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The 37th Annual CSUN Assistive Technology Conference and the 10th Volume of the Journal

The Center on Disabilities at California State University, Northridge is proud to welcome you to the tenth issue of the *Journal on Technology and Persons with Disabilities*. For ten years, the journal has been an important forum for academics and researchers to showcase their work and highlight advances in the field. The Journal is comprised of published proceedings from the Annual CSUN Assistive Technology Conference, representing sessions from the Journal Track.

Over the last three decades, the conference has become the most significant global platform for meeting and exchanging ideas. The CSUN AT Conference is committed to bringing the conference to everyone, supporting research and projects, and the value they contribute to knowledge, new innovations and best practices to promote inclusion for all. After two years, we welcomed everyone back in-person at the Anaheim Marriott. It was incredible to have old friends and newcomers alike back together!

We are proud to serve the science and research community by providing the open access publishing opportunity to all presented works. All works included in the ninth volume of the *Journal on Technology and Persons with Disabilities* were rigorously reviewed and accepted by both the Journal Track Review Committee and our esteemed Journal Panel of Chairs.

A special thank you to all the authors, the Journal Track Review Committee, Journal Panel of Chairs, the CSUN Center on Disabilities team, 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 success of the CSUN Assistive Technology Conference and the Journal.

Regards,

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Center on Disabilities
California State University, Northridge
18111 Nordhoff Street
Northridge, California 91330-8340

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THE JOURNAL ON
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Creating Accessible XR Technologies: Rehabilitation for TBI

Jesse D. Flint¹, Jennifer M. Riley¹, Caitlin J. Lang²

Design Interactive, Inc.¹, University of Central Florida²

jesse.flint@designinteractive.net, jennifer.riley@designinteractive.net,
caitlinjlang@knights.usf.edu

Abstract

Extended reality (XR) technology has the potential to serve as an assistive tool for those with functional limitations- Both as support for those with long-term disabilities, and as a rehabilitation aid for recovery following acute injuries. This paper will explore possibilities for XR in recovery from head trauma, as well as consider how XR can be adapted to support people with functional limitations. Implications for rehabilitation and re-training for individuals with traumatic brain injury (TBI) will be discussed. TBI survivors typically have deficits in spatial cognition that lead to difficulties in navigation tasks. Individuals with TBI experience impairments in navigation skills, specifically in landmark recognition, allocentric location (ability to remember where landmarks are located on a map), and path route knowledge (recall for which direction to turn at intersections). To date there are no guidelines on the implementation of Augmented Reality (AR) specific to the development of tools to assist survivors of TBI in navigation. The first section of this report will document research related to TBI as well as provide specific evidence-based guidelines for designing navigational aids for individuals with TBI. The next section will provide general guidelines for creating augmented reality (AR) and mobile systems targeting the training and support of navigation for individuals with TBI. The final section of the report will provide a use case to demonstrate how the guidelines would appear in a mobile application to support navigation and re-training of navigation skills in users with TBI.

Keywords

Augmented Reality, Virtual Reality, Extended Reality, Traumatic Brain Injury,

Navigation, Egocentric Navigation

Introduction

Traumatic Brain Injury (TBI) is a form of acquired brain injury caused by a bump, blow or jolt to the head (CDC 1). The most frequent causes of TBI in civilian populations are falls, motor vehicle crashes, struck by or against events, and assaults (Langlois et al. 375). Within military populations, the major cause of TBI is from blast injuries and can be caused by changes in atmospheric pressure from a blast wave (primary blast injury), by being struck by an object in motion from a blast (secondary blast injury) or by the person hitting something like the ground or inside of a military vehicle (tertiary blast injury) (Warden 398). Disability stemming from TBI can cause immense disruptions to activities of daily living, and occupational therapy is often necessary to re-train some daily tasks. TBI survivors typically have deficits in spatial cognition that lead to difficulties in navigation tasks (Livingstone and Skelton 21). Individuals with TBI experience impairments in navigation skills, specifically in landmark recognition, allocentric location (ability to remember where landmarks are located on a map), and path route knowledge (recall for which direction to turn at intersections) (van der Kuil et al 4).

Fidopiastis et al. (11) provided a user-centered design framework focused on creating virtual environments for rehabilitation of persons with head trauma. The framework extended the ISO 9241-210 guidelines set for interactive systems by requiring technology assessment prior to use for persons with functional limitations. These assessments included human factors testing of system components and the integrated system with a user-in-the-loop protocol. However, to date there are no guidelines on the implementation of Augmented Reality (AR) specific to the development of tools to assist survivors of TBI in navigation.

Discussion

Impacts to Navigation

Individuals with TBI experience difficulties with memory including facial recognition, story recall, semantic information, perspective memory, and autobiographical memory (Skelton et al. 189). These issues with memory result in decreased capability to traverse known routes or to learn new routes, and even the inability to recognize familiar places and landmarks (Skelton et al. 189). Barrash et al. (820) demonstrated that individuals with focal brain lesions to the medial occipital and posterior parahippocampal cortices in either hemisphere, the right hippocampus, and the right inferotemporal region demonstrated reduced capabilities to learn real-world navigation routes. Skelton et al. (13) demonstrated that individuals with TBI navigating in virtual environments in which the end destination was not clearly visible followed indiscriminate paths (vs. control participants that navigated directly to the known location), took longer to reach the destination, and required more distance to search for the destination. Individuals with TBI have particular difficulty with interpreting allocentric navigation instructions and translating from allocentric to egocentric navigation information (Cogné et al. 168). Allocentric navigation refers to navigation that uses cues external to the traveler such as landmarks via a 2D overhead map. Typical navigation platforms such as Google Maps found on most smartphones are examples of allocentric navigation. Egocentric navigation refers to navigation from the perspective of the traveler. First person shooter style video games in which a player explores their surroundings from the first person perspective is an example of egocentric navigation.

Because TBI can impact different areas of the brain, the degree and type of impairments relevant to navigation can vary across individuals. However, a review of 67 case studies across 58 research papers of neurological impairments by Claessen et al. (94) did find a trend for one or

more of three different areas of impairments. First, many of the case studies found that individuals experienced difficulty with identifying or remembering familiar or new landmarks. The second type of common impairment was for recalling and/or acquiring information about landmark locations and their interrelationships. Finally, many of the individuals have difficulty acquiring or remembering the paths between locations. They have a tendency to produce distorted maps or were unable to describe routes between landmarks.

Support for Individuals with TBI

Programs designed to assist people with TBI in daily living skills can include training that addresses navigation impairments. However, due to the chronic nature of TBI as a source of cognitive impairment, navigation training does not generalize well and individuals with TBI still wrestle with problems such as forgetting scheduled trips, forgetting the purpose of a trip mid-trip, failing to recognize bus stops even for trained routes, getting irrevocably lost if a bus stop was missed, and experiencing anxiety about traveling alone or the possibility of getting lost (Sohlberg et al. 1253). Livingstone and Skelton (28) demonstrated that focus on the use of proximal landmarks can aid navigation in TBI survivors. Aids for navigation for individuals with TBI need to be in a format that can be used on a regular basis, include capabilities for reminders, and have functionality that can address situation in which users find themselves off course. Aids need to provide information on landmarks.

Assistive mobile devices are commonly used by people with TBI during wayfinding and navigation due to their portability and non-stigmatizing advantages (Schipper et al. 839). Liu et al. (1) evaluated the effectiveness of a mobile navigation device in an outdoor environment with two separate display modalities. For the first study, the device was capable of embedding plain photographs, directional symbols, photographs with highlighted areas, and photographs with

overlaid arrows. In addition, the device provided just-in-time directions to the user via redundant audio and text communications. Unsurprisingly, results for the first study found that when audio, text, and image assets were unsynchronized or misaligned with the users' perspective, navigation errors increased. The second study sought to measure how different landmark characteristics might influence navigation performance. Specifically, the mobile device portrayed images of landmarks from the users' perspective (i.e., egocentric viewpoint) that were either distinct (i.e., sculpture) or non-distinct (i.e., flagpole). The results concluded that navigation errors decreased when landmark images matched the users' perspective and were unique.

