuals and impose various functional limitations on them (Machell). Functional limitations are defined as significant limitations in accomplishing one or more everyday tasks in both personal and professional contexts. such limitations range from difficulties in completing personal tasks such as exchanging cash on a shop counter (Bikson and Bikson) to difficulties in completing professional tasks such as filling up online forms (Theofanos and Redish). Assistive technologies (AT) are the technologies which assist BVI to overcome those functional limitations. Advancements in smartphones have profoundly impacted the quality and kind of the AT available to BVI (AFB) offering considerable potential to promote independence and participation of BVI. Extant research focuses on improving the smartphone accessibility and usability through designing newer AT or through studying BVI smartphone users' accessibility and usability challenges such as difficulty in acquiring touchscreen targets (Oliveira et al.), lower accuracy of gesture recognition (Kane et al.), difficulty in use of gestures (McGookin et al.), and the accessibility and usability challenges in interacting with iPhone using VoiceOver screen reader (Leporini et al.) etc. Research has designed various smartphone-based AT to help BVI complete a few specific personal and professional tasks such as navigating in-door/out-door (Makino et al.; Gallagher et al.; Murali and Coughlan), identifying and matching clothes (Burton et al.; Paisios, Rubinsteyn, and Subramanian), shopping independently (Kulyukin and Kutiyanawala), recognizing currency bills (Paisios, Rubinsteyn, Vyas, et al.), and safely exchanging cash (Paisios, Rubinsteyn, and Subramanian) etc. Such solutions utilize one or more affordances which emerge through BVI users' smartphone interactions. Affordances result from the contextually situated interaction between users and technologies to achieve specific objectives. Anecdotal evidence suggests that BVI take an advantage of such affordances in various innovative ways to overcome numerous functional limitations. However, as per our knowledge, no research till date, has attempted to identify the innovative affordances produced through BVI users' smartphone interactions. Consequently, we do not yet know the potential affordances produced through BVI users' smartphone interactions. Without that knowledge, our endeavors remain confined to designing smartphone-based solutions to enable BVI to successfully complete a few specific tasks instead of improving the overall smartphone design to facilitate the creation of various meaningful affordances to enable BVI to overcome functional limitations they face. As a first step, we ask, “what are the various affordances which are produced through BVI users’ smartphone interactions?” in this paper, we present the results of a qualitative field study eliciting various innovative affordances which were produced through BVI participants’ iPhone interactions in the personal and professional contexts.

## Methodology

We conducted a qualitative field study with three BVI participants (P1, P2, and P3). All three participants were adult, English-speaking, expert iPhone users working at the Industries of the Blind- Greensboro North Carolina. P1 and P2 were completely blind and worked in manufacturing function. P3 was partly sighted and worked in human resources function. We requested the participants to describe the personal and professional situations where they use an iPhone to overcome various functional limitations. We engaged in a free-flowing conversation with the participants individually. Each interview was thirty to forty minutes long. We audio-recorded the interviews and subsequently transcribed the recordings for interpretive analysis. The interviews are described below.

### *Participant P1:*

P1 narrated a situation when she wanted to find out what were her options for cooking. She was required to read the labels printed on multiple boxes in her refrigerator. She used the TapTapSee app. The app allows its user to take a picture, and then it transmits the picture to a remote human assistant. Within a minute, the assistant relays back the text describing the picture. Earlier, when she did not know about TapTapSee, she relied on various cues such as size of the box, weight of the box, and her memory to draw a probabilistic inference which often resulted into “refrigerator surprises." Now, the app enables her to avoid refrigerator surprises. P1 used that app also as a mirror to check her appearance before going to work. P1 used the WalkingGPS, a GPS navigation app, to navigate in outdoor spaces. The app could inform her about the obstacles on her way and her distance from those obstacles. Which enabled her to navigate safely and effectively in outdoor spaces. However, she did not find the app useful for indoor navigation. P1 used the KNFB reader, an optical character recognition app, to read the machine operation instructions painted on the machine. P1 used the Digit-Eyes, a QR code and barcode reader app, to label and identify her clothes at home. P1 used the ColorIdentifier, a color recognition app, to match the colors of the clothes before wearing them. P1 narrated a situation when she was left alone in a large hall and was trying to find the way out. She used the LightDetector, an app which can sense the ambient light, to figure out the direction of the doorway.

*Participant P2:*

P2 told us that she had used the TapTapSee app to read the numbers on her credit card. P2 used that app to see if the room floor was clear so that she could safely roll the vacuum cleaner. She also used that app to read the labels on the raw material boxes at work. At work, P2 used ColorIdentifier app to identify the colors of fabric and threads so that she could ensure that the thread color matches the fabric color while stitching the garments. P2 used the LightDetector app to determine if any lights in her home were left on by chance. She could thus avoid the wastage of energy.

*Participant P3:*

P3 told us that she had used the CamFind app, an app similar to the TapTapSee app, to monitor the visual appearance of a food item to ensure that the item was sufficiently baked. She mentioned that she took pictures of the food item at regular intervals to monitor the visual appearance of the item. P3 used the Digit-Eyes app to label and identify documents at home as well as at work. P3 used that app also to identify various products while shopping at a store. P3 used the KNFB reader app to read printed documents and notice boards at work. P3 worked into the HR function. Which required her to read many printed documents to successfully perform her job. She relishes the sense of independence the app gives her while performing her job.

## Analysis and Findings

Using the theory of affordances as a theoretical lens, we conducted an interpretive analysis of the BVI users' smartphone interactions to complete various task. In an effort to explain how animals perceive their environments, James Gibson (Gibson) a perceptual psychologist, suggested that surfaces and objects offered certain affordances for action. For example, if a terrestrial surface is nearly horizontal, nearly flat, sufficiently extended, and if its substance is rigid then the surface affords support. It is stand-able, permitting an upright posture for quadrupeds and bipeds. It is important to note that the four properties (horizontal, flat, extended, and rigid) would be physical properties of a surface if they were measured with scales and standard units used in physics. As an affordance of support for a species of animal, however, they need to be measured relative to the animal. Essentially, they are unique for that animal owing to the unique capabilities of that animal which allow the animal to take the advantage of the object properties to stand or walk on the support. Thus the affordance is realized only through the interactions between relevant capabilities of an animal and the capabilities/properties of its environment. Therefore, the concept of affordance is useful in explaining why human and material agencies become imbricated: Technologies have material properties, but those material properties afford different possibilities for action based on the contexts in which they are used.

We identified BVI user capabilities, technology properties/capabilities, the context in which the interaction took place, and the action potential/affordance that was produced through each interaction. The following table shows the results of our analysis.

**Table 1. Affordances Indentified.**

| Relevant iPhone App | Technology capabilities/Properties | Users' Action Capability | Context | Affordance produced |
|---|---|---|---|---|
| TapTapSee/ CamFind | To capture a picture, to transmit the picture to a remote human assistant, and to announce the text description relayed by the human assistant. | To click a picture of the desired object | Work | Read the printed labels on packs of raw material. |
| TapTapSee/ CamFind | To capture a picture, to transmit the picture to a remote human assistant, and to announce the text description relayed by the human assistant. | To click a picture of the desired object | Home | Avoid refrigerator surprises, check the appearance of food item during cooking, read the numbers on credit cards, check the status of the room floor, see oneself. |
| Walking GPS | To capture the user's location by utilizing the global positioning system. | To orient oneself in a desired direction, to walk. | Work | To commute safely to/from workplace. |
| Walking GPS | To capture the user's location by utilizing the global positioning system. | To orient oneself in a desired direction, to walk. | Home | Not applicable |
| Light Detector | To sense the variation in the surrounding light intensity, to play sounds of varied intensity | To perceive variations in sound intensity that indicate light intensity | Work | Find a doorway. |
| Light Detector | To sense the variation in the surrounding light intensity, to play sounds of varied intensity | To perceive variations in sound intensity that indicate light intensity | Home | Avoid wastage of energy. |
| Color Identifier | To determine the color of an object facing the camera | To focus the camera on the desired part of an object, to stitch. | Work | Stich the garments with the right color thread. |

| **Relevant iPhone App** | **Technology capabilities/Properties** | **Users' Action Capability** | **Context** | **Affordance produced** |
|---|---|---|---|---|
| Color Identifier | To determine the color of an object facing the camera | To focus the camera on the desired part of an object. | Home | Match the pair of clothes |
| Digit-Eyes | To scan a barcode/qr code, to store and retrieve the text description associated with that particular code from its repositary, and to announce the description. | To focus the camera on the bar code/QR code on an object | Work | Label and identify documents. |
| Digit-Eyes | To scan a barcode/qr code, to store and retrieve the text description associated with that particular code from its repositary, and to announce the description. | To focus the camera on the bar code/QR code on an object | Home | Label and identify documents, label and identify clothes, identify desired products while shopping. |
| KNFB Reader | To capture a picture, to detect iPhone's alignment with the text to be read, to extract the text from an image using Optical character recognition, and to convert digital text to digital speech. | To click a picture of the desired text | Work | Read printed documents, read notice boards, read machine operation instructions. |
| KNFB Reader | To capture a picture, to detect iPhone's alignment with the text to be read, to extract the text from an image using Optical character recognition, and to convert digital text to digital speech. | To click a picture of the desired text | Home | Read printed documents. |

**Discussion**

Our findings show that all three participants took an advantage of various apps on their iPhones to overcome their functional limitations. In the case of TapTapSee/CamFind, an iPhone is capable of capturing a picture, of transmitting a picture to a remote human assistant, and of announcing the text description relayed by that human assistant. The user, on the other hand, is capable of pointing the camera in a desired direction and of clicking a picture. At work, the interaction affords the user to read printed labels on the raw material boxes. At home, the interaction affords the user to avoid refrigerator surprises, to check the appearance of food item during cooking, to read the numbers on credit cards, to visually inspect the room floor, and to see oneself. In the case of WalkingGPS, an iPhone is capable of capturing the user's location by utilizing the global positioning system. The user, on the other hand, is capable of orienting herself in the desired direction and of walking according to the walking guidance provided by the app. At work, the interaction affords the user to commute to her workplace. At home, however, the interaction affords nothing. In the case of LightDetector, an iPhone is capable of sensing the variation in the surrounding light intensity and of informing its user of that variation by playing peculiar sounds of varied intensity. The user, on the other hand, is capable of perceiving the variations in the sound intensity, and of judging the direction of the light source and her distance from that light source. At work, the interaction affords the user to find a doorway. At home, the interaction affords the user to understand if the lights in her home are switched on or off to avoid the wastage of energy. In the case of ColorIdentifier, an iPhone is capable of determining the color of an object held in front of its camera. The user, on the other hand, is capable of pointing the camera in a desired direction. At work, the interaction affords the user to stich the garments with the right color thread. At home, the interaction affords the user to match the pair of clothes. In the case of Digit-Eyes, an iPhone is capable of scanning the barcode/QR code on an object, of storing and retrieving the text description associated with that particular barcode/QR code from its repository, and of announcing the retrieved description. The user, on the other hand, is capable of focusing the camera on the bar code/QR code on an object and of clicking a picture. At work, the interaction affords the user to label and identify documents. At home the interaction affords the user to label and identify documents, label and identify clothes, and to identify desired products while shopping. In the case of KNFBReader, an iPhone is capable of capturing a picture, of detecting its alignment with the text to be read, of extracting the text from an image using Optical character recognition, and of converting the digital text to the digital speech. The user, on the other hand, is capable of pointing the camera in a desired direction and of clicking a picture. At work, the interaction affords the user to read printed documents, to read notice boards, and to read machine operation instructions. At home the interaction affords the user to read printed documents.

## Conclusion

We conducted a qualitative field study with three BVI expert iPhone users to understand the innovative ways in which they used their iPhones to overcome various functional limitations they face due to their visual impairment. Using the theoretical lens of theory of affordances our analysis of the participants' iPhone interactions revealed various innovative affordances which can be produced through BVI users' interactions with their iPhones in various personal and professional contexts. Future research needs to identify ways to inform the smartphone design to systematically facilitate the creation of meaningful affordances for the BVI population in diverse personal and professional contexts.

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# Generating Nemeth Braille Output Sequences from Content MathML Markup

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## Abstract

The need for high-quality braille materials is one of the most challenging obstacles faced by visually-impaired students, especially for mathematical content. The need for visually-impaired students to communicate their work to sighted instructors often prevents them from participating in mainstream classrooms in STEM subjects. The goal of this current work is to provide a software system that supports the automatic generation of Nemeth Braille output in the context of a WYSIWYG equation editor designed for sighted math users. This software allows a sighted math user, who need not know Nemeth Braille, to produce high-quality braille materials for math in a fraction of the time, and at a fraction of the expense, of current best practices for print-to-braille translation. This software provides the basis for more immediate communication of mathematical content from sighted users to visually-impaired students, reducing communication barriers that inhibit visually-impaired students from participating in mainstream math and science classrooms.

## Keywords

Mathematical User Interfaces; Equation Editors; Nemeth Braille; Content MathML; Braille Translation Software.

## Introduction

The W3C Math Markup Language (Ion and Miner) has now been used for over fifteen years to represent structural forms (Content MathML) and print notations (Presentation MathML) for online mathematical expressions. Nemeth Braille (The Nemeth Braille Code for Mathematics and Science Notation) has now been used for over sixty years as a means to capture print math notation for tactile reading for low-vision and blind users. While Nemeth Braille has much in common with Presentation MathML in its intent to capture the appearance of print math notation, the design of its coding rules also shares much in common with Content MathML in its desire to preserve the structural form of the expressions it encodes.

Content MathML provides a common source representation that can be translated into multiple parallel output representations using an operator-based transformation rule framework to effect the translations (Dooley; 55-62). Using this framework, Content MathML can be transformed into Presentation MathML for print users, and can be transformed into Nemeth Braille for visually-impaired users, who may access the Braille output by means of refreshable braille devices or other tactile printing methods.

This framework enables the input from a sighted user to be displayed in a format that can be read by a visually-impaired user, where the simultaneous print and braille displays are updated upon receipt of each keystroke event.

## Discussion

The similarities in design between MathML markup and Nemeth Braille codes encourage a specific means to represent math expressions within a software system in a format that is accessible to both print and braille users. A single source representation (Content MathML) can be translated into multiple parallel output representations using an operator-based transformation rule framework to effect the translations (Dooley; 55-62). Using this framework, Content MathML can be transformed into Presentation MathML for print users, whether for online or offline use, and can be transformed into Nemeth Braille for visually-impaired users, who may access the braille output by means of refreshable braille devices or other tactile printing methods.

A large majority of the encoding rules for Nemeth Braille are purely structural in nature, and can be implemented in a straightforward fashion using the same transformation rule framework used to generate Presentation MathML. These rules include virtually all of the most common mathematical operators (signs of operation, comparison, and special symbols) as well as many that are beyond the scope of Content MathML (arrows, shapes, circled and squared operators), but that can be represented using extensions to Content MathML, and processed just as any other operator.

Other Nemeth encoding rules are more contextual in nature, and require more specialized techniques. Nested structure indicators for fractions (which require an additional indicator from the inside out) and radicals (which require an additional indicator from the outside in) can be supplied by a special routine to traverse the content expression tree to determine the number of indicators. A similar procedure is used to determine the proper encoding for nested combinations of superscripts and subscripts, and over scripts and under scripts. More specific procedures are needed to determine the circumstances dictating the use of spacing rules, numeric and alphabetic indicators, and the multipurpose indicator. These contextual rules are mostly limited in application, but serve the important role of distinguishing between similar braille sequences that code different expressions. While rules to encode combinations of textual and mathematical content are outside the scope of this work, as are encoding rules for spatial arrangements and tactile graphics, these forms also could be addressed within the current framework, albeit with considerably more effort.