A crucial aspect of treatment for individuals with TBI includes improvements in "participation" which includes the ability to engage in meaningful activities and having a sense of belonging (Schipper et al., 839). Johnson & Davis (520) demonstrated that individuals with TBI who received therapy in which they interacted more with activities in the community demonstrated improved integrated social contacts. The ability to navigate with independence while still having access to support could play a critical role in developing "participation" in individuals with TBI. Aids for navigation for individuals with TBI need to provide the capability to communicate with a caregiver and provide the caregiver with real-time information on the location of the individual that is traveling.

In addition to improvements in the quality of life of individuals with TBI, it has been demonstrated that Virtual Reality (VR) navigation training tasks might also improve long term memory. Caglio et al. (124) provided VR navigation training for 90 minutes per session for three sessions a week across a three month period for a TBI patient who had shown no cognitive improvements across one year of rehabilitations. After the VR navigation training, the participant

showed improvement on a number of visual-spatial memory learning assessments and also showed increased activity in the hippocampus based on fMRI scans.

Sorita et al. (1377) demonstrated that individuals with TBI learn routes approximately as well in a virtual environment and a real environment. Participants demonstrated that most learning occurred from the first to the second time through a practice route and that error rates for 2 out of 3 assessments of route learning and wayfinding were the same across virtual and real routes. However, the assessments in which no differences were observed were for allocentric measures such as sketching out the route that was followed. The main difference in performance was for the only egocentric measure in which participants sorted pictures of actual intersections. Aids for navigation for individuals with TBI need to include the ability to rehearse routes (most likely through Virtual Reality) before traveling a new route.

Guidelines for Designing AR Mobile Applications for Individuals with TBI

Based on the research presented in the previous section, the following are guidelines for designing AR mobile applications for individuals with TBI:

1. **Support user safety by connecting the user to their caregiver when they are in need of help.** The system should provide a help button for the user to initiate live and direct contact with caregivers when they need assistance. The system should alert the caregiver to potential safety information such as deviations from a route, inactivity.
2. **Provide photo or video-based information regarding landmarks and destinations to assist with recognition.** TBI users have difficulty remembering and often processing landmarks. Only proximal landmark information should be presented at any given time.

3. **Provide the user with an opportunity to practice and familiarize themselves with a route before they depart.** The user should have an option to rehearse the route before they depart, familiarizing them with the route, the navigational cues, and the landmarks.
4. **Provide the user opportunities to train with the device to understand the system.** In addition to rehearsing a route, it is important that the user is able to properly train on using the application before departing.
5. **Allow users to create reminders before, during, and at the conclusion of navigation.** TBI users typically forget that they are scheduled to take a trip, the reason that they are currently traveling, and why they have arrived at a destination. The user should have the option to set pre-trip and on-route reminder such as time to leave for a trip, bus route needs, and what they need to prepare for their trip.
6. **Provide re-routing information quickly and in supportive language.** TBI users experience frustration and confusion when their intended route does not go as planned (e.g., a bus stop is missed). Any re-routing of users must secure user attention quickly and present useful information on how to handle being off route. Possible options for user information are: reminders of the purpose of the trip and direction they should be headed, and suggestions to call a care giver for support.
7. **Present the user with limited options to support decision making and prevent the user from being overwhelmed.** Individuals with TBI can experience information overload when engaging in tasks that might have been relatively easy pre-injury (Fasotti et al. 47). When information overload makes the user aware of their reduced cognitive performance, emotional distress and impulsive behavior may result (Rath et al. 487).

Display no more than 2-3 working items per page or nested list.

8. **Limit the complexity of displays of sensory information.** In addition to limiting the number of decision points on any given page, the system should not display irrelevant stimuli. This, in tandem with guideline 7 will further help prevent information overload.
9. **Information should be displayed in a user-centric manner, which matches the user's perspective.** User-centric displays of navigation information reduce ambiguity in which way the user should be headed and eliminates the cognitive load of mentally translating allocentric information to the first person perspective.
10. **Provide redundant cues in multiple modalities.** Redundant cues promote clarity and reduce the chance that a message will be missed or misinterpreted (Wickens et al. 722). Audio directions should also be displayed visually when possible.
11. **Provide instructions in short, concise, and clear messages.** Language decrements can make understanding long and complex messages difficult. Messages should be as concise as possible and not include unnecessarily complex sentence structure or vocabulary.
12. **Slow down audio cues.** For longer sentences, it would be beneficial to slow down the cue so that slowed information processing speed or language decrements are less likely to interfere with the user's ability to understand them.
13. **Allow for repetition of cues.** The user should have the ability to easily replay audio messages or repeat visual or vibrotactile cues as needed, cues should be repeated frequently during long periods of time between new cues.
14. **Provide frequent repetition and assurance that the user is headed in the correct direction.** Individuals with TBI may be easily distracted, and need help focusing their attention. Providing frequent feedback will support them in staying on task.

15. **When giving the user a choice, provide the choice first, and the response selection action second.** Responses should be intuitive and simple. The user should not be required to hold a response in working memory, and the response should be intuitive. For example, rather than telling the user, “Say ‘let’s go’ to begin route to the doctor’s office,” a better prompt would be, “To begin your route to the doctor’s office, say ‘begin route’.”
16. **Support maintaining path while avoiding cognitive overload through just-in-time multimodal directional cues.** Auditory and visual cues should be consistent and simultaneous, but not overwhelming. If a user is approaching an intersection, the system should tell them just in time when they are approaching a turn, rather than reminding them several times as they approach from a distance.
17. **Progressive disclosure of route via a virtual path and waypoints to avoid cognitive overload while supporting navigation.** Facilities like airports and hospitals experience high volumes of users not familiar with the facility that tend to experience cognitive issues. These facilities stress using the concept of progressive disclosure to aid in navigation throughout the facility (Huelat, 17; Liu et al., 25). Users are presented only with information that is necessary to get them to their next waypoint or decision point.

Use Case of AR in Navigation Applications

Based on the literature, certain features of a navigation support and re-training application are highly applicable to AR technologies available on smart phones. One of the key difficulties with navigation for individuals with TBI is with allocentric (top down 2D map projections) navigation. A navigation support and re-training application could use AR to overlay direction of travel on the actual scene in which a traveler is moving. Figure 1 presents a visualization of a visual AR egocentric travel mode overlay. The next issue of highest

importance with TBI navigation is with the use of landmarks. Many users have difficulty processing landmarks even for known locations. A possible solution that AR could provide is the replacement of the use of landmarks with the use of “waypoints” which are simple representations of the next area a user will need to arrive at. Use of waypoints coincides well with the use of “proximal landmarks” used in some studies as the users is simply focused on the next (proximal) location they need to achieve. Waypoints could indicate (for example by changing color) that a traveler has successfully navigated to the next stage of their trip. Figure 2 demonstrates the use of a waypoint in which the base of the waypoint has turned green to indicate that the traveler has successfully arrived as well as AR arrows indicating the next direction of travel and a text box indicating the direction of the traveler’s “next steps”.



Fig. 1. Example of AR Used to Present Egocentric Information for TBI Travelers.