The operator-based transformation rule framework, augmented by special techniques for contextual encoding rules, is sufficient to encode all of the mathematical content addressed by the Nemeth Braille rules, to a high degree of precision. This framework has been implemented as an extension to an existing equation editor for Content MathML markup (Dooley; 55-62) that is currently used in an assessment platform to collect constructed math responses to high-stakes assessment items. The Nemeth Braille extensions described here will be used to provide access to the online assessment platform for low-vision and blind users.

The testing regimen for the transformation from Content MathML to Nemeth Braille was accomplished by means of a special test page that embeds the equation editor, which generates the Presentation MathML and the Nemeth Braille encodings for a sequence of test cases, each of which are displayed on the page so the correspondence between the presentation forms can be verified by a sighted user. In addition, hand-generated alternate text for each test case is displayed and marked so it can be announced by a screen reader, and the braille encoding is marked so it may be displayed on a refreshable braille device. Using this test page, a blind tester was able to verify the correspondence between the hand-generated alternate text, and the machine-generated braille output, for 948 separate test cases, within two days, and provide specific feedback to improve the generated braille.

## Conclusions

As described in (Dooley; 55-62), operator-based transformations from Content MathML to Presentation MathML are well understood, and represent a specific case of the more general approach to the separation of structure and style found in other web languages. These transformations allow math content forms to be translated into any number of presentational forms, including Presentation MathML, and Nemeth Braille.

Further work on the operator-based transformation framework and the quality of the braille output it generates would include addressing a few remaining issues in the implementation of certain contextual rules, completing the list of known operators to include limits, derivatives, and integrals, and extending the framework to support markup for content that contains both literary and mathematical expressions.

As time goes on, more and more of the means and methods by which math and science are taught are being transformed into electronic and/or online forms. Online math instruction and assessment are now high-profile lines of business for major publishing companies and consortia, and are transforming education at all levels. Electronic textbooks and other materials are increasingly replacing paper-based alternatives, and teacher-student interactions are taking place using social media, online meeting rooms, and distance learning systems. As these transformations take place with increasing speed, the accessibility of these solutions lags behind due to the inherent difficulty of providing accessible math software in an online world. Online math software presents unique challenges that are not found in text-based software, further compounding the difficulty in making such software accessible. Moving forward, the need for access to online math content will override all other concerns related to the communication of mathematics. If visually-impaired students are to succeed in mathematics in the classroom at all grade levels, their participation needs to be fully online and fully interactive. By reducing the time and cost involved in braille translation, this work has the potential to produce a truly level playing field for visually-impaired students in mainstream STEM classrooms.

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The Journal on Technology and Persons with Disabilities

# Generating Content MathML Markup from Nemeth Braille Input Sequences

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## Abstract

The need for high-quality braille materials is one of the most challenging obstacles faced by visually-impaired students, especially for mathematical content. The need for visually-impaired students to communicate their work to sighted instructors often prevents them from participating in mainstream classrooms in STEM subjects. Backward translation from Nemeth Braille to print mathematics is a difficult and time-consuming process even for teachers of the visually impaired, who may not have an extensive understanding of the mathematical concepts underlying the notation. The goal of this current work is to provide a software system that supports the automatic backward translation of Nemeth Braille input, in the context of a WYSIWYG equation editor designed for sighted math users. This software allows a Nemeth Braille user who is unable to access the printed form of an equation to produce high-quality print mathematical formulas in a fraction of the time, and at a fraction of the expense, of current best practices for braille-to-print translation. This software provides the basis for more immediate communication of mathematical content from visually-impaired Nemeth Braille users to sighted instructors and peers, reducing communication barriers that inhibit visually-impaired students from participating in mainstream math and science classrooms.

## Keywords

Mathematical User Interfaces; Equation Editors; Nemeth Braille; Content MathML; Braille Translation Software.

## Introduction

The W3C Math Markup Language has now been used for over fifteen years to represent structural forms (Content MathML) and print notations (Presentation MathML) for online mathematical expressions (Ion and Miner). Nemeth Braille has now been used for over sixty years as a means to capture print math notation for tactile reading for low-vision and blind users (The Nemeth Braille Code for Mathematics and Science Notation). While Nemeth Braille has much in common with Presentation MathML in its intent to capture the appearance of print math notation, the design of its coding rules shares in common with Content MathML its desire to preserve the structural form of the expressions it encodes.

Content MathML provides a common target representation that can be created by keyboard input events using a key event-based transformation rule framework to effect the construction of mathematical expressions (Dooley, 55-62). Using this framework, input key event sequences from a braille keyboard may be used to invoke input transformation rules to create, delete, and/or modify a current expression in a manner that simulates Nemeth Braille mathematical expression entry, but which creates Content MathML expressions as the output of the keying process. In this fashion, a common framework may be used to create Content MathML using a QWERTY keyboard for sighted users, and using a braille keyboard for visually-impaired users.

This framework enables the input from a sighted user to be displayed in a format that can be read by a visually-impaired user, and vice versa, where the simultaneous print and braille displays are updated upon receipt of each keystroke event, regardless of the type of keyboard used to produce the event.

**Discussion**

As described in Dooley, key-based transformations that modify one Content MathML expression to create a new Content MathML expression may be used to allow a QWERTY keyboard to create mathematical structures. These rules allow an equation editor to create, on each keystroke, the Content MathML markup that corresponds to the user's input. The Content MathML can then be transformed into Presentation MathML for print users, whether for online or offline use, and can be transformed into Nemeth Braille for visually-impaired users (Dooley and Park), who may access the braille output by means of refreshable braille devices or other tactile printing methods.

The input events generated by a braille terminal typically encode six- or eight-dot braille cells in ASCII braille, which allows each braille dot pattern to be treated as if it were a single character input event. These input events are transmitted from the hardware, via the user's screen reader software, to the equation editor. Then the same key-based transformation framework used to interpret key events from a QWERTY keyboard can be used to interpret braille events from a braille terminal.

For a large majority of the input rules for a QWERTY keyboard, one key event is enough to effect an immediate transformation in the current expression. In a similar fashion, a single braille cell that represents a specific symbol can be immediately encoded to create that symbol in the equation editor. Other Nemeth Braille encoding rules consist of sequences of braille cells that cannot be distinguished from each other by a single initial cell. As a result, the transformation rule framework for expression entry is augmented by a finite-state machine to track the state of the current input sequence while waiting until the end of the sequence to effect a transformation in the current expression. The finite state machine uses named input states to describe input sequences. As a simple example, a QWERTY keyboard produces a capital "A" using a single keyboard event, while a braille keyboard requires two cells (dot-6 dot-1) before the capital A can be added to the expression.

The finite-state machine is sufficient to encode rules that support the use of the numeric indicator (dots-3456) for the input of numbers, while allowing the numeric indicator to be omitted in situations where the following numerals are unambiguous. The baseline indicator is supported for moving outside the scope of subscripts and superscripts, which is more natural concept for a braille user than the use of arrow keys for a visual user. Type form indicators for Greek upper-case and lower-case letters (including alternate forms), and script and Fraktur upper-case and lower-case letters are also implemented as special input states invoked by the natural braille cell sequences used to encode these characters.

More complicated examples of the use of the finite-state machine involve input sequences for shape indicators, negated operators, and composed relations. In some cases, one valid input sequence may be contained as a prefix to a longer input sequence for a different operator. For example, the input sequence for the less-than operator (dot-5 dots-13) may be extended by the horizontal bar character (dots-156) to form the less-than-or-equal operator. In these cases, the equation editor effects the input rule to create the less-than operator after receiving the first two cells, then replaces it with the less-than-or equal-operator after receiving the horizontal bar.

The input-rule transformation framework to create Content MathML from Nemeth Braille input has been implemented as a special browser test page that embeds the equation editor (Dooly), which receives key events from the QWERTY keyboard for visual users, and braille cell events encoded as ASCII braille from a refreshable braille device for visually-impaired users. The braille cells are received from the braille device via screen reader device drivers that deliver the input events to the equation editor embedded as a JavaScript component in a browser. Through this arrangement, a visually-impaired user can input math on the braille keyboard, and a sighted user can input math on the QWERTY keyboard, and both input streams can be directed to the same instance of the equation editor. A special input mode switch is used to communicate to the equation editor which keyboard is being used so it can apply the appropriate input transformation rules.

## Conclusions

As described in Dooley, key-based transformations from named key events into Content MathML are well understood, and represent a specific case of a more general approach to the separation of application structure from user interface behaviors. These transformations allow math content forms to be created from many kinds of input events, including QWERTY key events as is done in other equation editors, and Nemeth Braille input cells, as described here.

Further work on the operator-based transformation framework and the fidelity of the Nemeth Braille input encoding it accepts would include addressing a few remaining issues in the implementation of certain contextual input rules for certain math operators, completing the list of known operators to include limits, derivatives, and integrals, and extending the framework to support markup for content that includes both literary and mathematical expressions.

As time goes on, more and more of the means and methods by which math and science are taught are being transformed into electronic and/or online forms. Online math instruction and assessment are now high-profile lines of business for major publishing companies and consortia, and are transforming education at all levels. Electronic textbooks and other materials are increasingly replacing paper-based alternatives, and teacher-student interactions are taking place using social media, online meeting rooms, and distance learning systems. As these transformations take place with increasing speed, the accessibility of these solutions lags behind due to the inherent difficulty of providing accessible math software in an online world. Online math software presents unique challenges that are not found in text-based software, further compounding the difficulty in making such software accessible. Moving forward, the need for access to online math content will override all other concerns related to the communication of mathematics. If visually-impaired students are to succeed in mathematics in the classroom at all grade levels, their participation needs to be fully online and fully interactive. By reducing the time and cost involved in braille translation, this work has the potential to produce a truly level playing field for visually-impaired students in mainstream STEM classrooms.

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The Journal on Technology and Persons with Disabilities

# New Accessibility Features in MathJax

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## Abstract

Recent changes in the landscape for assistive technology solutions for Mathematics on the web have prompted the development of MathJax into a single rendering and accessibility solution. We present our current efforts that depend on a novel semantic interpretation of Presentation MathML expressions. This allows us to introduce a new notion of responsive equations, on which we build advanced accessibility features with improved reflow of content, selective highlighting, and dynamic speech text generation, as well as an innovative interaction technique based on abstracting and intelligently summarizing sub-expressions.

## Keywords

STEM Accessibility, Mathematics, MathJax

## Introduction

The text-to-speech translation of mathematical expressions has always been a challenging problem and is one major obstacle for fully inclusive education. Consequently, a number of software solutions have been researched over the years (see Karshmer, Gupta, and Pontelli (664-669) for an overview). As web delivery grows, web-accessibility for mathematics is more important than ever. Although Mathematical formulas on the web can be represented in their own specialized markup language, MathML (Carlisle, Ion, and Miner), as part of the HTML5 standard (W3C), only very few major browsers implement MathML rendering natively. Consequently MathJax (MathJax Consortium) a JavaScript library for rendering Mathematics in any browser, has become a quasi-standard for displaying Mathematics on the web.

Accessibility features have been a core functionality of MathJax since its inception. But while in 2010, this meant MathPlayer (Soiffer, 205-206) compatibility, zoom, magnification, and copy&paste features, today we find ourselves in a very different assistive technology (AT) landscape for mathematics. MathPlayer has been forced into becoming a secondary library, while general screen readers like ChromeVox (Sorge, Chen, Raman, and Tseng) and VoiceOver (Apple VoiceOver) have implemented (partial) support for MathML. Nevertheless the core problem persists: browser vendors continue to show little interest in implementing MathML natively, thus damaging accessibility on a fundamental level for all non-blind users. At the same time, MathML rendering solutions on the web, such as SVG or HTML/CSS converters, cannot rely on web standards such as ARIA to provide intermediary solutions.

To overcome the challenges of this changed landscape, we have developed some advanced accessibility features for MathJax. At the core of this work lies a procedure for the semantic interpretation and enrichment of presentation MathML that is based on the speech rule engine originally implemented as part of ChromeVox's open-source technology and that also drives the Benetech/MathMLCloud project. The semantic interpretation not only improves the structure of the presentational content, but also allows us to implement advanced accessibility features, which include the following:

10. Improved reflow of expressions for better support of small screens and magnification.
11. Structural abstraction of meaningful sub-formulas together with their interactive exploration and synchronized highlighting that can be helpful for dyslexic readers.

12. Direct generation of speech strings and their exposure to third party screen readers to allow for a uniform reading experience of mathematics for visual impaired users independent of platform or AT environment they use.

**Semantic Enrichment**

The semantic enrichment is a heuristic procedure that effectively constructs a term tree representing a mathematical expression by analyzing its presentation MathML elements, interpreting their type, role, and font, and turning them into semantic nodes with a parent pointer and a variable number of children. The core of the semantic information goes beyond Presentation MathML and identifies the underlying mathematical structure of an expression. It allows us to identify function applications, functional types, operator scope, limits etc., while aiming to stay faithful to the original notation, and not fixing too much of the semantics, which could lead to false interpretations. It consequently provides a much more shallow interpretation than a full-blown semantic markup language like Content MathML.

As an example, consider the quadratic equation $ax^2 + bx + c = 0$, which is syntactically, with the exception of the $x^2$, a linear sequence of single expressions, and is commonly written as such as in MathML, a single row with nine elements. The semantic interpretation will rewrite it into a tree where the top layer is an equality with two branches, where the right branch is 0, while the left branch itself is a tree representing a sum with three summands.

The heuristic approach both conservatively improves the original Presentation MathML input and extends it beyond presentational information. Consequently the semantic information can be embedded using HTML5-compliant data-* attributes. This provides flexibility for embedding the complete information while leveraging standard APIs to recover it for application developers. The resulting enhanced MathML is embedded in MathJax's internal format as well as its output so that other technologies can leverage the additional information while remaining backwards compatibility to any other MathML tool.

The conservative changes to the MathML source itself already improve the quality of the original source by fixing common authoring issues such as missing grouping or unbalanced fences. As an immediate improvement, the resulting MathML is easier to digest both visually and aurally, as well as for exploration via AT. It also improves basic reflow of mathematics by enabling line-breaking algorithms to better identify good breakpoints. This semantic enrichment is being leveraged in the new accessibility features we have developed.

**Responsive Equations**

The first application focuses on visual representation of mathematics on small screens. Responsive web design and progressive enhancements are the cornerstone of modern web design. For mathematics, however, reflow is extremely difficult as mathematical presentation is usually two-dimensional and predominantly table-oriented, especially as most mathematics is still primarily designed for print layout. To overcome this, we have developed a rendering mode that is fundamentally different from traditional layout. Leveraging the approach of (math) accessibility tools, this technique visually summarizes a math fragment rather than forcing iterated line breaks (which quickly destroy legibility on small screens). Instead, sub-expressions are collapsed into icon-like representations to fit the equation to the screen width. This approach leverages the semantic enhancement for identifying sub-expressions and estimating their size as well as for providing a suitable iconic representation that summarizes the collapsed sub-expression (e.g., we use + to indicate a sum, an integral symbol for a collapsed integral, etc.).

While initially hidden from view, thus not interfering with the reading flow and page layout for large text magnification or small screens, hidden sub-expressions can be manually expanded in an explorative fashion either by clicking the summary symbol with the mouse or alternatively using pinch and zoom gestures on touch-screen devices. Similarly, expressions can be collapsed by clicking on the relevant parts of a sub-expression.