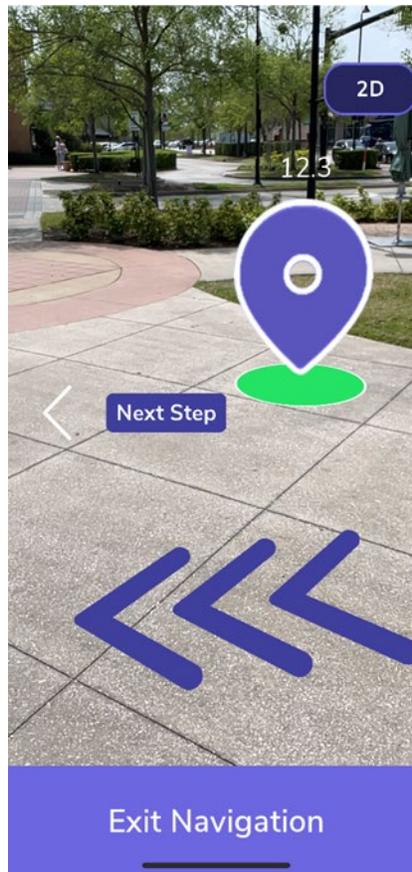


Fig. 2. Example of AR Waypoint Indicating Successful Arrival.

Conclusions

Wickens et al (653) proposed that map-study and practice in augmented or virtual spaces may provide a direct path to acquiring higher-order spatial skills in a representative environment, though to the best of our knowledge, this strategy has not been reviewed thoroughly in TBI-related literature. We propose future research into whether route practice in AR improves environmental mental models in individuals with TBI, and provides a benefit over traditional, 2D map study.

Haptic cues can provide information in an unobtrusive manner and provide redundancy to supplement auditory and visual information. Future research should determine how best to incorporate haptic, tactile, and vibrotactile cues to support individuals with TBI. Research is

needed to determine whether vibrotactile cues through a mobile device can effectively support wayfinding in individuals with TBI, or if TBI hinders the ability to use and remember vibration patterns as directional indications.

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Loneliness in the Aging Population with Visual Disabilities

Hyung Nam Kim
North Carolina A&T State University
hkim@ncat.edu

Abstract

Loneliness is likely to be affected by the level of subjective satisfaction with an individual's interpersonal relationships such that everyone could feel lonely regardless of visual ability/disability. However, little is known about the degree to which people with visual disabilities develop loneliness especially among older populations and how they manage their emotions. To address the knowledge gap, this study invited 18 older adults with visual disabilities to interviews. The participants completed the instruments of the UCLA Loneliness Scale and the Trait Meta-Mood Scale (TMMS) to measure the loneliness levels and the emotional intelligence abilities (i.e., emotional attention, clarity, and repair abilities) respectively. This study provided evidence that older adults with visual disabilities experienced a range of loneliness from low to severe and showed individual differences in emotional intelligence abilities by degree of loneliness, dimensions of emotions (i.e., valence and arousal), and a sociodemographic background (i.e., living alone and with others). The results of this study will be beneficial to many researchers and professionals in developing interventions to reduce loneliness in older adults with visual disabilities, for example, by improving their emotional attention, clarity, and repair abilities.

Keywords

Emotional Intelligence, Gerontology, Emotional Well-Being, Visual Impairment, Individual Differences, Emotional Ergonomics

Introduction

Loneliness is not synonymous with social isolation (i.e., lack of social contact) and is more likely associated with a subjective experience (Hawkley and Cacioppo 218). Loneliness is caused by a perceived difference between “interpersonal relationships that an individual currently” has and “those that the individual wishes to” have (Perlman and Peplau 123).

Loneliness is considered as a common emotional distress syndrome with a high risk factor for early mortality and a variety of physical health and psychiatric problems (Cacioppo et al. 238). Loneliness is more dangerous than obesity and as damaging to health as smoking 15 cigarettes every day (Health Resources & Services Administration), strongly related to suicidal ideation (Stravynski and Boyer 32), Alzheimer’s disease (Sundström et al. 919), and likely to affect the immune and cardiovascular system (Hawkley and Cacioppo S98).

Loneliness affects both people with and without visual disabilities. It is well documented that poor visual acuity is related with loneliness (Alma et al. 843). Evans (603), for example, conducted a survey using the UCLA Loneliness Scale (Russell et al. 290) with 84 American veterans who became blind. The survey found that 20% of the respondents experienced loneliness after determination of blindness. Increased loneliness in people with visual disabilities is associated with decreased economic well-being, mental health issues, dissatisfaction with activities of daily living, and low quality of life (La Grow et al. 487).

Despite evidence that people with visual disabilities are vulnerable to loneliness, little is known about how older adults with visual disabilities deal with the feeling of loneliness in terms of appraisal, expression, and regulation of emotions. Emotional intelligence is a type of social intelligence referring to the degree to which an individual can monitor one’s own and other’s emotions, discriminate among them, and use the information to guide one’s thinking and actions

(Mayer and Salovey 433). Emotional intelligence perceived by those with visual disabilities could, thus, help us to obtain a deep understanding of their ability to manage emotions including loneliness. This study aims to offer an in-depth understanding of the emotional intelligence capabilities of older adults with visual disabilities at risk of experiencing loneliness.

Methods

Participants

This study invited a convenience sample of 18 older adults with visual disabilities who should speak English, be 65 years old or older, and have visual disabilities (i.e., visual acuity level worse than 20/70, (World Health Organization)). Table 1 shows the participants' sociodemographic characteristics.

Table 1. Characteristics of the Participants (n=18).

| Characteristic | Number |
|---|---------------|
| Visual Acuity | |
| Between 20/70 and 20/200 | 2 |
| Between 20/200 and 20/400 | 10 |
| Between 20/400 and 20/1200 | 1 |
| Less than 20/1200, but has light perception | 1 |
| No light perception at all | 4 |
| Duration of Visual Disabilities (years) | 28.11±24.21 |
| Onset of Visual Disabilities (years)^a | |
| Early onset (n=4) | 7.00±5.89 |
| Late onset (n=14) | 56.29±15.00 |
| Age (years) | 73.39±8.17 |
| Gender | |
| Male | 3 |
| Female | 15 |
| Race/Ethnicity | |
| African American | 7 |
| European American | 11 |

| Characteristic | Number |
|---|---------------|
| Marital Status | |
| Married | 5 |
| Not Married | 4 |
| Widow/Widower | 4 |
| Divorced | 5 |
| Education | |
| High school or equivalent | 7 |
| Bachelors | 6 |
| Masters | 4 |
| Doctorate | 1 |
| Occupation | |
| Full time | 1 |
| Unemployed | 6 |
| Retired | 11 |
| Household Income | |
| < \$25,999 | 8 |
| \$26,000 – \$51,999 | 6 |
| \$52,000 – \$74,999 | 2 |
| ≥ \$75,000 | 1 |
| Declined to say | 1 |
| Head of Household | |
| Living alone | 10 |
| With family, relatives, friends, or combination of them | 8 |
| Diagnosed with Health Conditions | 10 |
| Participation in Physical Exercise | 10 |

^a Participants with early-onset visual disabilities had lost their sight before they reached 11 years of age (Voss et al. 1737).

Materials

Emotional intelligence abilities were measured with the Trait Meta-Mood Scale (TMMS). The TMMS is a 30-item self-report measure with a 5-point Likert scale designed to assess the attention to the feelings (13 items, Cronbach's $\alpha = .86$), the clarity of the emotional experiences (11 items, $\alpha = .88$), and the repair of the negative emotions (6 items, $\alpha = .82$)

(Salovey et al. 125). Loneliness was measured with the University of California Los Angeles (UCLA) Loneliness Scale version 3 (α ranging from .89 to .94) that is a 20-items self-report measure with a 4-point Likert type scale (Russell et al. 472). A score < 35 indicates a low degree, a score ≥ 35 indicates a moderate degree, a score ≥ 50 indicates a moderately high degree, and a score ≥ 65 indicates a severe high degree of loneliness. (Perry 293).