As an example, consider the identity of Ramanujan in Fig.1, which describes a continued fraction. On the left we have the fully expanded version, while on the right is its maximally collapsed counterpart, where the product in the denominator on the left-hand side of the equation and the continued fraction on the right-hand side are hidden and abbreviated by a dot multiplication symbol and a fraction slash, respectively.

$$\frac{1}{\left(\sqrt{\phi\sqrt{5}-\phi}\right)e^{\frac{2}{5}\pi}} = 1 + \frac{e^{-2\pi}}{1+\frac{e^{-4\pi}}{1+\frac{e^{-6\pi}}{1+\frac{e^{-8\pi}}{1+\ldots}}}}$$

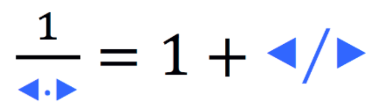

Fig. 1. A complicated expression and its maximally collapsed version.

**Structural Abstraction and Synchronized Highlighting**

Responsive equations also serve as a foundation for a new approach to assisting users with learning disabilities. Mathematical expressions are generally large collections of mostly unconnected symbols in two-dimensional layout and can therefore be particularly daunting for readers with dyslexia. MathJax provides support in particular aimed at dyslexic readers by:

1. Simplifying the structure of formulas using the collapsing technique described in the previous section.
2. Enabling interactive exploration of semantically relevant sub-expressions.
3. Providing synchronized, customizable highlighting for sub-expressions.

For this purpose we have implemented a web interface that allows users to explore the content using click, keyboard, or touch events. As opposed to the purely responsive equation approach, however, where the initial state of collapse of an equation depends on many, not necessarily user controlled, factors like screen size, page size, or zoom factor, this interface offers the user fine-grained control over the structural exploration of an expression.

Initially the structure of a formula is maximally simplified as demonstrated in Fig. 1 above and lets users individually explore the equation by manually expanding selected sub-expressions. The sub-expression elements are nested so that only the next level of the collapse is revealed, and the collapsed content is then identified by a mathematical symbol representing the semantic content of the underlying expression as before. The basic idea of this approach is to present a user with an outline of the formula, visually summarizing the most important components, and letting them choose time and order in which to dive deeper into an expression, thus avoiding the cognitive overload of having to deal with too many symbols at once.

As formula exploration can be done either by point and click or via the keyboard, we offer a number of highlighting options to further support readers with learning disabilities. For the former, we have two modes of highlighting: semantic components can be highlighted when hovering over them, thus also indicating that they can be further abstracted, or alternatively, all hierarchical composition of semantic sub-expressions can be shown by underlaying them with a background color of incrementally increasing intensity.

Keyboard-driven exploration is implemented using a simple navigation model that allows readers to select a formula and explore it using the arrow keys. We again exploit the semantically enriched structure by traversing sub-formulas in terms of semantic components rather than their syntactic structure. For example, when traversing the quadratic equation $ax^2 + bx + c = 0$, the first level would consist of three elements: the left-hand side of the equality, the equality sign, and 0. When diving into the left-hand side, the next level would consist of the three summands and their plus signs. During traversal, sub-expressions can be expanded or collapsed using the enter key. Visually, keyboard navigation is supported by synchronized highlighting of traversed expressions. All highlighting options are fully customizable, offering users choices of fore- and background colors, to combine their own preferred high-contrast colors, as research on optimal color selection for dyslexic readers is still inconclusive (see Rello and Baeza-Yates).

## Screen Reader Support

To aid readers who rely on screen reading technology, MathJax now also provides new accessibility features for voicing of mathematics, particularly aimed at visually impaired and blind users. While some screen readers already exploit MathJax's ability to expose MathML underlying a rendered mathematical formula to either voice mathematics directly (e.g., in the case of ChromeVox or VoiceOver), or by using a third-party library like MathPlayer (Soiffer, 205-206) for speech translation, users still have to depend on their screen reader's ability to understand MathML for mathematics support. In order to make users independent of a screen reader's math capabilities and to provide a platform independent, uniform user experience when reading mathematics, MathJax provides an aural rendering engine by exploiting the direct access to the speech rule engine that generates the semantic tree transformation in the first place.

This allows us to directly generate speech text, not only for the mathematical formula itself, but for all its component sub-expressions as well. MathJax offers options for text generation by currently providing two rule sets: MathSpeak (Nemeth) and the ChromeVox rule set (Sorge, Chen, Raman, and Tseng). Both have a choice of reading styles, pertaining mainly to their verbosity, for example, verbose, brief, and super-brief in the case of MathSpeak.

Generated text can be embedded either as alt-text, alongside the semantic data in the MathML and DOM structure via data attributes, or computed incrementally on the fly. Text is exposed to screen readers using ARIA technology, which allows us to integrate speech generation with the features we have already presented in this paper.

*Summarization*

The collapsing methodology used for visually responsive equations provides a natural basis for generating text summaries of mathematical formulas in lieu of their full description. These summaries can be presented more intelligently in speech. For example, a collapsed sub-expression that consists of a sum of four elements would only have a visual collapse indicating summation but can have an aural description of "Sum of four elements". As a consequence, summaries provide a quick overview of a formula or its parts and most importantly are generally considerably shorter than the full textual description.

*Continuous Reading*

Summarization is therefore the foundation for a unique MathJax feature to improve reading comprehension of full mathematical texts. As fully voicing even small formulas can be quite long-winded and time consuming, thus often distracting from the actual content of a publication, we exploit the summarization feature to provide an improved reading experience for mathematical documents. Instead of exposing the full mathematical formula to a screen reader, only the summary for the most collapsed version of that formula is exposed via an ARIA label.

For example, voicing the Ramanujan identity from before in MathSpeak's verbose mode leads to a string of 66 words (435 characters), whereas the corresponding summarized version is “StartFraction 1 Over collapsed product with 2 factors EndFraction equals 1 plus collapsed continued fraction”, a string with 15 words (108 characters). Even in superbrief mode, the full expression is 66 words (298 characters), while the summary is 12 words (80 characters), only.

This approach aims to emulate a casual reading style, in which a reader is more interested in getting the overview of the content of a publication and only will dive deeper into a particular expression if necessary or interested. This drastically reduces the time needed to skim through a publication using a screen reader.

### *In-depth Inspection*

Finally, a screen-reader user can still inspect each formula by engaging with it interactively. This is implemented via the previously explained exploration interface where speech strings for sub-expressions that the reader is traversing are computed and exposed to screen readers via ARIA Live regions. In addition, positional information of expressions is exposed, such as numerator, denominator, base, or superscript. Finally, the ability to collapse and expand certain sub-expressions lets a reader switch between summary descriptions and full verbose voicing for expressions on the fly.

## Conclusions

We have presented an AT extension that turns MathJax from a purely visual rendering library for mathematics on the web into a universal rendering solution. The accessibility features aim to provide a uniform user experience regardless of their choice of platform, browser, or screen reader, or indeed how the mathematics is rendered in a page. The extension is open source and freely available from github; it can be integrated directly by web authors, or is offered as an option in MathJax's context menu for users to select.

## Acknowledgements

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# Automatic Pre-Journey Indoor Map Generation Using AutoCAD Floor Plan

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## Abstract

Accessible maps are very useful for the visually impaired because they can learn maps and routes prior to their upcoming journeys. These maps are usually generated by an existing GIS database, e.g. Google Maps or ArcGIS, which are popular in outdoor environments. Though a pre-journey on an indoor map is useful and encourages the visually impaired to travel independently, the generation of accessible indoor maps still involves a lot of manual work, which makes pre-journey task inconvenient to the users. In this project, we propose a hybrid method to automatically generate indoor maps, from AutoCAD architecture floor plans, which are usually available for buildings made within three decades. Our approach extracts semantic information from AutoCAD files, e.g. location of rooms, exits, other landmarks, etc., which could help to further analyze the 2D floor plan images. It then generates both graph-based topological and traversable maps, which are useful for constructing accessible maps that can be used in pre-journey tasks. Experiments have been performed in an indoor facility to test the performance of the system.

## Keywords

Assistive Technology, AutoCAD, Accessible Map, Pre-Journey, Visually Impaired, Computer Vision.

## Introduction

Visually impaired people have a need for an easy way to navigate themselves in new indoor environments. Various efforts have been made to develop indoor navigation software for the visually impaired people (Fallah et al. 21-33, Ganz et al. 19, Zhang et al. 159–162), but many of them rely on other infrastructures or sensors and are also costly, therefore are not easy to scale up. As a supplementary solution, a pre-journey approach allows visually impaired people learn spatial environments or plan route priors to their travels. The solution only need accessible maps of the indoor facility, hence it's economic and effective (Ishikawa et al., 74–82). Accessible maps (Zeng and Weber 290–298, Kumar 1) are usually generated by an existing GIS database, e.g. Google Maps or ArcGIS, which are popular in outdoor environments. The generation of accessible indoor maps still involves some manual work and is a non-trivial task, therefore, automated process of accessible indoor map generation can ease the spatial knowledge acquisition and pre-journey task, and hence improve the life quality of the visually impaired. Such work can also be useful in the task of robot rescue or autonomous navigation in indoor environments.

In this paper, a hybrid algorithm is proposed to automatically convert an architectural floor map into an accessible indoor map, which eases pre-journey tasks to many visually impaired users. Fig. 1 shows the system work flow. Given an AutoCAD floor map, two output maps are generated using our proposed algorithm, where Fig. 1(a) shows the original AutoCAD floor plan. Fig. 1(b) is a topological map and it shows the geometric relations among different rooms in the building, which can be used to generate a navigation brief that provides a simple summary of a route and Fig. 1(c) is a 3D floor map that can be used to calculate turn-by-turn directions in pre-journey tasks. How the algorithm works is shown in Fig. 2: (1) the system reads an architectural floor plan (such as an AutoCAD file), extracts information of each entity (room, corridor and so on) and layers, and then stores them into a database; (2) an image-based analytics method is applied to extract each room's layout–entity polygon; (3) the system identifies the geometric relations between neighborhood rooms and corridors, which allows a topological graph of the entire building to be computed; (4) a 3D floor map and a traversable map are finally generated.

## Discussion

### *Related Work*

Many outdoor GPS-based accessible navigation systems are available, such as Ariadne GPS, BlindSquare and Sendero Seeing Eye GPS, which provide normal navigation features to blind users. However, none of them works in indoors since there is no accurate GPS signal available. Research shows that on average people spend around 87% of their time in indoor environments (Klepeis et al., 2001), hence indoor spatial knowledge acquisition plays a very important role to improve the quality of daily life of the visually impaired. In the last decade, researchers have been working on WiFi or Bluetooth-based navigation approaches, and a few public facilities have tested such approaches (e.g. SFO airport, The American Museum of Natural History). These approaches, however, usually require large-scale infrastructure changes and tedious sensor installations and calibrations procedures, thus making such kinds of requirements very costly and not easy to scale up.

Pre-journey learning is the process of learning spatial environment or plan travel route prior to an actual travel. The process helps cognitive map development and encourages visually impaired people travel independently (Ivanchev, Francis, and Ulrike 81-88; Meneghetti et al 165-178). Research (Ishikawa et al., 74–82) shows cognitive map development using a map can help people to understand the 3D space, and it’s even more effective than a navigation system, which only provides passive spatial learning.

Outdoor accessible map generation can be done by converting existing GIS database into accessible map, e.g. Google Map and ArcGIS. However, not many existing GIS indoor databases are available, and hence the generation of indoor accessible map still requires a lot of manual work. As such, automated process of accessible indoor map generation will be very useful to ease the development of pre-journey systems and help the visually impaired on spatial knowledge acquisition.

*System design and implementation*

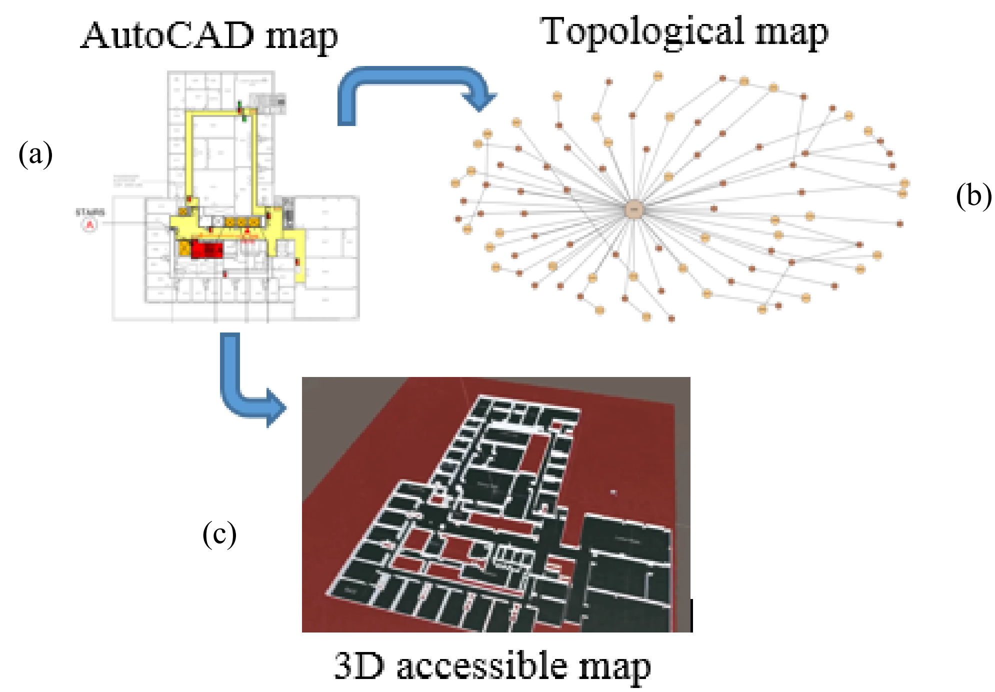



Fig. 1. The proposed system.

In this project, we aim to develop a system to automatically generate accessible maps of indoor facilities from architectural floor plans (such as AutoCAD files). The accessible maps comprises basic entity and layout of indoor environments. The entity includes the entrances and exits of the building and each floor (e.g. escalators, elevators and staircases), rooms, corridors and landmarks (restrooms, water fountain, information desks, public safety office, etc.) The layout includes the locations of entities and the geometric relations among different entities. In order to use the maps in the pre-journey tasks (Ivanchev, Francis, and Ulrike 81-88; Meneghetti et al 165-178), both the navigation brief and turn-by-turn navigation guidance are needed.

The turn-by-turn navigation can be calculated, with a 2D or 3D traversable map with each entity and its occupied region labeled in the image. In the traversable map, traversable and non-traversable area are labeled and the A* algorithm (Hart, Nils and Bertram, 100–107) is used to calculate an optimal route given both source and destination entity locations. Therefore, our system needs to automatically produce a traversable map.

The navigation brief includes a summary of the optimal route. For example, if an visually impaired person starts with the building entrance and plans to go to the Computer Science Department at F930, the brief only includes a list of entities on the route, for example, hallway, elevator, the 9th floor, and the room F930. Therefore, a topological map, a graph with the connection among neighborhood entities (as shown in Fig. 1), needs to be constructed. In the graph, a line (edge) connects two (entities) if they directly connected.

Each entity (rooms, corridors, exits and landmarks) is defined as a polygon in the image. An accessible image needs the label of each polygon in the image. Though the floor plan in AutoCAD is a vector image (e.g. lines, arcs and other simple geometric shapes), the entity polygons is not available. So the correspondences between the geometric shapes and the entities are unknown when the architectural floor map is drawn. Therefore, we first need to extract entity polygons from the AutoCAD file and then analyze the geometric relations among different entity polygons to build the topological map. Some simple computer vision algorithms are applied to complete the above tasks.