Procedures

Participants were recruited with supports from community organizations that provide services for people with visual disabilities (e.g., a community center and a library for the blind). This study was approved by the Institutional Review Board (IRB). Each participant was invited to an interview (less than 60 minutes) and completed the questionnaires of TMMS and UCLA Loneliness Scale. The interviewer read out loud for participants.

Results

Loneliness

The UCLA loneliness scale showed adequate internal consistency (Cronbach's $\alpha=0.93$), and the overall loneliness score was 38.89 ± 13.78 . Eight participants indicated a low degree of loneliness (26.75 ± 3.62), five indicated a moderate degree (39.40 ± 3.29), four indicated a moderately high degree (55.75 ± 3.77), and one indicated a severe high degree as the loneliness score was 66. For the data analysis purpose, the participant with a severe high degree of loneliness ($n = 1$) was integrated in the group who had a moderately high degree of loneliness. The Kruskal-Wallis test confirmed that the three groups had significantly different loneliness scores, $H(2) = 13.82, p = .001$. The ad-hoc Mann-Whitney U tests with Bonferroni correction were performed to follow up on the significant finding. All the three groups had significantly different loneliness scores: low vs. moderate loneliness ($U = 0, z = -2.94, p = .003, r = -.81$);

moderate vs. moderately high loneliness ($U = 0, z = -2.47, p = .014, r = -.82$); low vs. moderately high loneliness ($U = 0, z = -2.73, p = .006, r = -.79$). Sociodemographic factors were also examined. The loneliness levels between those living alone (41.20 ± 15.50) and those living with others (36.00 ± 11.63) were not significantly different ($U = 32.50, z = -.67, p = .50, r = -.16$).

Emotional Intelligence

The TMMS questionnaire measuring emotional intelligence showed adequate internal consistency (Cronbach's $\alpha = 0.73$). The Kruskal-Wallis test indicated that participants' emotional intelligence scores were significantly different depending on the level of loneliness, $H(2) = 10.35, p = .006$. The ad-hoc Mann-Whitney U tests with Bonferroni correction were performed to follow up on the significant findings. The level of emotional intelligence of the participant group with low loneliness (4.01 ± 0.52) was higher than that (3.60 ± 0.62) of their peer group with moderate loneliness, which was marginally significant, $U = 98.50, z = -2.36, p = .018, r = -.38$, but also significantly higher than that (3.34 ± 0.73) of the group with moderately high loneliness, $U = 80, z = -2.88, p = .004, r = -.46$. The results suggest that a higher level of loneliness is likely to be observed in people with a lower level of the emotional intelligence abilities in overall.

Furthermore, the emotional intelligence scores were broken down into three categories (i.e., attention, clarity, and repair) to be compared by degree of loneliness. The Kruskal-Wallis test showed that the attention, clarity, and repair ability scores were significantly different depending on the loneliness levels, $H(2) = 11.09, p < .01$. The ad-hoc Mann-Whitney U tests were performed with Bonferroni correction. The clarity level of the participant group with low loneliness (4.17 ± 0.33) was significantly higher than that (3.68 ± 0.11) of the group with moderate loneliness, $U = 0, z = -2.97, p = .003, r = -.82$, but also significantly higher than that (3.23 ± 0.58) of the group with moderately high loneliness, $U = 3.5, z = -2.45, p = .014, r = -.68$. The results

suggest that a higher level of loneliness is likely to be observed in people with a lower level of clarity ability.

Discussion

Loneliness

The overall mean of loneliness scores of older adults (age 65 and over) with visual disabilities was 38.89 ± 13.78 , ranging from low to severe high degree of loneliness, and none of them indicated that they were not lonely at all. A study by Russell (20), one of the most widely cited loneliness studies, reported that the overall mean of the loneliness scores of sighted older adults (age 65 and over) was 31.51 ± 6.92 , which is lower than that of older adults with visual disabilities in this study. Thus, it could hypothetically be argued that higher loneliness is likely to be found in older adults with visual disabilities than their sighted peers; however, other sociodemographic factors that were not considered (e.g., other emotional concerns, years of onset, and so on) may lead to different results. For example, Evans et al. (103) measured the loneliness level among older adults (age ranged from 53 to 76 years) with legal blindness (i.e., visual acuity equal to 20/200 or worse) and reported that the mean loneliness score was 42.2 ± 8.3 , which is greater than that of older adults with visual disabilities in this study; yet, Evans et al. (105) included clinically depressed participants. Therefore, it can be argued that older adults with visual disabilities who suffer from depression may feel lonelier than their peers who do not have such emotional challenges. Foxall et al. (86) also measured the loneliness level of individuals with visual disabilities and reported that the overall mean was 32.56 ± 10.13 , which is lower than that of older adults with visual disabilities in this study. Yet, the lower degree of loneliness in Foxall's study may be caused by different characteristics of the participants; for example, both younger and older individuals (ranging from 22 to 94 years) participated in their study but also

individuals who had residual vision were included but those with blindness were excluded from their study. In contrast to previous studies, the present study contributes to advancing knowledge of loneliness in community-dwelling older adults (age 65 and over) with visual disabilities whose visual acuity ranges from 20/70 up to blindness.

The participants in this study consisted of a combination of those living alone and those living with others, and we found that their loneliness levels were not significantly different. The result suggests that the onset of loneliness is less likely to be influenced by the condition of living *with* or *without* someone in the home. Such living conditions and the perceived loneliness have also been discussed in other loneliness studies. For instance, Foxall et al. (10) found no significant difference in loneliness levels between older adults with residual vision living alone and those living with family members. In addition, other loneliness studies that were conducted with sighted people provide comparative insights. For example, Yeh et al. (135) revealed that among older participants (72.6±5.5 years old) without visual disabilities living with someone, 60.8% felt lonely a little bit, 35% felt lonely somewhat, and 4.2% felt lonely strongly. Another aging study (Lim and Kua 4) found that a significantly higher frequency of social contacts was observed in sighted older adults (mean age 66 years) living alone than their peers living with others. Based on the results of those previous studies, it can be argued that older adults with visual disabilities – regardless of living alone or with someone – would still feel lonely while being influenced by both quantity and quality of their social and emotional relationships with people. Cacioppo et al. (977) also contended that people feel lonely even if they are in the crowd. Loneliness is believed to be a complex emotional construct (Yanguas et al. 302). Hyland et al. (1089) introduced multi-dimensions of loneliness, i.e., “*low*”, “*social*”, “*emotional*”, and

“*social and emotional*” loneliness. Our future research will further examine in detail the perceived loneliness of older adults with visual disabilities by referring to the four dimensions.

Emotional Intelligence Abilities

This study also examined the emotional intelligence abilities of older adults with visual disabilities, e.g., how much they can pay attention to the inner emotional states, how much they can understand and discriminate among different emotions, and how much they can regulate emotions and repair negative emotional experiences. As there have been a few published articles that investigated the emotional intelligence of people with visual disabilities, the findings of this study contribute to advancing knowledge of it, especially among those in old age. For instance, Kumar et al. (4) investigated the emotional intelligence in young age groups and reported that students with visual disabilities in senior secondary schools tended to show a lower level of emotional intelligence abilities as compared to sighted peer students. Salovey et al. (611) examined in detail the three subscales (i.e., attention, clarity, and repair abilities) among sighted students and reported that the mean of clarity levels was 3.27 ± 0.90 and the mean of repair levels was 3.59 ± 0.90 , which are lower than the clarity (3.57 ± 1.09) and repair (4.16 ± 0.87) levels of the older adults with visual disabilities in this study. Therefore, it can be argued that older adults with visual disabilities are likely to show an elevated level of perceived emotional intelligence as they get older. Other studies in gerontology (Anwar 295; Fariselli et al. 2) also suggest that aging contributes to improvement of one’s emotional intelligence. There are more evidence, for example, age does not significantly interfere with emotion management (Cabello et al. 1); the ability of regulating emotions remains intact in older adults (LaMonica et al. 1; Ochsner et al. 1); and old age is related with more stable and satisfying emotional well-being (Carstensen and Mikels 117; Carstensen et al. 21).