The proposed algorithm consists of four steps (as shown in Fig. 2):

- Parse the AutoCAD floor plan and extract useful layers and semantic information.
- Detect entities (e.g. rooms, corridors, exits and landmarks) using a region growing algorithm.
- Build geometric relations among different entities and construct a topological graph, with the entities as vertices and connections (doors or opening) as edges.
- Extract the contour of the entity polygons and build a 3D accessible map.

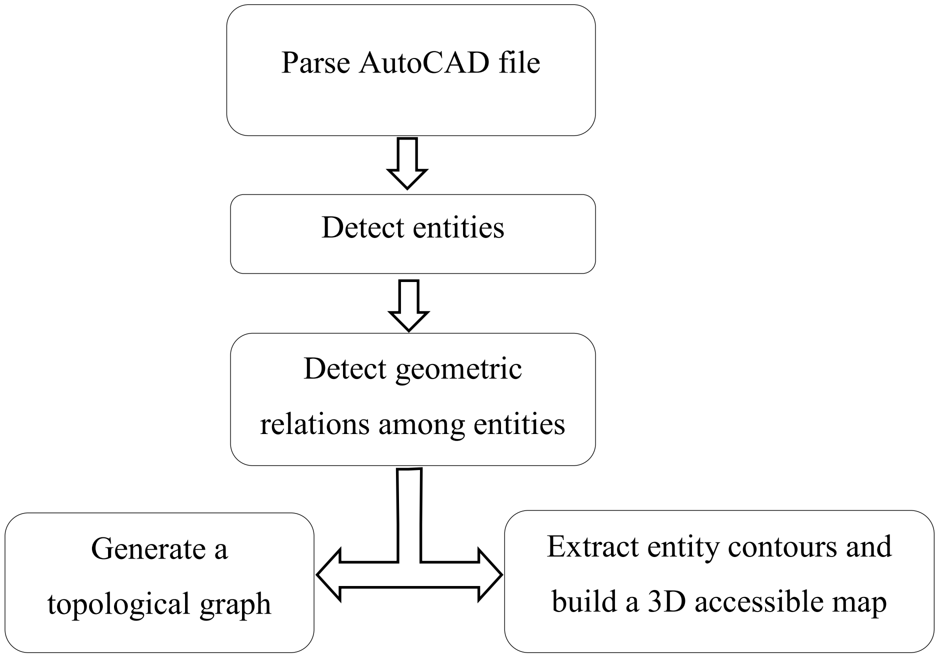
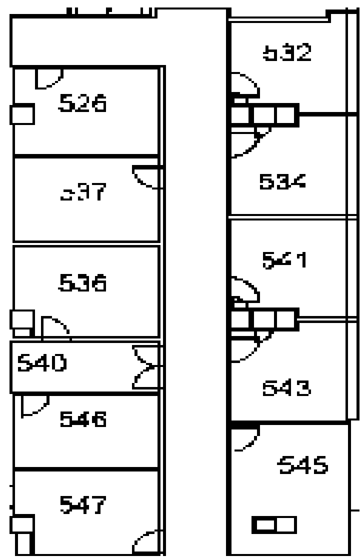



Fig. 2. The flowchart of the proposed algorithm.

We will discuss each step in the following subsections.

**Parse the AutoCAD floor plans and extract useful layers and semantic information.**

We first extract layers from a DXF file, based on the DXF specifications on the Autodesk website, for example, a layer is text annotations that includes the room numbers, and another layer provides the locations of room centers in the floor map. In addition, we extract semantic information from the AutoCAD file, which are the locations of entities, including rooms, exits, elevators, restrooms and some landmarks. All the above information are stored into a database. Note that some layers are not needed in the pre-journey task, for example, electricity map, which is therefore removed in this step.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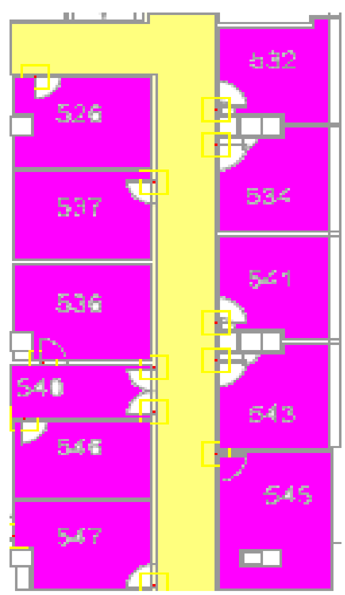
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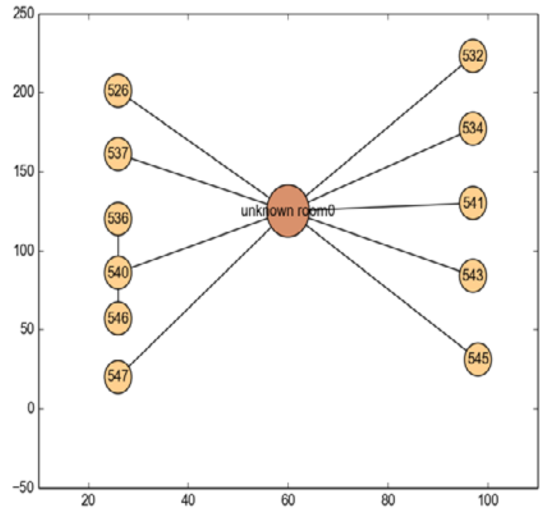
3(b)




3(c)

Fig. 3. Results of the region growing algorithm. (a) Small section of the original floor plan; (b) The result of region growing: purple area are pixels detected within each room; (c) The corresponding graph, where the "Unknown room0" is the corridor.

**Detect entities using a region growing algorithm.**

In the second step, we first render a floor image, as shown in Fig. 3(a) from the database. Note, only useful information is drawn, and all unnecessary information are not rendered in this image. We then create the entity polygons using a simple computer vision algorithm – region growing.

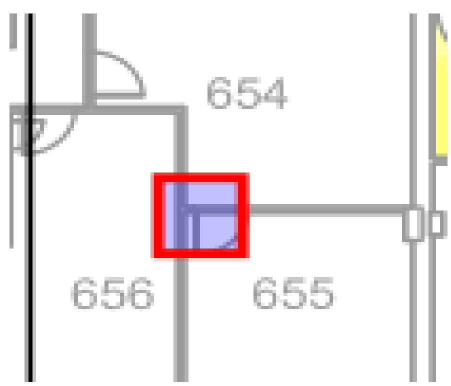
First the floor map image is converted into a binary image and wall partitions are drawn in black, and open space, such as rooms and corridors are empty, as shown in Fig. 3(a). Then we query semantic information obtained in the first step to obtain the entity number and centroid of an entity. Starting with the centroid, we apply a region growing approach (Rosen 798), to scan through the empty space in the entity and hence the image region of each entity is obtained. The process is repeated until all known entities (in the database) have been processed and the labeled entry is saved into the entity list.

Because some entities may not be available in the database, for example, corridors may not be identified in the database, they are still empty in the image. Then we can scan each pixel in the floor image. For any empty pixel, we run the same region growing method. We store the labeled entity into the entity list if its area is greater than a threshold (>50 sq. feet). The above process is repeated until there are no more empty area in the floor image. Fig. 3(b) shows the result after region growing is applied.

**Build geometric relations among different entities and construct a topological graph.**

In this step, the labeled entities are connected with neighborhood entities to build a topological graph. We first query the semantic information for the position of doors, since doors connect and separate rooms and corridors, and then we start to process and extract relationships between rooms and corridors. Note, the corridors are usually not marked in the AutoCAD files so we declare any open space connecting multiple rooms as a corridor.

A simple computer vision algorithm to identify the geometric relations between two entities works as follows. For each door position d (x, y) (Fig. 4(a)), we create a region of interest (ROI) (x - p, y - p, x + p, y + p) where p is the padding initialized to 1, in the lookup table (an image where each pixel value is equal to the entity the pixel belongs to). Pixels with the value 0 do not belong to any entity.). If there is only 1 unique nonzero pixels, then we increase p by 1 and create a larger ROI until the ROI contains at least 2 unique nonzero pixels (a door connects two entities, represented by the two unique nonzero pixels). In order to make sure only two entities connected through the door, two entities with the smallest distance from the ROI's center (the door) are identified. Fig. 4 shows an example, the room 654 and 655 are connected through the door in the Fig. 4(a).

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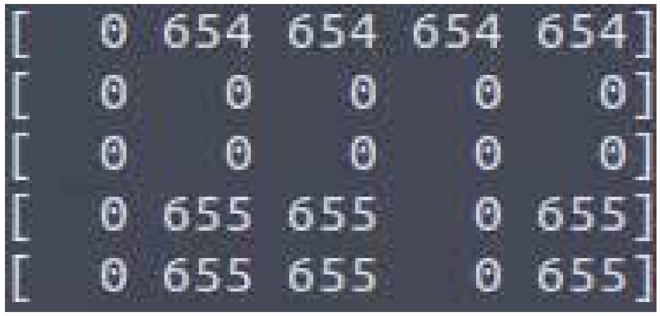



4(b)


4(c)

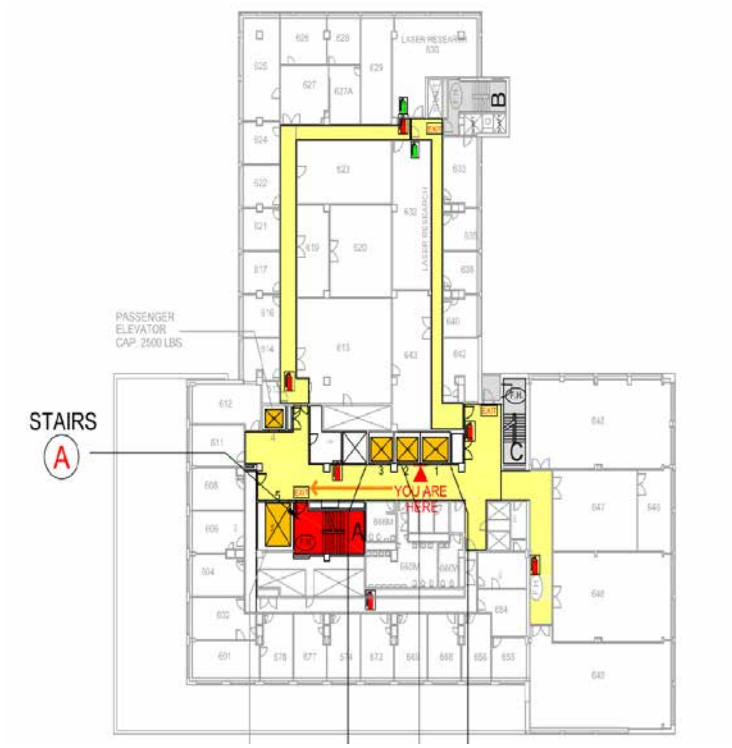
Fig. 4: (a) A small section of a map. The red box shows the ROI around a door of the room 655; (b) The pixel values within the ROI; (c) The two unique room numbers nearest to the ROI's center are identified, and room 654 and 655 are connected in the topological graph.

The above process is repeated on all doors in the database, hence the geometric relations among entities are built. A topological graph is then constructed, with each entity as a vertex and each door connecting with two entities as an edge. Fig. 3(c) shows the graph generated from Fig. 3(a). The navigation brief problem can be modeled as searching the shortest path in the graph and can be calculated using the Dijkstra's algorithm (Dijkstra, 269-271).

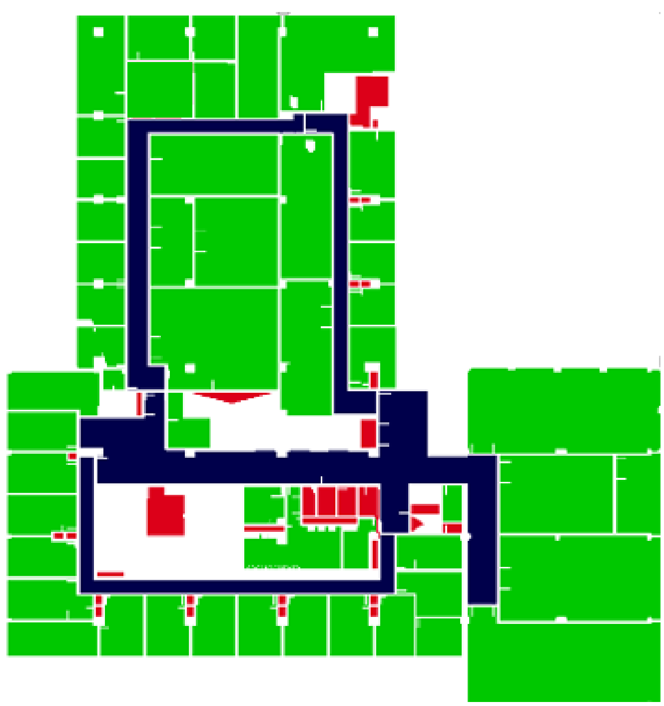
**Extract contour of the entity polygons and build a 3D accessible map.**

After we perform the region growing method and find the shape of each entity, we perform contour extraction using Open Computer Vision library, which computes the contours of each entity polygon. Each contour is simply a list of vertices of the polygon. We iterate over each vertex and insert them into a file (using JSON format.) The content of the JSON file is structured in the following way, for each entity.

*Entity n: {the coordinates of polygon vertices, the coordinates of door(s)}*




5(a)



5(b)

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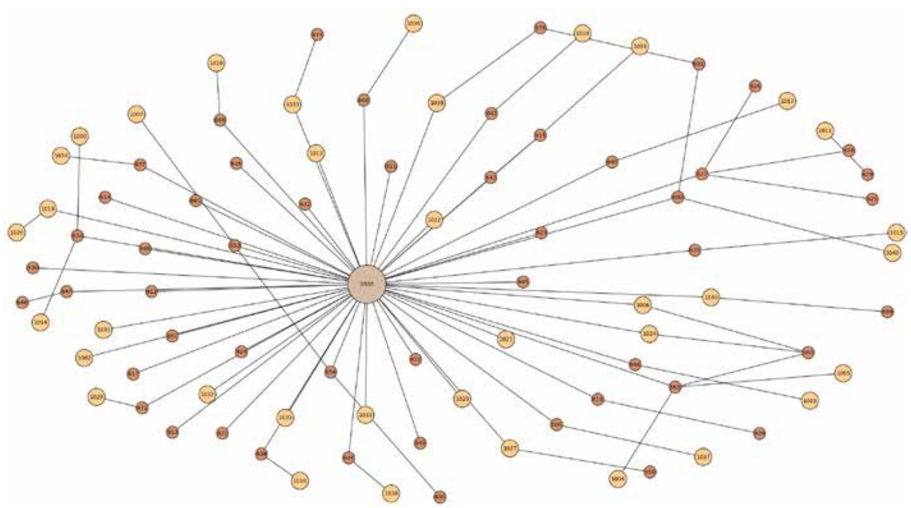

5(d)

Fig. 5: (a) A map of one floor of a campus building. (b) A visualization of the lookup table after region growing is performed. (c) The 3D traversable map rendered in Unity3D. (d) The topological map, each node is represented by a note and an edge represent the connectivity between two entities.

The JSON file is loaded into the Unity3D engine and a 3D floor map is constructed automatically. The traversable map is built and an optimal route can be computed by using A* algorithm (Hart, Nils and Bertram, 100-107).

*Experiments*

We have performed the proposed algorithm on an AutoCAD file of a complex campus building. Fig. 5(a) shows the input AutoCAD map (the image only shows the map of one floor). We first parse the AutoCAD file, and extract useful layer and semantic information, which are stored into a database. We then render a new floor image that only includes wall structures from the database. The region growing method is applied into the new floor image and entities are identified from the image. In Fig. 5(b), the green regions represent rooms and blue regions represent corridors. Once the entities are extracted, the geometric relations among entities are calculated and a topological map is successfully built. Furthermore, the contour of entity polygons in the floor image is extracted and saved into a JSON file. A 3D traversable floor map is built in the Unity3D game development environment (Fig. 5(c)) and a turn-by-turn navigation direction can be calculated.

We manually verify the accuracy of the topological and traversable maps. For the topological map, we compare it with the original AutoCAD map. We derive a topological map from the AutoCAD map and compare it with the one generated by our proposed algorithm. They match correctly. For the 3D traversable map, we project it into a 2D space and it aligns with the original AutoCAD map correctly as well.

To test the performance of the topological and the 3D traversable maps, each time we randomly select two entities from the AutoCAD map and we manually calculate the shortest path between two entities. We then compute the navigation summary (using the Dijkstra's algorithm) from the topological map, and the turn-by-turn directions (using A* algorithm) from the 3D traversable map. We compare the three paths and they match correctly. The above test is repeated several times, the paths are all consistent.

## Conclusions

In this project, we designed a hybrid approach to automatically generate indoor accessible maps from AutoCAD architectural floor maps, which are available for buildings built in the past three decades. Both the topological map and the traversable map of the indoor environment are constructed, which could be used to create a navigation summary, and an accessible map of the facility. The visually impaired can learn the spatial layout of indoor environments on the accessible map. In addition, a pre-journey application can be developed on the accessible map that allows visually impaired plan routes prior to their travels on a tablet or a smartphone, which is our current ongoing project.

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The Journal on Technology and Persons with Disabilities

# Indoor Localization for the Visually Impaired Using a 3D Sensor

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## Abstract

An indoor localization system offers a significant assistance to the visually impaired in their daily lives by helping them localize themselves and further navigate an indoor environment. RGB-D sensor (e.g. Google Tango Tablet) is able to provide three-dimensional information of the environment around the sensor, which can be used for localization and navigation. In this paper, we propose a system that uses the Tango Tablet to first pre-build an 3D model of an indoor environment, and then utilize the newly captured RGB-D information and an Iterative Closest Point (ICP) algorithm to calculate the device's (i.e., user's) location and orientation corresponding to each RGB-D image. Voice feedback is provided to the users via text-to-speech. The system has three components: an environmental modeling and optimization module, a pose estimation module, and a GUI module. Experiments have been carried out in real indoor environments to test the performance of the system in terms of both time and accuracy.

## Keywords

Assistive Technology, Indoor Localization, 3D modeling and matching, Mobile Computing, 3D Model Optimization.

## Introduction

An indoor localization system is of significant importance to the visually impaired in their daily lives by helping them localize themselves and further navigate unfamiliar indoor environments. As of August 2014, there are 285 million visually impaired people in the world according to the World Health Organization, among who 39 million are blind. Compared to sighted people, it is much harder for visually impaired people to navigate indoor environments. Nowadays, too many buildings are unfortunately mainly designed and built for sighted people; therefore, navigational tasks and functions that sighted people take for granted could be huge problems to visually impaired people. Despite a large amount of research has been carried out for robot navigation in the robotics community, and several assistive systems are designed for blind people, efficient and effective portable solutions for visually impaired people are not yet available.

Indoor localization in general has been an area that attract researchers to tackle various problems using different sensors; detailed are discussed below in the Related Work section. Previous work in the computer vision community uses 2D images for localization and navigation, which is challenging due to lack of texture in the indoor environments. In this project, we use fully 3D information automatically captured by a tablet with a depth sensor to localize the device itself. In order to facilitate navigation for the visually impaired, we design, implement and evaluate the system to calculate the position and orientation of the device with the following two steps: (1) use a tablet with depth sensor to prebuild a large 3D indoor environment; (2) apply Iterative Closest Point (ICP) algorithm to a newly captured RGB-D (color and depth) image to calculate the user's new position and orientation. The system includes three components: environmental modeling, pose estimation algorithm, and GUI design. The experiment tested with real model within a university laboratory shows a real time and accurate performance.

## Discussion

### *Related Work*

People who are not visually impaired rely almost exclusively on vision to know where they are in a new indoor environment. Since the visually impaired cannot use vision for this task, they need to use alternative sensory tools to collect information to explore the environment. However, the majority of the tools at their disposal are not able to tell them their locations accurately, not even for navigation. For example, a white cane can help them to determine whether an area is walkable or not, but it cannot provide the user their location information. A dog may help to lead the user to walk along a known path, but the user still needs other information to reason his/her location when he/she wants to change the route. GPS is sometimes used for localization in outdoor environments, but it does not function well in an indoor environment because of the significant signal attenuation. Radio Frequency (RF) based methods, e.g. WiFi or Bluetooth, are applied in indoor environments, but they heavily depend on extra devices (wireless routers or iBeacons) pre-installed in the environment. Previous work (Hu, Zhu, and Zhang 600-614; Irschara et al 2599-2606) in the computer vision field explored methods to process images by image matching and estimates the location information. However, image matches are error-prone in the indoor and urban environments with large textureless areas.

Some researchers use Structure from Motion (SfM) to create street 3D models in the outdoor environment, and recognize the places utilizing images from Internet (Torii et al 1808–1817; Zeisl, Sattler and Pollefeys 2704–2712; Sattler et al 2102–2110). Other researchers use Bag of Words (BoW) (Cao, Chen, and Fan 1-19) or ConvNet features (Sunderhauf et al 4297–4304) to represent outdoor environments for localization. However, few researchers focus on the indoor scenarios, especially for an assistive localization purpose. In addition, a practical SfM model heavily relies on the richness and distinguishes of environmental features extracted from the images, which is hard to use in environments where few features are available (such as rooms with white walls).

Mobile and wearable devices are cheap and ubiquitous nowadays, which accelerate the advancement of both general computer vision research and assistive applications. Farinella (Farinella et al 1086–1100) uses Android phones to implement an image classification system with DCT-GIST based scene context classifier. Altwaijry, Moghimi, and Belongie (167-174) apply Google Glass and develop an outdoor university campus tour guide application system by training and recognizing the images captured by Glass camera. Paisios (Paisios 2012), a blind researcher, creates a smart phone app for the Wi-Fi based blind navigation system. Manduchi (Manduchi 9-12) proposes a sign-based way-finding system and tests the blind volunteers with smart phones to find and decode the information embedded in the color marks pasted on the indoor walls. However, there is very few research work on designing user-friendly smart phone apps for helping visually impaired people to localize themselves and navigate through an indoor environment.

*System Design and Implementation*

We construct the system with three components: an environmental modeling and optimization module, a pose estimation module, and a GUI module; the details of which are discussed in the following subsections. The environmental modeling and optimization module is to utilize the device depth information to create 3D indoor environmental model and use corresponding color information to optimize the model. In the pose estimation module, a newly captured RGB-D image is used to align itself with the pre-built 3D model for calculating the device's location. An easy-to-use GUI module is designed with voice feedback for the visually impaired users. Fig. 1 shows the system diagram.

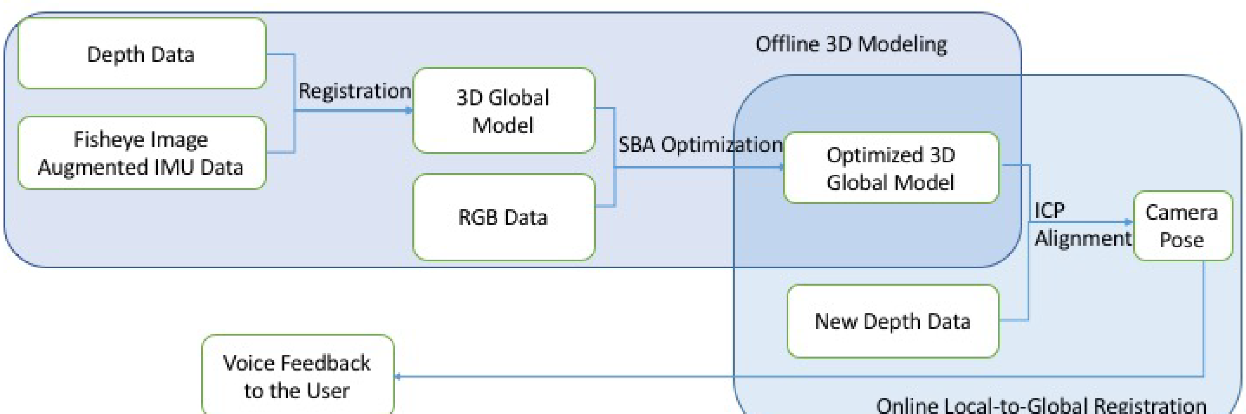



Fig. 1. 3D-sensor-based indoor localization system diagram.

**3D modeling and optimization**

With recent advance of depth and motion sensors (e.g. Google Tango Tablet, Microsoft Kinect and Structure IO) and development of 3D reconstruction technology (Dryanovski, William, and Xiao 1553-1559), we propose to apply the 3D depth sensor in the localization task. We use both 2D images and 3D depth information captured by a Google Tangle Tablet to improve robustness of location estimation. In this project, a pre-built model of the environment must exist before any localization can take place. The model is created as follows.

4. Capturing piecewise local 3D models of the environment and measuring the corresponding pose information of the Tablet.
5. Fusing the piecewise 3D models by transforming each model to a common coordination system using the given pose information of each local 3D model, and a global optimization framework is applied to increase the accuracy of fusion process (Lourakis and Antonis, 1).

Since Project Tango's Tablet device uses an Inertial Measurement Unit (IMU) for providing pose, augmented using built-in fisheye visual features, there are motion drifts accumulated while the sensor sensing the environment. Thus, loop closure is needed to adjust the generated global model by traversing the same area for a second time, and distribute drift errors along the motion path. In our work, we use Sparse Bundle Adjustment (SBA) (Lourakis and Antonis, 2) for the loop closure. The general idea of SBA is first to find a sequence of pairs of 2D image features and corresponding 3D points, and then project the 3D points back to the 2D images using the known camera intrinsic parameters and unknown extrinsic parameters, which includes the camera's pose information. By minimizing the distance between the projected features and observed features, we estimate the optimized camera motion parameters.

### Pose estimation

As we have discussed in Step (1), the major component of the system is the accurate 3D reconstruction of the global model, which has been done offline on a separate machine. In our implementation, we have a reconstructed global model generated by stitching RGB-D data of frames together with the camera pose data of each frame. To localize the Tablet device, a user captures new RGB-D data at a new location by holding the Tablet, and the indoor navigation system then registers the new data with the pre-built global 3D model using the ICP algorithm (Zhang 119-152), in order to calculate the pose where the new data is captured. The registration algorithm will return a transformation matrix whose rotation matrix and translation vector can give us the orientation and position of the camera, respectively.

### Graphic User Interface (GUI) design

In order to make the system applicable to the visually impaired, we've designed a GUI on the tablet using audio-tactile feedback, which reminds and guides users to adjust the tablet poses when capturing new RGB-D data for localization, and informs user the estimated location. Since the blind people cannot see the screen and are usually not comfortable with complex GUI, we simplify the interface by adding a big button on the right bottom part of the screen. Once the user presses the button, the tablet will begin to capture surrounding 3D data, and feedback to the user via voice after calculating the location. Fig. 2 shows an image of the GUI layout.

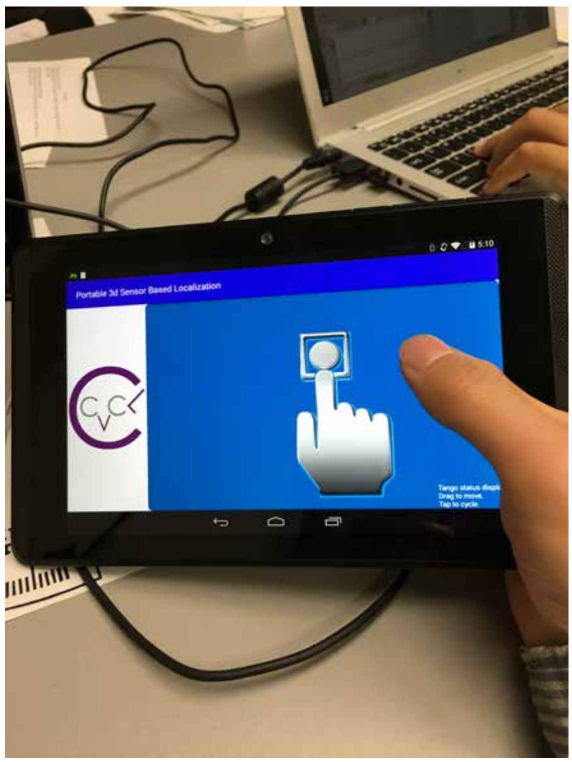
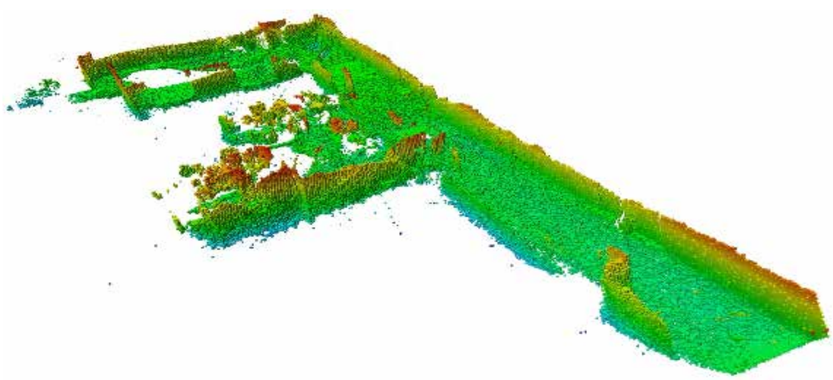



Fig. 2. GUI design. The large bottom right button is for starting localization service, and the rest area can be used for displaying information for administrative purpose.

*Experiments*

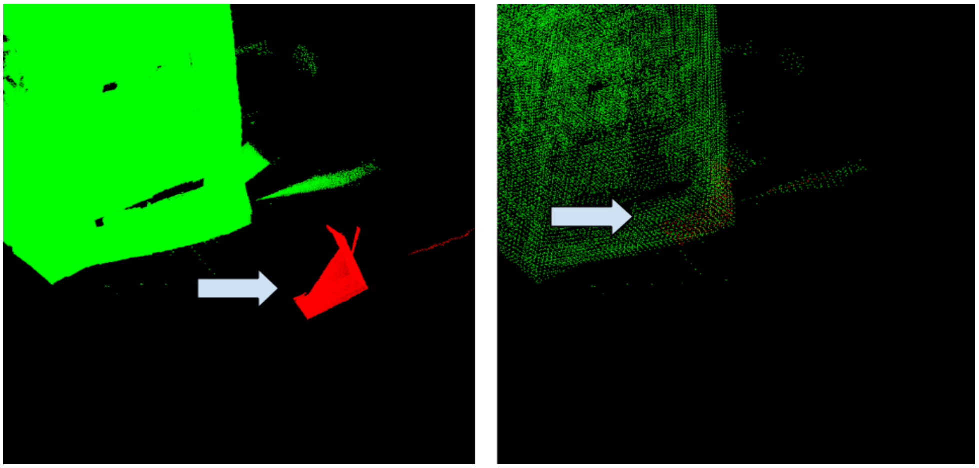
The Google Tango Tablet, which has a 3D sensor onboard, is adopted in our experiments. We have built a few large global 3D models in a campus building, as shown in Fig. 3. In the Fig. 3(a), we build a 3D model for an indoor research lab by scanning the room for 5 times, each with a different tilt angle. A short video of this model can be accessed from this link: https://goo.gl/ILFlTg. In the Fig. 3(b), half of the 8th floor of our NAC building are scanned and visualized. We then captured some RGB-D frames at different locations and apply the aforementioned registration method to estimate where each RGB-D frame is captured, that is the location of the user. The system can estimate correct locations in the experiments.