Furthermore, various theories of emotions offer valuable insights into understanding of the experience of emotions in older adults. Socioemotional Selectivity Theory (Carstensen et al. 103) posits that when people perceive time as finite (e.g., end-of-life), they are likely to give priority to finding emotional meaning and satisfaction from life in the moment rather than maximizing future rewards. As a result, older adults tend to focus on mood-enhancement goals (e.g., reducing the willingness of accepting negative experiences) instead of focusing on other goals such as gathering more information, experiencing novelty, and expanding breadth of knowledge for future (Carstensen 103). The Life-Span Theory of Control (Heckhausen and Schulz 284) poses that aging causes people to decrease the capacity to control their environment and achieve their developmental goals; therefore, older adults are more likely to rely on secondary control strategies such as emotional regulation to change *themselves* to adjust to a given situation instead of primary control strategies that change the *situation*. Cacioppo et al. (12) also explained the elevated emotional well-being via social neuroscience, that is, the lower activation in amygdala (*located close to the hippocampus in the frontal portion of the temporal lobe, essential to the ability to feel certain emotions* (Pessoa 3416)) could selectively hinder the processing of negative stimuli, leading to protections against threats to well-being. As the present study did not include younger people with visual disabilities, our future research will further investigate the aging effect on the emotional intelligence abilities between younger and older people with visual disabilities.

Loneliness and Emotional Intelligence Abilities

This study compared the perceived emotional intelligence abilities by different levels of loneliness. A higher level of loneliness was observed in the participants with a lower level of emotional intelligence in overall. In particular, the participants with a higher level of loneliness

tended to have a lower level of the “clarity” ability. Given the results of this study, it could be hypothetically argued that the clarity ability is likely to contribute to lowering the perceived loneliness. There is evidence that the clarity ability plays an important role in regulating mood; for example, an individual who is clear about his/her emotion is likely to rebound from induced negative mood (Salovey et al. 126). Palmer et al. (1907) also reported that the clarity ability was positively related to life satisfaction. Salovey et al. (129) uncovered that the clarity ability was significantly intercorrelated with another emotional intelligence construct, *the repair ability*.

Given the finding that older adults with visual disabilities are vulnerable to experiencing loneliness, there is a need to develop a training program that aims to enhance the emotional intelligence abilities (especially the clarity ability), as adequate training is found to be effective in improving the emotional intelligence abilities (Grant 257). The findings of this study are expected to contribute to a knowledge foundation to develop an emotional intelligence training program for older adults with visual disabilities.

Limitation

This study included 3 male and 15 female participants. There is evidence that a relationship exists between gender and perceived loneliness (Borys and Perlman 63; Stokes and Levin 1069) as well as between gender and emotional intelligence (Brackett et al. 1387; Fernández-Berrocal et al. 77). This study might result in different outcomes if it included more male participants. Our future research will be conducted by addressing the limitation.

Conclusions

This study found that older adults with visual disabilities were vulnerable to the feeling of loneliness (ranging from low to severe), and those with different degrees of loneliness showed different abilities to pay attention to, clarify and repair emotions. This study provides valuable

insights into the development of interventions to promote emotional well-being in older adults with visual disabilities at risk of experiencing loneliness.

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Preliminary Research on AI-generated Caption Accuracy Rate by Platforms and Variables

Rebecca Graham, Jinhee Choo

Westminster College, University of Illinois at Urbana-Champaign
grahamrn@westminster.edu, jchoo@illinois.edu

Abstract

As a result of the global Coronavirus pandemic, there has been a rapid increase in online courses and digital educational materials, specifically video content. It is a legal requirement in the United States that these educational materials be accessible to those with disabilities. In the case of educational videos, this requires that clean and accurate captions are provided, as well as text or audio descriptions of all visual images within the video, in a format that is accessible to learners. Many educators lack an understanding of the details of the legal requirements and the skills, financial resources, staff, and technical support needed to fulfill them. As a result, many rely on Artificial Intelligence (AI)-generated captions and descriptions for their educational videos, if they provide them at all. Here, we report the results of a preliminary analysis of the accuracy rates of several popular platforms used to create AI-generated captions. Based on our results, these AI-generated captions have, on average, an accuracy rate of 89.8%, which does not meet the current legal requirements and industry standards for digital accessibility. We show the importance of manually copyediting captions and share insights from our data analysis which will assist educators to make their video content more accessible.

Keywords

Captions, Accessibility, Accuracy, Artificial Intelligence

Introduction

2020 saw a steep and rapid increase in online instruction as educators worked to find ways to teach during a global pandemic. In the rush to provide digital content, specifically video content, accessibility is often overlooked. To many, accessibility in education refers to things like wheelchair access and extended time for exams, but digital accessibility—the degree to which digital content is accessible and usable by learners with a variety of disabilities—is crucial to ensuring that all learners have an “equal opportunity to benefit” (U.S. Dept. of Justice) from the content, especially at a time where many educators have been forced to pivot to online learning.

Accessibility, when it comes to video content, requires providing captions, audio descriptions of images or actions taking place in the video, and providing a video player which supports screen reader use and keyboard navigation. The scope and focus of this study is limited to captions. Captions are time-synchronized text versions of the words and sounds in a video. Captions are designed for use by Deaf or Hard of Hearing learners, but also benefit learners on the Autism Spectrum, with ADHD and other cognitive differences, as well as able-bodied and neurotypical learners for whom English is not their native language, or who need to watch videos in a sound-sensitive area.

However, captions are only accessible and useful if they accurately reflect the words and sounds in the video. Incorrect spelling and punctuation, or misrepresentation of the words spoken, can change the meaning of the content, instructions, and/or field-specific terms presented in educational videos. For learners who are able to hear the audio, this can be confusing and frustrating; learners found these types of errors to be a “distraction” and that they limited “the value of the captions” (Morris et al., 235). For Deaf or Hard of Hearing learners,

the implications are more serious. Inaccurate captions leave them at a significant disadvantage as the captions may be their only method of accessing the content. When it comes to captions, accuracy matters.

The Americans with Disabilities Act (ADA) requires that learners with disabilities be given an “equal opportunity to benefit” (U.S. Dept. of Justice) from all content. Section 508 of the Rehabilitation Act of 1973 further states that all digital media must meet the Web Content Accessibility Guidelines (WCAG) at the AA level. WCAG 2.1, issued in June 2018, recommends that “captions [be] provided for all prerecorded audio content in synchronized media” (W3C) but does not address issues of accuracy. The legal requirements surrounding caption accuracy come from the Federal Communications Commission (FCC) mandate, 47 CFR 79.1(j)(i), issued in 2014 which states that

Captioning shall match the spoken [word]...in their original language (English or Spanish), in the order spoken, without substituting words for proper names and places...Captions shall contain proper spelling (including appropriate homophones), appropriate punctuation and capitalization, correct tense and use of singular or plural forms, and accurate representation of numbers with appropriate symbols or words.

The FCC provided an amendment to the document which clarified that “punctuation and capitalization [should] reflect natural linguistic breaks and the flow of the dialogue” (Federal Communications Commission, 17913). A later clarification concerning a quantitative measure of accuracy was added which provided the broad guideline of meeting current industry standards; The industry standard, as of 2020, is an accuracy rate of 99% or higher (Enamorado).