3(a)



3(b)

Fig. 3. A partial global 3D model includes corridors and rooms.



4(a) 4(b)

Fig. 4. Apply the ICP based registration algorithm for localization. (a) Local model (RGB-D frame, 3 feet by 3 feet, in red) and a partial global model (in green) before registration; (b) Registration result shows newly captured frame is correctly aligned with the global model, which indicates the location is correctly estimated.

Fig. 4 shows some experimental results. The green part represents the partial global 3D model of Fig. 3(b), whereas the small red model (a corner of a lab) indicates a local 3D model, which is a RGB-D frame captured after the global 3D model is built. Fig 4(b) shows the location is correctly estimated. A short video of this process can be accessed via the link: https://goo.gl/VqBZrp.

An optimized 3D model eliminating drifts is critical for an accurate indoor localization. In our work, we utilize the Sparse Bundle Adjustment (SBA) for improving the 3D model built with Tango device. We first extract SIFT features on all color images corresponding to each depth image, and then match them pairwise. After that, we select the qualified SIFT features by setting a threshold to make sure each qualified feature appears at least multiple images. Then we find the corresponding 3D points for each feature from the depth images. The SBA then accepts the features and corresponding 3D points and outputs optimized camera poses. Fig. 5 shows SBA optimization on the synthetic data, where the left part of Fig. 5 shows the camera poses and 3D points before SBA optimization, and the right part of Fig. 5 shows the new poses and points after the optimization.

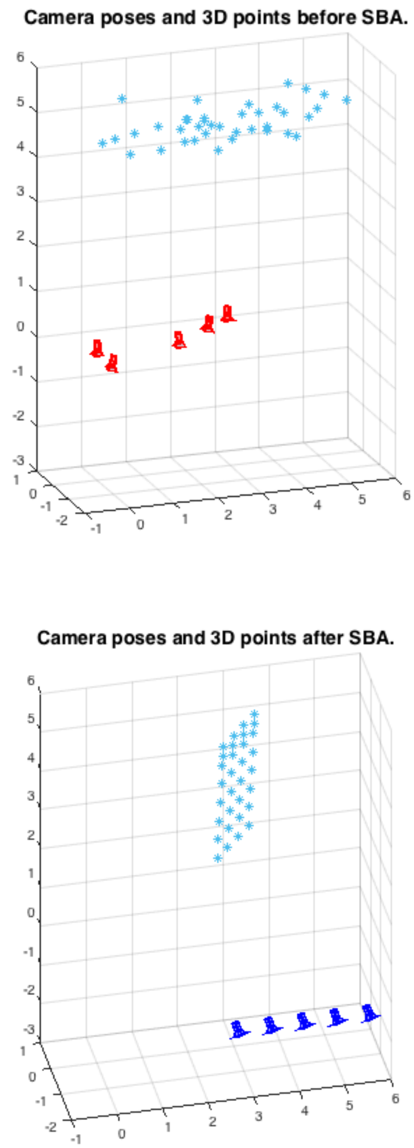



Fig. 5. Camera poses and 3D points before and after SBA optimization.

## Conclusions

In this paper, we proposed a new method of localization for visually impaired, using a tablet with depth sensor. We believe the study is important for visually impaired, since portable depth sensors become popular on some tablets and smartphones. As ongoing work, we are expanding the testing database to larger environments, e.g. a whole campus building. In addition, we are going to recruit blind subjects for more formal testing and revise our system design based on their feedbacks.

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# Smart Signage: Technology Enhancing Indoor Location Awareness for People with Visual Impairments

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## Abstract

We developed and evaluated a BLE-based indoor location awareness system called Smart Signage to provide blind and visually impaired people with better accessibility to the built environment. The Smart Signage system consists of three components; a user component, an environmental component, and a smartphone app. The user component implemented with a Bluetooth low energy beacon tag, which transmits radio signal representing user need every set interval to the environmental component within the set range, can be attached to conventional O&M aids like a long cane. The environmental component, which can be attached to existing tactile signs, continuously sees if the user component comes in and out, using an embedded Bluetooth low energy beacon receiver. When a person who walks with the user component is within the set range, the environmental component automatically plays a recorded voice or simple ticking sound. Based on the sound cue, the user recognizes what/where it is. The smartphone app is used to configure both the user and environment components. The user evaluation conducted with 9 participants found that the Smart Signage system had reasonable level of feasibility, acceptability and usability by showing the potential users had very positive opinions and attitudes toward the developed system.

## Keywords

Indoor location awareness, smart sign, Bluetooth low energy, Internet of Things.

## Introduction

Accessibility to the built environment significantly affects safe and independent daily life and community participations of people with disabilities (Shakespeare and Officer; Whyte; Imrie and Kumar). It is also an important consideration for a truly inclusive society. As a result of the American with Disabilities Act Accessibility Guideline (ADAAG), most public buildings are currently providing tactile (Braille and raised print) signs intended to help blind and visually impaired people gain easier access to their facilities. Surprisingly, however, these tactile signs are rarely used by visually impaired people because they have no proper way to locate them. Even if people with visual impairments could locate tactile signs, in many cases, they may not be meaningful, as only about 5% of visually impaired people in US are Braille literate (Johnson).

To address the above issues, several patents have been disclosed and some of them are already on the market. For example, Hart (Pat. No. 4,930,236) (Hart) and Hoshi (Pat. No. 4,934,079) (Hoshi) disclosed passive infrared-based detection technologies. Carter (C. M. A) used available visible light optical interruption as a detection technique. However, this approaches not only requires available visible light as a source being interrupted by the target, but is also susceptible to variations in ambient light levels. As commercial products, Talking Signs system (Bentzen and Mitchell) is the most well-known product, which was developed as an environmental labeling system to allow blind individuals to locate and identify landmarks, signs, and facilities of interest in the environment. It uses coded infrared transmitters as labels, and the user's handheld receiver converts the transmissions into speech. A prototype system ("Pathfinder," modeled on Talking Signs) was evaluated in a London subway station (Bentzen and Mitchell). Similar approaches have been taken in the European OPEN (Orientation by Personal Electronic Navigation) project (Seelman et al.), the SEAL Pilot-Light system, the Tele-Sensory Marco system, the RNTB Infra Voice, and the AudioSigns infrared orientation system. Verbal Landmarks system (Loomis, Golledge and Klatzky) used a series of infrared similar to the Talking Signs system. It adopted an inductive loop system that is activated when a portable receiver is within range (approximately 5 feet). When it is activated, a verbal message is generated. However, the message is non-directional and the feature of the messages is a little bit different from that of the Talking Signs. While the Talking Signs typically produce the room number or landmark, and allow users to use this information to navigate, this system gives instructions to specific goal states (e.g., "The bathroom is North 5 steps and to the right"). However, most of these products are not used in real world, because these commercial products are high cost and the users are required to have their handheld receivers in addition to their conventional orientation and mobility aids (i.e., canes and guide dogs). More importantly, most of them do not provide enough information necessary to be oriented effectively. Moreover, complexity of implementations and maintenance prevent various buildings and facilities from adopting such options actively.

As another solution to address the issue above, we developed a new design concept that originates from the perspectives of individuals with visual impairments who acquire location awareness by pinpointing sound source, designed a prototype system called Smart Signage, and evaluated the prototype system with visually impaired individuals and blinded volunteers. In this paper, we present the design concept and the research procedures.

## Design Procedures

As the first step of the design, we researched end user needs and product requirements through the method of Quality Function Deployment (QFD) (Akao). This method presents the relationship between the end user needs and design requirements to transform end user needs into product/system requirements and technical specifications. To collect the end user needs, interviews with 15 end users, including 12 individuals with visual impairments and 3 building managers were conducted. Through telephone interviews, the following two open-ended questions were asked. (1)"What do you think are the most important factors in improving current signage systems?" (2)"What kind of functions do you want to be added to the signage system?" All interviewees were encouraged to give at least 3 answers to each question in order of importance.

From the results of the collected responses, a QFD matrix revealed critical user needs and identified important technical design requirements that are related to user needs. To generate the design ideas to meet the user and technical needs, brainstorming was used as a group creativity technique. With this method, a number of design ideas were generated to improve the indoor location awareness for people with visual impairments by means of a better signage system, including remote readable infrared, audible infrared, applied GPS technology, radio-based, ticking or verbal sound, computer vision based print/text recognition, Bluetooth low energy-based, speech recognition-based, applied smart card, sensor network, electronic cane with barcode reader, electronic guide dog, autonomously guided mobile robot, and electronic tactile pavement.

To evaluate feasibility and priority among the generated design ideas, the Pugh's selection chart method (Huang and Mak) was adopted, which compares alternative solutions against a set of criteria (user needs retrieved from the QFD matrix). From this assessment, the three top ranked ideas were selected. (1)Bluetooth low energy (BLE, also known as Bluetooth Smart), (2)ticking or verbal sound, and (3)sensor network. After further discussion, the three top ranked design ideas was combined into one integrated system. Through this approach, a final design idea was determined and a working prototype system called Smart Signage was implemented.

## Implementation of Smart Signage

The smart Signage is a BLE based indoor location awareness assistance system. BLE is a wireless personal area network technology designed by the Bluetooth Special Interest Group (SIG) primarily aimed at novel applications in the healthcare, fitness, beacons, security, and home automation industries (Bluetooth-SIG). As it provides considerably less power consumption, reduced cost and simpler yet more efficient communication compared to conventional wireless technologies (i.e., Wi-Fi, GSM, ZigBee, classic Bluetooth, etc.) (Bluetooth-SIG), BLE as one of the most remarkable Internet of Things technologies has drastically gained in popularity. To establish a BLE-based interactive system, in general, the following 2 interrelated components are involved: tag and receiver. The BLE tag is a tiny device which periodically broadcasts radio signal (called advertising packets) containing its unique identifier, information about its status like remaining battery capacity, and user defined custom data or embedded sensor measures. Its ultra-low power consumption enables the tag to run for year(s) on a standard coin-cell battery and its transmission interval can be adjustable. The receiver is a BLE device which repeatedly scan the preset frequencies to receive the data currently being broadcasted from the tags and pass the received data as system commands or parameters to other modules. The BLE receiver can identify each tag, estimate the distance to it by measuring the received signal strength, monitor its own health, and interpret the user defined custom data. The most common use-case of BLE beacons is for retailers to provide their customers with product information, flash sales or deals (called micro-targeted advertising) when they come close to specific products or areas where the BLE tags are distributed and attached in their shop. General consumers can also use the BLE beacons to inexpensively automate their homes. For example, the beacons can be used to control lights in a house as soon as someone with a smartphone as a BLE receiver has entered it, or open doors or window shades.

The Smart Signage system consists of three components; a user component, an environmental component, and a smartphone app. The user component, which can be attached to conventional O&M aids like a long cane, includes a Bluetooth 4.0 BLE tag transmitting signal representing user need every set interval to the environmental component within the set range and a tiny push button used to resend a request to the environmental component. The environmental component, which can be attached to the service site, includes a PCB base containing a microprocessor, a BLE receiver, and a sound chip. It takes a continuous distance reading. The measuring distance can be adjustable by adjusting the on-board trimmer. The received signal strength is sued to see if the user walks in or out. The sound chip can store up to 10 seconds of sound and play it back to the user. Using the smartphone app, it is possible to configure both the user and environment components. When a person who walks with the user component is within the set range, the environmental component automatically plays a recorded voice or simple ticking sound. Based on the sound cue, the user recognizes what/where it is. The recorded voice is not turned on again until the person is away from the set range. The user can get the sound played again anytime by pressing the tiny button on the user component. A coin sized battery is used for the user component and environmental component, respectively.

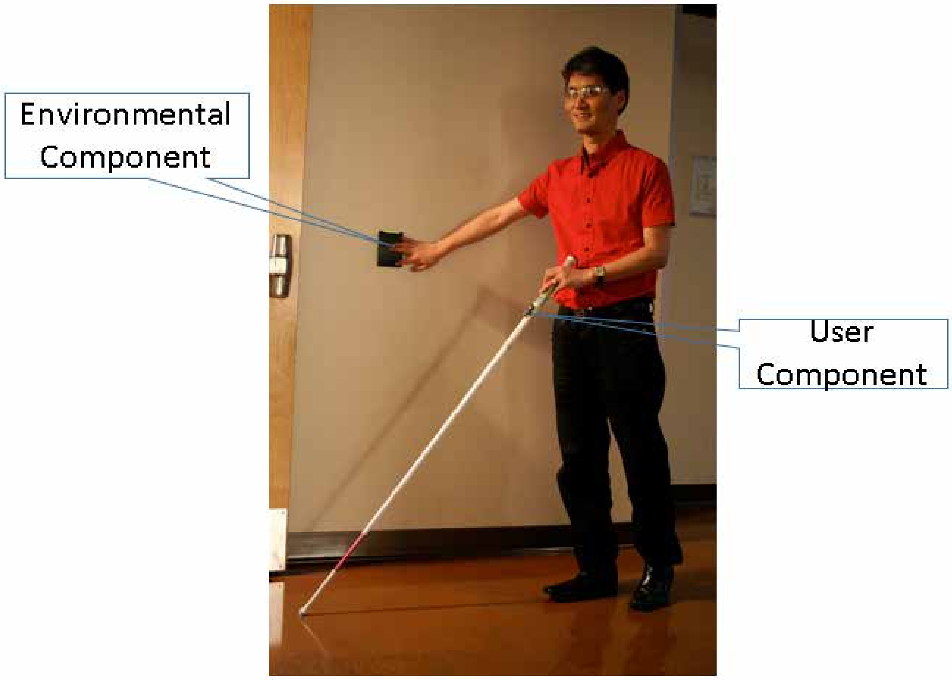


Fig. 1. Smart Signage.

## Evaluation of Smart Signage

The user evaluation was conducted in the hallway at the Forbes Tower, an office building within the Department of Rehabilitation Science and Technology in the University of Pittsburgh. Nine volunteers participated in the user evaluation. As shown in Fig. 1, each participant has time to try out the user component, putting it in his/her pocket or attaching it to a long cane. Environmental components were placed on the wall along the hallway. The participant had to be blindfolded if he/she was a sighted person. Participants walked around the evaluation site with the user component for at least five minutes, evaluating the Smart Signage system by accessing the environmental components.

After the participant performed the evaluation, a quick interview session was made with the following open-ended questions: (1)"How do you feel about the interface of the user component?", (2)"How do you feel about the contents of information provided by the environmental component?", and (3)"How do you feel about the accessibility (distance, sound volume, etc.) of information provided by the environmental component?". From the hands-on practice and the interview session, it was demonstrated that Smart Signage system had reasonable level of feasibility, acceptability and usability by showing the potential users had very positive opinions and attitudes toward the developed Smart Signage system.

## Discussion

In this research, we developed and evaluated a BLE-based indoor location awareness system called Smart Signage to provide blind and visually impaired people with better accessibility to the built environment. Acknowledging the great potential of the BLE beacons, several research groups have investigated the possibilities of using them to help visually impaired travelers navigate around the space. For example, Indoo.rs and LightHouse for the Blind and Visually Impaired are currently testing such a system in the San Francisco Airport (Lowensohn). UCAN Go and Calvium are working to use beacons to help visually impaired people navigate arts museums in Wales (Reid). Ifinity reports they have implemented a beacon-based indoor navigation system in the Warsaw Centre for the Disabled (M. C. S. A). Royal London Society for the Blind collaborating with ustwo is carrying out a BLE-based wayfinding project called Wayfindr (RLSB) to provide people with visual impairments a more independent navigation. They installed BLE beacons throughout a subway station, and when the users got into the station, a prototype smartphone app gave audio directions to them, interacting with the beacons. Researchers from IBM and Carnegie Mellon University's Cognitive Assistance Laboratory have developed a smartphone app called NevCog to help people with blindness and severe visual impairments (Dan). The app uses BLE beacons placed around Carnegie Mellon's campus (every 8-12 meters along all major walkways) to provide users with better location accuracy and more precise directions, rather than relying on traditional GPS technology which does not work for indoor navigation.