When measuring caption accuracy rates, the industry standard is to break down the measurement into two categories: Word Error Rate (WER) and Formatted Error Rate (FER)

(Edelberg). WER measures the degree to which the captions accurately reflect the exact words spoken including spelling and verb tense. FER measures the accuracy of elements like grammar, punctuation, and capitalization. In order to be considered compliant with the FCC mandates, the overall accuracy rate—both categories combined—must meet or exceed 99%. In an attempt to meet this requirement, many have turned to auto-captions—captions generated using speech-to-text or automatic speech recognition software and Artificial Intelligence (AI) based algorithms. AI-generated captions are the easiest, fastest, and cheapest option available to. With so many educators relying on AI-generated captions, the question of how accurate these AI-generated captions are is becoming increasingly important. The research team set out to determine if AI-generated captions are currently capable of meeting the legal requirements around digital accessibility by achieving the industry standard of a 99% or higher accuracy rate.

1. Literature Review

While research has been done into how captions impact knowledge retention and test performance, there has been very little research measuring and analyzing the accuracy of those captions. One of the first articles to tackle this issue was published in 2008 and addressed the beginnings of Automatic Speech Recognition (ASR) and its use in the classroom. The study reported that the software had significant limitations around formatting and punctuation (Wald et al. 3). The software at the time functioned based on “statistical probabilities of word sequences and not syntax or semantics” (Wald et al., 11) and therefore the accuracy of the words chosen was not reliable either. The proposed solution was to have live, real-time caption editing that occurred as the lectures were being recorded; this has proven to be both cost and resource-prohibitive. ASR technology has come a long way, but as this research will show, these same types of formatting and word errors still persist and can significantly impact caption accuracy.

The only article found which directly attempted to measure and analyze AI-generated captions of videos in higher education was Parton's 2016 work which focused specifically on YouTube's algorithm and concluded "that auto-generated captions are too inaccurate to be used exclusively" (Parton, 8) and that the "auto-captions would not appear to meet the Office for Civil Rights criteria...[meaning that] Universities are therefore unlikely to be meeting their legal obligation to provide accessible material" (Parton, 15) if they are relying solely on AI-generated captions.

2. Methods

During the Fall 2020 semester, a manual review was conducted of the accuracy of four major AI-generated caption platforms: Kaltura, Microsoft's Class Transcribe, Google's YouTube, and Panopto. Five videos were selected to be tested across platforms and details about the videos including length, number of words spoken, and metadata (video title, related course, speaker) were recorded. Videos were selected using the following criteria: videos were to be less than 15 minutes in length, were to cover a variety of topics and levels of difficulty (referred to as content density), and were to provide diversity among the variables to be tested. Variable categories, including sex of the speaker, rate of speech (165 words per minute is considered "quick speech"), presence of an accent, and the density of the content ("heavy" content contained complex or field-specific terms and acronyms; "light" content did not), were selected with the intent to measure to what extent these aspects impacted the accuracy of the automatic captions [Table 1].

Table 1. Video Metadata.

| Title | Length | # of Words | Content Density | Sex | Speed | Accent |
|----------------------------------|---------------|-------------------|------------------------|------------|--------------|---------------|
| What It Means to Be Professional | 3:02 | 494 | Light | Female | Moderate | No |
| Information and Technology | 9:35 | 1649 | Heavy | Male | Fast | No |
| Demand Curves | 12:57 | 2297 | Heavy | Male | Fast | No |
| The Goal of Financial Management | 7:47 | 860 | Light | Female | Moderate | Yes |
| Balance Sheet: Fiscal Year | 5:25 | 592 | Heavy | Female | Moderate | Yes |

Videos were uploaded to each of the platforms and automatic captions were generated.

The resulting transcript files were downloaded and manually copyedited according to the APA style guide with the “track changes” feature turned on. Errors were recorded by type as specified in FCC 47 CFR 79.1(j)(i): Word-level accuracy (“match the spoken words... in the order spoken...[with] proper spelling...[and] correct tense”), punctuation, and capitalization. To align with industry standard measurements, errors were divided into formatting errors and word errors. Incorrect spelling and incorrect tense were counted as word errors, per FCC 47 CFR 79.1(j)(i).

Accuracy rates were calculated by error type and then as an overall accuracy rate for the transcript. The number of errors by type (A) were calculated and subtracted from the total number of words spoken (B) to obtain the number of error-free words. The number of error-free

words was then divided by the total number of words spoken (B) to obtain the accuracy rate (C)

$$\text{for each type of error: } \frac{(B-A)}{B} = C$$

Example (from video 1): Total words spoken: 494, Total formatting errors: 12, Total word errors: 3, FER: $(494-12)/494 = 97.5\%$, and WER: $(494-3)/494 = 99.3\%$ This calculation was repeated using the total number of errors (all types combined) to obtain the overall accuracy rate. Total errors: $12 + 3 = 15$ and Overall $(494-15)/494 = 96.9\%$

3. Results

The average overall accuracy rate across platforms was 89.8%, nearly 10 percent below the industry standard. Average accuracy rates by platform ranged from 84.6% to 93.6% [Table 2a-2d], with a p of 0.000936 [Table 3a-3b]; no platform produced an overall accuracy rate that met the 99% minimum [Table 4].

Table 2a. Accuracy Rates for Each Video for Kaltura.

| Video | FER | WER | Total Accuracy |
|--------------|------------|------------|-----------------------|
| Video 1 | 97.5 | 99.3 | 96.9 |
| Video 2 | 96.7 | 97.8 | 94.5 |
| Video 3 | 91.9 | 97.2 | 89.2 |
| Video 4 | 98.3 | 96.9 | 95.3 |
| Video 5 | 98.6 | 94.0 | 92.7 |

Table 2b. Accuracy Rates for Each Video for Microsoft.

| Video | FER | WER | Total Accuracy |
|--------------|------------|------------|-----------------------|
| Video 1 | 90.0 | 98.4 | 88.5 |
| Video 2 | 86.7 | 96.6 | 83.3 |

| Video | FER | WER | Total Accuracy |
|--------------|------------|------------|-----------------------|
| Video 3 | 87.5 | 96.2 | 83.8 |
| Video 4 | 94.8 | 97.8 | 92.6 |
| Video 5 | 95.7 | 94.7 | 90.5 |

Table 2c. Accuracy Rates for Each Video for Google.

| Video | FER | WER | Total Accuracy |
|--------------|------------|------------|-----------------------|
| Video 1 | 82.8 | 99.8 | 82.6 |
| Video 2 | 84.5 | 99.7 | 84.2 |
| Video 3 | 83.1 | 98.9 | 82.0 |
| Video 4 | 87.8 | 99.7 | 87.4 |
| Video 5 | 88.3 | 98.3 | 86.7 |

Table 2d. Accuracy Rates for Each Video for Panopto.

| Video | FER | WER | Total Accuracy |
|--------------|------------|------------|-----------------------|
| Video 1 | 97.4 | 99.8 | 97.2 |
| Video 2 | 94.0 | 96.8 | 90.8 |
| Video 3 | 93.5 | 95.7 | 89.4 |
| Video 4 | 97.3 | 97.7 | 95.0 |
| Video 5 | 97.3 | 96.0 | 93.0 |

Table 3a. Sum, Average, and Variance for Overall Accuracy Rate.

Summary: α 0.05; H1: $\mu < 99.0$; H0: $\mu \geq 99.0$

| Groups | Count | Sum | Average | Variance |
|-----------|-------|-------|---------|----------|
| Kaltura | 5 | 467.8 | 93.56 | 7.528 |
| Microsoft | 5 | 439.1 | 87.82 | 17.767 |
| Google | 5 | 422.9 | 84.58 | 5.792 |
| Panopto | 5 | 465.4 | 93.08 | 9.852 |

Table 3b. Anova Single Factor Analysis for Overall Accuracy Rate.

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---------------------|---------|----|------------|------------|------------|------------|
| Between Groups | 280.292 | 3 | 93.43067 | 9.128769 | 0.000936 | 3.238872 |
| Within Groups | 163.756 | 16 | 10.23475 | Empty cell | Empty cell | Empty cell |
| Total | 444.048 | 19 | Empty cell | Empty cell | Empty cell | Empty cell |

Table 4. Average Accuracy Rate by Platform.

| Platform | FER | WER | Total |
|-----------|------|------|-------|
| Kaltura | 96.6 | 97.0 | 93.7 |
| Microsoft | 90.9 | 96.7 | 87.7 |
| Google | 85.3 | 99.3 | 84.6 |
| Panopto | 95.9 | 97.2 | 93.1 |

Kaltura and Panopto had the highest overall accuracy ratings at 93.1% and 93.6% while both Microsoft and Google's platforms failed to even reach 90% overall accuracy. All platforms tested scored higher in the WER category than the FER category showing that across platforms, the AI algorithms have an easier time recreating the words spoken than applying grammar rules such as punctuation and capitalization.

3.1 Results by Platform

Kaltura's automatic captioning system produced an overall accuracy rate of 93.7% (96.6% FER, 97.0% WER); 62% of formatting errors were incorrect punctuation, mostly incorrect comma placement, and 31% of error were sentence splits [Table 5a].

Table 5a. Formatting Error Rate by Error Type for Kaltura [6].

| Error Type | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Total | Percent |
|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|----------------|
| Punctuation | 5 | 25 | 126 | 6 | 3 | 165 | 0.62 |
| Sentence Split | 6 | 13 | 52 | 7 | 5 | 83 | 0.31 |
| Capitalization | 1 | 12 | 5 | 1 | 0 | 19 | 0.07 |

Table 5b. Formatting Error Rate by Error Type for Microsoft.

| Error Type | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Total | Percent |
|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|----------------|
| Punctuation | 22 | 116 | 143 | 20 | 7 | 308 | 0.50 |
| Sentence Split | 26 | 89 | 128 | 18 | 15 | 276 | 0.45 |
| Capitalization | 3 | 15 | 9 | 6 | 3 | 36 | 0.06 |

Table 5c. Formatting Error Rate by Error Type for Google.

| Error Type | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Total | Percent |
|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|----------------|
| Punctuation | 32 | 118 | 178 | 37 | 11 | 376 | 0.42 |
| Sentence Split | 32 | 90 | 153 | 49 | 31 | 355 | 0.39 |
| Capitalization | 21 | 47 | 55 | 19 | 27 | 169 | 0.19 |

Table 5d. Formatting Error Rate by Error Type for Panopto.

| Error Type | Video 1 | Video 2 | Video 3 | Video 4 | Video 5 | Total | Percent |
|-------------------|----------------|----------------|----------------|----------------|----------------|--------------|----------------|
| Punctuation | 5 | 64 | 75 | 9 | 5 | 158 | 0.53 |
| Sentence Split | 6 | 28 | 68 | 12 | 11 | 125 | 0.42 |
| Capitalization | 2 | 6 | 6 | 2 | 0 | 16 | 0.05 |

Kaltura performed 2.8% worse overall on videos where the speaker spoke quickly (>165 wpm), with a 3.6% decline in FER. Content density appeared to play some role in accuracy, with “light” content achieving an overall accuracy rating that was 3.4% higher than the “heavy” content [Table 6a].

Table 6a. Average Accuracy Rate by Variable by Platform for Kaltura.

| Variable cell | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Moderate Speed | 98.1 | 96.7 | 95.0 |
| Fast Speed | 94.3 | 97.5 | 91.9 |
| Accent | 98.5 | 95.5 | 94.0 |
| No Accent | 95.4 | 98.1 | 93.5 |
| Light Content Density | 97.9 | 98.1 | 96.1 |

| Variable cell | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Heavy Content Density | 95.7 | 96.3 | 92.1 |

Table 6b. Average Accuracy Rate by Variable by Platform for Microsoft.

| Variable | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Moderate Speed | 93.5 | 97.0 | 90.5 |
| Fast Speed | 87.1 | 96.4 | 83.6 |
| Accent | 95.3 | 96.3 | 91.6 |
| No Accent | 88.1 | 97.1 | 85.2 |
| Light Content Density | 92.4 | 98.1 | 90.6 |
| Heavy Content Density | 89.9 | 96.0 | 85.9 |

Table 6c. Average Accuracy Rate by Variable by Platform for Google.

| Variable | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Moderate Speed | 86.3 | 99.3 | 85.6 |
| Fast Speed | 83.8 | 99.3 | 83.1 |
| Accent | 88.1 | 99.0 | 87.1 |
| No Accent | 83.5 | 99.5 | 82.9 |
| Light Content Density | 85.3 | 99.8 | 85.0 |
| Heavy Content Density | 85.3 | 99.0 | 84.3 |

Table 6d. Average Accuracy Rate by Variable by Platform for Panopto.

| Variable | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Moderate Speed | 97.3 | 97.8 | 95.1 |
| Fast Speed | 93.8 | 96.3 | 90.1 |
| Accent | 97.3 | 96.9 | 94.0 |
| No Accent | 95.0 | 97.4 | 92.5 |
| Light Content Density | 97.4 | 98.8 | 96.1 |
| Heavy Content Density | 94.9 | 96.2 | 91.1 |

Kaltura had one instance of a word error which seriously altered the meaning of the content. In one video, the sentence “It just makes the problem more intractable.” was rendered as “It just makes the problem more tractable” giving the content the exact opposite meaning as was intended. This illustrates the importance of carefully reviewing and copyediting AI-generated captions to ensure content is being correctly represented.

Microsoft’s automatic captioning system produced an overall accuracy rate of 87.7% (90.9% FER, 96.7% WER). 50% of formatting errors were incorrect punctuation, 45% were sentence split errors, and 6% were incorrect capitalization [Table 5b]. Rate of speech appeared to play a significant role in Microsoft’s performance, with a 7.1% decline in overall accuracy when the speaker spoke quickly. These errors were mostly found in the FER category, specifically, Microsoft’s algorithm struggled with correct comma placement. Surprisingly, there was little difference (< 1%) in the WER, where one might assume that the algorithm would struggle to identify individual words with a faster rate-of-speech.

Google’s automatic captioning system produced an overall accuracy rate of 84.6%

(85.3% FER, 99.3% WER). Google's AI-generated captions were able to achieve a 99% average for WER (with three of the five videos exceeding 99%), however, Google's average FER was the worst of the platforms tested at 85.3% (5.7% worse than the next lowest scoring platform). Specifically, Google's platform performed significantly worse than the other platforms in the capitalization category, with 19% of formatting errors resulting from incorrect capitalization.

It is important to note that Google's automatic captioning system does not remove vocal stutters, fillers (um, uh, etc.) or repeated words the way that all three of the other platforms do. Best practice is to not include these types of filler words in captions as they clutter the screen and have a negative impact on grammatical accuracy and comprehension. The presence of these filler words was not counted as an error, as the captions do directly reflect what was spoken in the video, however one should consider that additional copyediting will be needed to remove these words before publishing a video.

Panopto's automatic captioning system produced an overall accuracy rate of 93.1% (95.9% FER, 97.2% WER) with incorrect punctuation accounting for 53% of formatting errors, sentence splits accounting for 42% of errors, and the remaining 5% of formatting errors were incorrect capitalization [Table 5d]. Panopto performed worse on videos where the speaker spoke quickly (> 165 wpm), with a 5% decline in overall accuracy. Like the other platforms tested, this decline in accuracy was seen in the FER (3.5% difference) more than in the WER (1.5% difference).

3.2 Results by Variable

Looking at the data across all four platforms broken down by variable – sex of the speaker, rate of speech, presence of an accent, and content density – revealed some consistent factors which impacted accuracy. The most significant impact seems to be rate of speech. On

average, the AI-generated captions were 4.3% less accurate with a faster speech rate (91.5% overall accuracy vs. 87.2% overall accuracy) [Table 7].