However, the aforementioned BLE-based accessibility projects have similar critical limitation as the currently available Talking Sign system, including lack of directional information and non-standard communication protocol relying on proprietary hardware and software. On the contrary, as the Smart Signage lets the environment recognize and provide the users with sound cue or audible information, they acquire better location awareness by pinpointing the sound source. In addition, as our solution is based on standard communication and data coding mechanisms defined by Bluetooth 4.x specification approved by Bluetooth Special Interest Group, it is possible for others to easily implement a more accessible indoor awareness service on a relatively modest budget. The BLE devices can be purchased at $10-$20 per unit. They last between 1-5 years depend on the brand/type and transmission frequencies and ranges. Moreover, by extending the design concept presented in this research, it is also possible to implement a much wider range of accessibility services for individuals with differing disabilities. For example, universal door access/control service as a personalized, accessible, responsive door access and control service for individuals with disabilities will be able to work as a manual or automatic door opener for people with mobility impairments depending on the severity of their disabilities, or serve as a talking sign for individuals with blindness. Safety alerting service will be able to provide individuals with disabilities with adaptive feedback when the user is approaching an environmental object (e.g., emergency warning triangle/cone, safety notice board) marked with an environmental component. Universal elevator button control service as a personalized, accessible, responsive access service will be operated by speech recognition for people with mobility issues, provide auditory feedback for the visually impaired, or give some instructions to a person with cognitive issue or to a novice wheelchair user. Accessible pedestrian signals service will provide longer pedestrian lights for people with mobility impairments or give auditory feedback for individuals with visual impairments.

**Acknowledgements**

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# Cognitive Fatigue and the ManageMyFatigue App

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## Abstract

Cognitive fatigue is the decrease in alerting and orienting, with an overall drop in executive function and attention on any given task (Holtzer et al. 108). It has been found to affect 73% of individuals with brain injury for an average of five years post-injury. Despite pharmacological treatments, up to 80% of patients consistently exhibit extreme levels of tiredness.[10] The use of rehabilitation technology is specifically essential in acting as an assistive prosthetic in fostering increased independence and control over their own lives. The ManageMyFatigue (MMF) App was designed by Michelle Wild to help identify and manage cognitive fatigue and mental exhaustion by providing feedback to the user. We hypothesized that individuals with brain injury can learn how to use and implement the MMF App into everyday life. Eleven subjects with varying degrees of brain injury participated in training and posttest evaluation to determine their ability to successfully use the app, measured by total proficiency. Our results indicate that individuals with brain injury can learn how to implement the MMF app into everyday life. Our hope is that the MMF will not only help manage cognitive fatigue, but increase quality of life by increasing insight and self-awareness.

## Keywords

Brain injury, cognitive fatigue, rehabilitation, technology.

## Introduction

Cognitive fatigue is the decrease in alerting and orienting, with an overall drop in executive function and attention on any given task (Holtzer et al. 108). This is particularly prevalent in brain injury rehabilitation, with an average duration of five years post-injury across 73% of all affected patients (Olver, Ponser, & Curran 841). Brain injury rehabilitation is the recuperation of traumatic and non-traumatic injuries. Traumatic injuries includes motor vehicle accidents, falls, sports concussions, and other injuries producing traumatic impact to the head. Non-traumatic injuries include those injuries such as strokes, tumors, and metabolic and toxic illnesses producing neurological symptoms. Rehabilitation occurs in several phases, beginning with acute care immediately following an injury, and then acute rehabilitation. Acute rehab may then be followed by outpatient rehabilitation or transitional living. The last and often times most enduring phase is longitudinal rehabilitation.

The primary goals of rehabilitation include the restoration of functions to preinjury ability, and the development of compensatory strategies where previous levels cannot be restored. Compensatory strategies are techniques and skills geared towards learning how to do things differently. This is important because they provide patients with a renewed sense of autonomy as they navigate the perils of life long recovery, as opposed to overly relying on others. The use of rehabilitation technology is specifically essential in acting as a prosthetic in fostering increased independence and personal control. Technology helps patients identify gaps between current and previous levels of function to create greater insight and self-awareness, while drawing a parallel process to the cognitive underpinnings of the development of new skills. Unfortunately, complex and invisible symptoms such as cognitive fatigue can often interfere with the rigors of rehabilitating an injury, while simultaneously decreasing day to day function.

Cognitive fatigue has been found to be pervasive across a wide variety of other neurologic, physical, and psychiatric illnesses as well. Despite pharmacological treatments, up to 80% of patients consistently exhibit extreme levels of tiredness (Marin & Menza 12). Fatigue significantly impacts every aspect of one’s life. It can impact a person’s ability to successfully maintain a job, go to school, and/or perform necessary responsibilities at home. Consequences include decreased self-confidence and self-esteem, difficulties with making decisions, and feeling confused and disoriented. While many resort to stimulants and opt to push through tiring activities (Howard et al. 1290), a practical solution to effectively deal with and manage daily fatigue is still not widely available. Recent research suggests that time-on-task is a more powerful predictor of fatigue than task difficulty (Sandry et al. 5). Thus, helping users monitor their time-on-task and remember to take breaks is key to successfully managing fatigue. Increased energy also improves self-regulation; a critical component of learning and problem solving after brain injury.

*Problem and Purpose*

The ManageMyFatigue (MMF) App was designed by Michelle Wild to help identify and manage cognitive fatigue and mental exhaustion. It accomplishes this by providing feedback, and thus creating self-awareness about a user's level of energy, based on the user's input about previous attempts in performing similar or identical activities. With the concept of time-on-task in mind, the problem raised by the current study was whether or not individuals with brain injury could successfully use and implement the MMF App. We hoped to build upon a previous pilot study which will be further discussed below. We hypothesized that individuals with brain injury can learn how to use and implement the MMF App into everyday life.

*Methods*

The pilot study took place over two days, with a four day break between sessions. Four students (one male and three females) were selected from the Coastline Acquired Brain Injury (ABI) Program in Newport Beach, CA. There were no dropouts.

The current study took place over seven days. Twelve volunteers (six males and six females) were recruited from the Coastline Acquired Brain Injury (ABI) Program in Newport Beach, CA. There were five dropouts which left us with three males and four females for a total of seven subjects.

In total, eleven subjects participated in both studies combined. A copy of the MMF App was provided as compensation. The ABI program consists of four levels (tiers) of post-brain injury level of functioning. Each tier is described in detail below. No subject had previous exposure to the MMF App. Once selected, subjects were invited for a thirty minute training session, where the purpose of the research study was explained and consent was obtained. Subjects were shown how to access twelve video tutorials on the MMF website, for a total viewing time of forty-six minutes. An access card with instructions for how to do so from home was also provided. The MMF App was downloaded for each subject individually onto their personal electronic devices (tablet or smartphone). They were instructed to complete the training videos by the time the group met for posttest evaluation. Posttest evaluation covered twenty-one app specific tasks to gain used as a measure of total proficiency. Each task was evaluated as complete or not complete. A copy of the posttest evaluation is marked as Figure 1.

| **TASK**<br>"Scoring: 0 not completed; 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **SUBJECT** | **SUBJECT** | **SUBJECT** | **SUBJECT** | **SUBJECT** | **SUBJECT** | **SUBJECT** | **SUBJECT** |
| ***MMF App SETTINGS*** | | | | | | | | |
| Wake-up Alarm (set time) | | | | | | | | |
| Daily Task Setup Reminder (set time) | | | | | | | | |
| Evening Wrap-up Reminder (set time) | | | | | | | | |
| Bedtime Reminder (set time) | | | | | | | | |
| Alert sound (set ) | | | | | | | | |
| | | | | | | | | |
| ***MMF App MyTasks*** | | | | | | | | |
| Create a Work Category | | | | | | | | |
| Add the following two tasks: Email (30 min OD) and Filing (20 min | | | | | | | | |
| Edit the Work Category to say Work/Volunteer | | | | | | | | |
| Edit the Work Category Filing Task OD to 30 | | | | | | | | |
| Create a School Category | | | | | | | | |
| Add the following two tasks: Homework (40 min OD) and Reading | | | | | | | | |
| Delete the Reading Category and any of its tasks | | | | | | | | |
| Add one break unique to you | | | | | | | | |
| Delete one of the existing break activities | | | | | | | | |
| | | | | | | | | |
| ***MMF App MyDay*** | | | | | | | | |
| Add Work/Volunteer-Email Task w/a 2:00 PM | | | | | | | | |
| Add the School-Reading Task w/out a reminder | | | | | | | | |
| Add one other task w/out a reminder | | | | | | | | |
| Edit School-Reading Task to have a 3:00 PM | | | | | | | | |
| Reorder the tasks: 1st-School-Reading; 2nd- task you selected; 3rd- | | | | | | | | |
| Start one of the tasks and stop it before the timer | | | | | | | | |
| Choose a break activity and set it for 10 min | | | | | | | | |

Fig. 1 MMF posttest evaluation form.

Tier 1: Mostly impaired scores in neuropsychological testing. Includes difficulties with language, attention and concentration, verbal and visual memory, processing speed, and executive functioning. Low scores on behavioral measures and community integration (i.e.

home, social, vocational productivity). Require assistance with attendance and punctuality, self-awareness and self-regulation, judgment and decision making, and compensatory strategies for memory difficulties.

Tier 2: Scores include borderline to low average neuropsychological testing, with some impaired ranges. Scores typically reflect left versus right hemispheric injury patterns (i.e. poor language with good visual skills or vice versa). Moderate behavioral and community integration scores. Slow processing speed and may feel “foggy.” Require assistance with completing tasks on time (i.e. completing assignments, paying bills, scheduling appointments) and decision making.

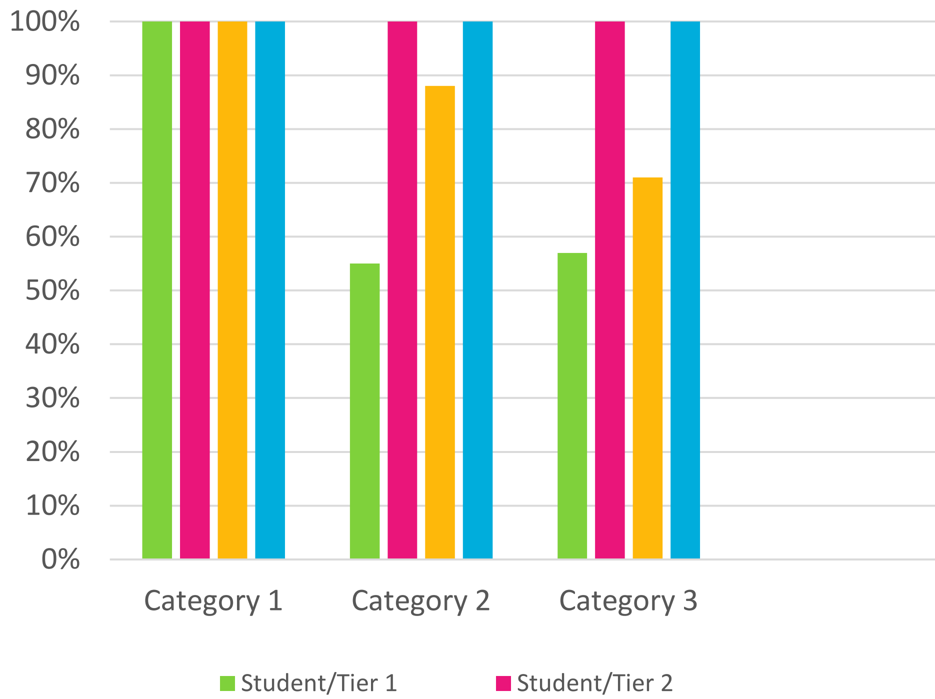
Tier 3: This includes mostly low average neuropsychological scores with some average and borderline ranges. There are fewer difficulties with decision making. These individuals may have difficulties finding words but can express themselves. May take longer to perform certain tasks, but are able to work through them on their own. Testing reflects mild behavioral and community integration scores. Individuals are beginning vocational or educational transition.

Tier 4: Mostly low to average neuropsychological testing, with some high average to superior scores. Individuals exhibit good behavioral awareness and self-regulation, with good compensatory strategies across all needed areas. Community integration is also good. These individuals are preparing to transition with a firmly developed and approved educational and/or vocational plan.

**Discussion**

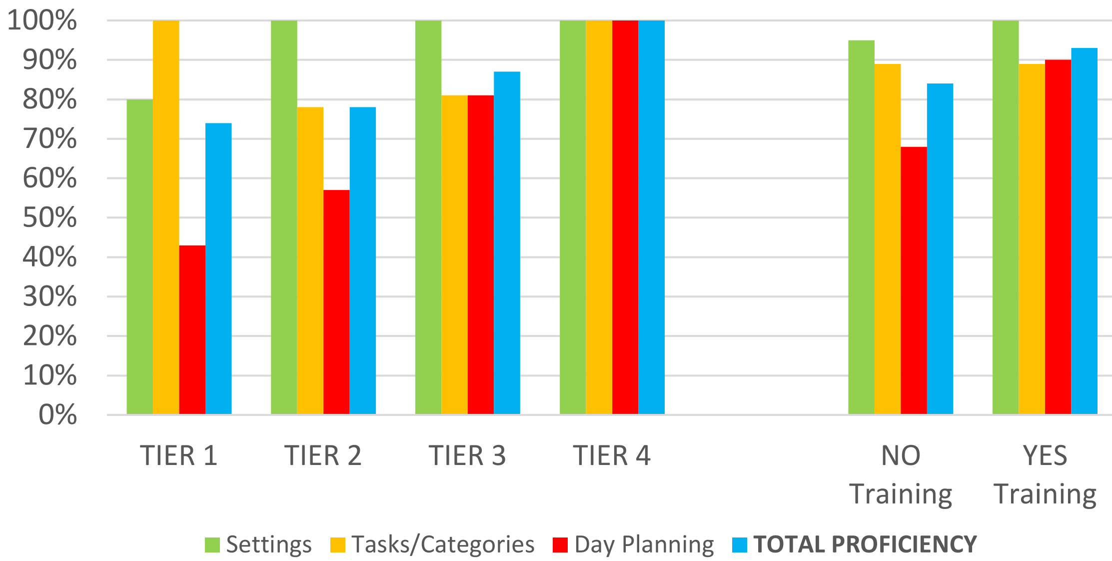
The current study sought to build on a previous pilot research demonstrating the functional and cognitive ability of individuals with brain injury to learn how to use the MMF App. Our initial research found post-test evaluation rates for the following in total proficiency: Tier 1, 71%; Tier 2, 100%; Tier 3, 86%; Tier 4, 100%. Table 1 shows the level of proficiency across each task.

Table 1. Level of total proficiency evaluation (Study 1)




Similarly, our current research found the following: Tier 1, 74%; Tier 2, 78%; Tier 3, 86%; Tier 4, 100%. Table 2 shows the level of proficiency across each task.

Table 2. Level of total proficiency evaluation (Study 2)




Our results indicate that individuals with differing levels of brain injury demonstrate the capacity to learn how to use and implement the MMF App in recognizing and managing cognitive fatigue. Moreover, our results indicate that learning performance decreases as more complex tasks within the app are demanded. For example, setting up basic settings and routine tasks appears to be easier than planning an entire day. Interestingly, in the pilot study, our Tier 1 participant did not complete the training and attributed his low score in total proficiency to not knowing how to use the app. In contrast, our second study elucidates the ability of some individuals to learn how to navigate the app, even in the absence of training. Although this may simply be the result of advanced technology skills, it is worth noting the MMF App's relative ease of use for some individuals.

Limitations of the current study include generalizability of the results to survivors of brain injury in other settings. The current subject cohort was recruited from an acquired brain injury rehabilitation program. By this very nature, subjects in this program may have certain advantages, including moral and social support, which may positively affect self confidence in undertaking novel projects. In addition, our small sample size further impacts plausible generalization.

## Conclusion

With such varying degrees of severity, cognitive fatigue can affect an individual's physical, psychological, and emotional well-being. Often times all three networks are simultaneously impacted, producing debilitating effects while reducing an individual's quality of life. In addition, enduring exhaustion has the potential to exacerbate already difficult living conditions resulting from serious health difficulties, including financial uncertainties, employment disruption, community reintegration, and disturbances in personal identity. After brain injury many are left having to redevelop a sense of self. Cognitive fatigue exacerbates the rehabilitation process while impacting autonomy, insight and self-awareness, and judgment and decision making skills.

Successful integration of rehabilitative technology can mitigate these factors. The current study examined the ability of individuals with brain injury to learn how to use the MMF App. Our results indicate that these individuals do in fact, have the cognitive ability to learn how to use and implement the app. In addition, we found the MMF App can be learned even in the absence of technical training. We are currently examining whether or not the MMF produces measureable positive changes in overall quality of life. Our hope is that the MMF App will provide patients with the independent ability to manage and minimize fatigue, so they may successfully return to leading productive, organized lives.

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THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

# A Survey on Video Relay Service Application Interface Preferences

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## Abstract

Before the invention of the telecommunication relay services (TRS), Deaf Americans who wanted to use public communication systems, such as the telephone network, faced issues of confidentiality and inconvenience because they needed assistance from a hearing person. With the introduction of telecommunication devices such as the teletypewriter (TTYs) and Video Relay Services (VRS), deaf Americans gained a measure of functional equivalency with their hearing peers. This research reports on an iterative survey and redesign to create a high fidelity user interface design based on their responses and to discover more about user's VRS usage.

## Keywords

Deaf, Hard of Hearing, Video Relay Services.

## Background

Around ten percent of people worldwide and in the United States, including senior citizens, have hearing losses and can benefit from functional equivalency in telecommunications (U.S. Census Bureau, 2015). In the United States, the government provides Telecommunications Relay Services which is mandated by Title IV of the Americans with Disabilities Act (ADA), which resulted in substantial progress in inclusion.

An important component of the Telecommunications Relay Services is the Video Relay Service (VRS). The Video Relay Service provides functional equivalency for people whose preferred visual communication is American Sign Language. VRS connects the deaf signer with a hearing speaker through a sign language interpreter who translates sign to speech and vice versa in real-time. These services have come a long way with the introduction of higher bandwidth infrastructure and better compression methods for a more satisfying user experience. In addition to that, the use of mobile phones and "smart devices" have increased the portability and possibilities of using VRS with higher mobility.

VRSs are widely used by deaf and hard of hearing as an accessible computing application that provides functional equivalency. Users sign to an interpreter who then speaks to the intended audience to relay the communication. Speaking users' speech is then translated into sign language so the deaf user can comprehend it. Previous work provided by Minoru Yoshida (Minoru 2009) concluded that a technical background was needed to configure and use VRS devices. That study was conducted in 2008 and technology such as portable devices have become ubiquitous in everyday life possibly making parts of the study invalid at this time. It examined stationary videophone technology used on either televisions or other displays, while videophone capable mobile phones are now widely available and used. The newer, mobile option forms the focus of this study.

## Methodology

### *Survey Development and Implementation*

We did an initial user survey, a round of design iteration, and then a final survey of feedback on the newly designed prototypes. The eligibility of participants is contingent on year born, hearing loss, and consent to participate. Additional requirements for survey participants include previous experience with VRS, the ability to articulate themselves and full completion of the survey after it is started.

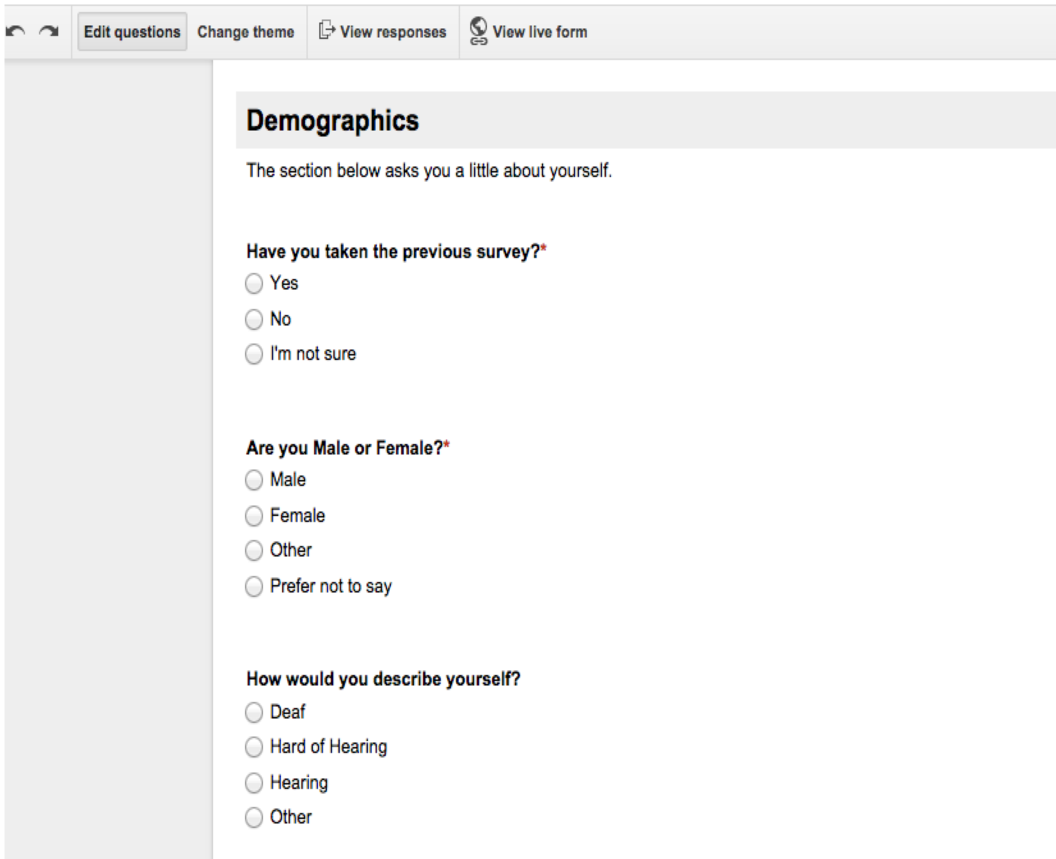


Fig. 1. Screen capture of survey #1.

Information required within each survey includes gender, year born, and other questions involving the preferences they may or may not have concerning specific features and portrayals of these features. Participants self-volunteered to take the survey through a link available on multiple social media platforms such as Facebook, e-mail, and word of mouth.


Fig. 2. A sample image to support a survey question.

The attached message is a small amount of information regarding the study rationale and future impact. Participants submit the survey results for storage in the Google Forms database, which then presents data visually by a series of charts and pie graphs.

## Results

### *Descriptive Statistics*

This section provides information on the distribution of descriptive statistics including gender, year born, level of hearing loss and years of VRS experience. The results are separated into two groups depending on which survey that was taken.

### *Gender Distribution*

Each survey found it difficult to create an equal balance between the two genders. The first survey was only able to capture 3 females and the second the same.

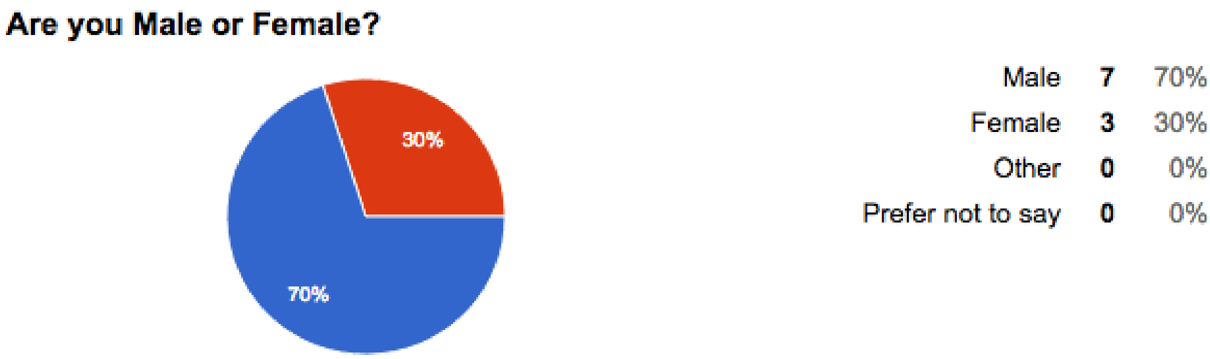


Fig. 3. Gender Distribution from Survey #1.

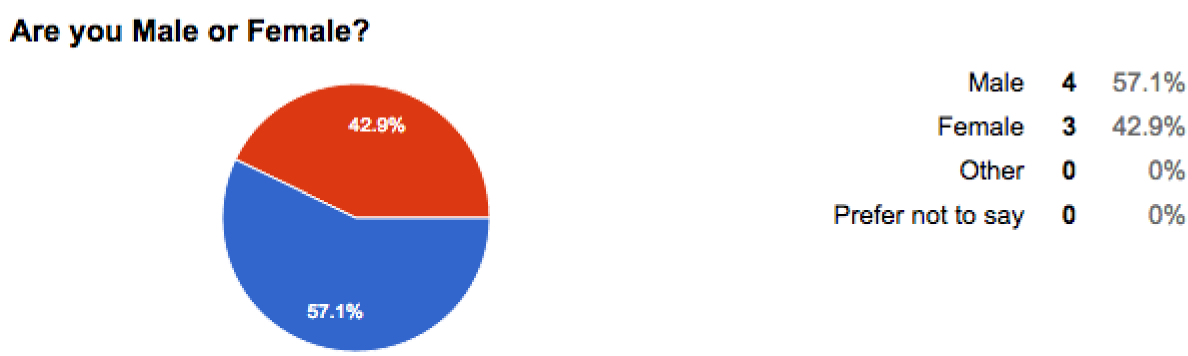


Fig. 4. Gender Distribution from Survey #2.

*Year of Birth*

The question asked of participants was "What year were you born? While the answer formats varied from the participants' age, to the year born, I was able to determine the year of birth for those who answered incorrectly. Survey 1 presented a majority of participants, 9 out of ten responding, being from the age of 18 to 45, and while survey number 2 had respondent's age as an optional question, the range was 1990 to 1994.

*Multiple Choice Questions*

After analyzing the first survey, we came to find that users more typically use VRS on their personal computers and use the service around 3 times per week if not less. Participants responded positively to any suggested feature being added including call time, multiple views, separation of call history, and choosing from a list of functions for in call settings.

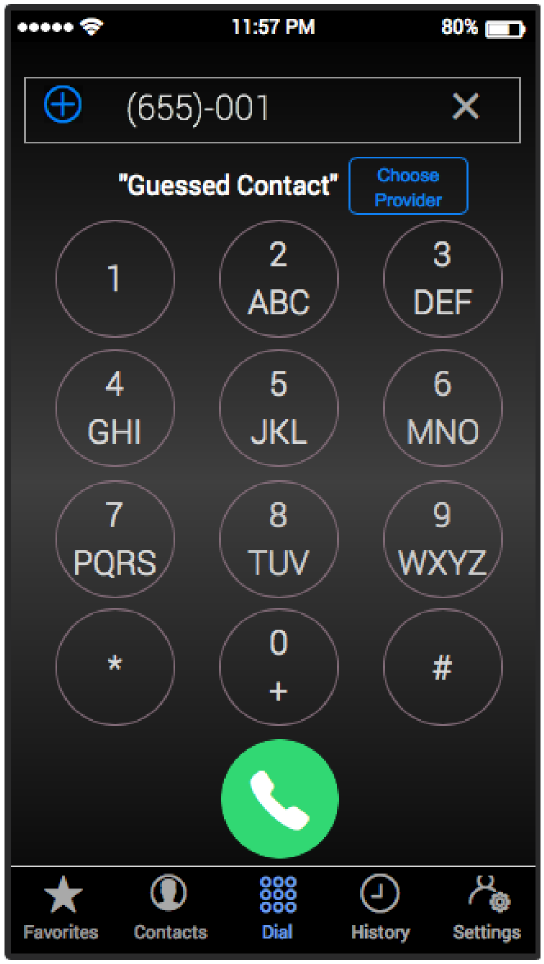


Fig. 5. Second Iteration of predicted contact design.

Once the second survey was implemented, the diagrams and examples were updated to show that the data from the first survey was applied. Participants were then asked to rate and give an opinion on each design. Figure 4 shows the feature allowing the use of the dial pad to guess the contact that the user is most likely calling. Users were presented a prototype as such as asked how clear it was in portraying that, and how much they liked it.

Feedback on most designs was positive. While some prototypes were clear to understand, some users did not agree with the color scheme and contrast, which did not apply to this study as much as their opinion on each feature. All around there was mostly satisfied responses so this allowed us to continue with the final phase of design iteration, the final prototype.

### *Final Prototype*

The final prototype was developed using all the feedback and suggestions from the participants of the first two studies. Using Human Computer Interaction (HCI) guidelines and applying some of Norman's Principles, we developed an interactive prototype through the program "JustinMind". This allowed functionality to be shown through simulations and simulated button selecting.

## Discussion

Data received in the initial survey showed that three VRS companies were on par with each other in terms of popularity. Data also showed that a majority (90%) of participants used one VRS company primarily, the other 10% used more than one. Yet not having data on why each individual used a specific carrier or multiple, one can only use assumptions.

The participants' total length of VRS use had two means. One being less than five years, and the other more than five years. This is perhaps skewed due to the small sample size and the mean age of the group interviewed being 28.5. A majority of the group was under the age of 30, so it could be possible that the group was later to adopt VRS due to being a younger age.

Data showed signs of participant confusion in terms of how certain features we presented. In figure 6, many respondents voiced opinions of confusion due to the size of the middle user icon. They were unsure of how to perceive that and if the size of that was a factor affecting the applications use. After reviewing the first survey, it was determined that it was fine to leave the icon as is due to the use as a metaphor and not so much as a representation of the final product.


Fig. 6. Example of VRS call using “video in video.”

Another interesting observation is that users primarily used VRS on their personal computers, then smartphones, and finally with a videophone device. There was no correlation between year born, length of time using VRS technology, and what type of device was used primarily. The preferences on starting the VRS application to a specific function was not unexpected. 40% were interested in the dial pad being the first option at startup, and another 30% were more interested in having their favorites in place of that. Data received in the second survey showed that users can have many different preferences and opinions on many features.

## Conclusion

The results of this study has implications for deaf and hard of hearing signers who use VRS services. The consumers clearly prefer a more visual and intuitive interface. They also prefer a large screen size. At the same time, the deaf and hard of hearing participants had widely varying preferences, and it would be best to design the software to provide a limited set of options so that they can enjoy fully access without feeling overwhelmed or in charge of the electronic equipment.

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