Table 7. Average Accuracy Rate by Variable.

| Variable | FER | WER | Total |
|-----------------------|------------|------------|--------------|
| Male | 89.7 | 97.4 | 87.2 |
| Female | 93.8 | 97.7 | 91.5 |
| Fast Speed | 89.7 | 97.4 | 87.2 |
| Moderate Speed | 93.8 | 97.7 | 91.5 |
| Accent | 94.8 | 96.9 | 91.7 |
| No Accent | 90.5 | 98.0 | 88.5 |
| Light Content Density | 93.2 | 98.7 | 91.9 |
| Heavy Content Density | 91.5 | 96.8 | 88.3 |

This most impacted formatting issues such as comma placement and sentence splits (4.1% difference in FER, virtually identical WER).

Surprisingly, accuracy rates were higher across all four platforms for non-native English speakers or speakers with a noticeable accent (approximately 3% higher, overall). This finding directly contradicted our hypothesis with regard to how the AI algorithms would handle accented speech. Upon deeper review, we determined that speakers with noticeable accents spoke more slowly, likely in an intentional effort to be understood. We believe that the rate of speech is the determining factor and not the presence or absence of an accent.

Content density played a moderate roll in accuracy on all platforms except Google. A difference of, on average, 1.7% in FER across all four platforms was present (93.2% FER for

“light” content and 91.5% FER for “heavy” content). However, due to the overlap between those who spoke quickly and those who were covering heavier content, it is difficult to definitively state which variable is responsible. We believe that, as in our analysis of accented speech, the difference in FER is more likely to be caused by the rate of speech rather than the complexity of the content (which is unlikely to impact capitalization, punctuation, or sentence splits).

We were unable to analyze the impact that the sex of the speaker may play (whether related to pitch, tone, or volume of voice, or to any potential bias in the algorithms) because of a 1:1 overlap with rate of speech. Our female speakers spoke more slowly and our male speakers more quickly resulting in differences in accuracy rates which exactly mirrored those found in the rate of speech category. Further study is needed to determine any role this variable might play in caption accuracy.

It is important to note that no single variable produced statistically significant differences in performance for any of the platforms ($p > 0.05$) [Tables 8b and 9b].

Table 8a. Sum, Average, and Variance for FER.

Summary: $\alpha 0.05$; $H1: \mu < 99.0$; $H0: \mu \geq 99.0$

| Groups | Count | Sum | Average | Variance |
|---------------|--------------|------------|----------------|-----------------|
| Kaltura | 5 | 482.2 | 96.44 | 7.218 |
| Microsoft | 5 | 454.8 | 90.96 | 17.183 |
| Google | 5 | 426.5 | 85.3 | 6.745 |
| Panopto | 5 | 479.5 | 95.9 | 3.885 |

Table 8b. Anova Single Factor Analysis for FER.

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---------------------|---------|----|-------------|------------|--------------|-------------|
| Between Groups | 404.026 | 3 | 134.6753333 | 15.37785 | 0.0000566756 | 3.238871517 |
| Within Groups | 140.124 | 16 | 8.75775 | Empty cell | Empty cell | Empty cell |
| Total | 544.15 | 19 | Empty cell | Empty cell | Empty cell | Empty cell |

Table 9a. Sum, Average, and Variance for WER.

Summary: α 0.05; H1: $\mu < 99.0$; H0: $\mu \geq 99.0$

| Groups | Count | Sum | Average | Variance |
|-----------|-------|-------|---------|----------|
| Kaltura | 5 | 485.2 | 97.04 | 3.743 |
| Microsoft | 5 | 484.1 | 96.82 | 1.712 |
| Google | 5 | 496.4 | 99.28 | 0.432 |
| Panopto | 5 | 486 | 97.2 | 2.715 |

Table 9b. Anova Single Factor Analysis for WER.

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---------------------|---------|----|------------|------------|------------|------------|
| Between Groups | 19.5175 | 3 | 6.505833 | 3.025265 | 0.060194 | 3.238872 |
| Within Groups | 34.408 | 16 | 2.1505 | Empty cell | Empty cell | Empty cell |
| Total | 53.9255 | 19 | Empty cell | Empty cell | Empty cell | Empty cell |

Performance on individual variables was +/- 2% of the average accuracy rates across all three

measures (FER, WER, Overall accuracy). Repeating the study with a larger sample size, and specifically a sample set that included videos chosen to reduce or remove variable overlap may produce a more significant data set. Despite the lack of statistical significance, observing the variance in accuracy rates by variable has provided important insights into actions that the speaker and caption editors can take to ensure more accurate and accessible, videos.

Discussion

As stated, rate of speech had a measurable impact on the accuracy of the captions produced. A first step toward accessible video content is for the speaker to focus on intentionally maintaining a rate of speech around 120-160 wpm, which is the range where most “people comfortably hear and vocalize words” (Barnard). This will likely help to provide the AI algorithm a clear indication of the need for ending punctuation and may reduce sentence split errors.

While maintaining speech rate should help to improve automatic caption accuracy, post-production copyediting of captions will still be necessary. We highly recommend employing a team of post-production experts to ensure a high-quality and accessible end product. This team should include a trained copyeditor who can accurately apply grammar, style, and spelling rules and someone with field-specific content knowledge to ensure that acronyms and field-specific terms are accurately represented. Specific attention should be paid by the copyeditor to comma placement and sentence splits as those accounted for roughly 80+% of the formatting errors found in this study.

Conclusions

The data show that the AI-generated caption platforms tested were not currently able to consistently produce captions which meet the legal requirements and industry standards required

of higher education. While the four platforms tested represent only a sample of those available on the market, Kaltura, Microsoft, Google, and Panopto are used by a large number of higher education institutions. Therefore, it is reasonable to assume, based on this data, that institutions who are relying solely on AI-generated captions, regardless of which platform they are using, are likely not meeting the legal requirements set forth by the ADA and Rehabilitation Act of 1973 or the industry standards established by the FCC.

That is not to say that AI-generated captions should not be used. Budget, staffing, and time constraints are a serious issue in higher education and manual transcription of videos is both unrealistic and unnecessary. AI-generated captions provide an excellent starting point for creating accessible video content; with the addition of manual copyediting, either by trained copyeditors or via community collaboration, accessible videos can be created that meet the legal requirements and industry standards.

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AI Based Recommendation and Assessment of AT for People with Cognitive Disabilities

Peter Heumader, Tomas Murillo Morales, Klaus Miesenberger
Institut Integriert Studieren, Johannes Kepler University Linz,
Altenbergerstraße 69, 4040 Linz
peter.heumader@jku.at, tomas.murillo_morales@jku.at,
klaus.miesenberger@jku.at

Abstract

Nowadays a considerable amount of assistive technology (AT) is available for people with cognitive disabilities. However, many users with cognitive disabilities do not make use of any AT, as they are not aware of which suitable technologies are available for their specific needs. This paper describes a modern web-based recommendation system, named Buddy, that enables persons with a cognitive disability to discover AT without the need for external support

Keywords

web accessibility, cognitive accessibility, assistive technology

Introduction

In recent years a considerable number of accessibility tools have become available on the market, aiming to provide better support to people with cognitive disabilities when accessing the World Wide Web (Miesenberger, K., Edler, C., Heumader, P., & Petz, A.: Tools and Applications for Cognitive Accessibility). Being able to access and navigate the Web in an autonomous manner is essential for inclusion in society in most aspects of daily life, such as education, work, leisure, and overall participation in society. Although increased web accessibility is being improved by policy, standards and regulations, there is evidence that the uptake of digital content by people with cognitive disabilities and their formal and informal service sectors has been considerably lagging behind.

State of the art

Despite the lack of legally binding requirements, technical support for cognitive accessibility is being developed at different levels (Miesenberger, K., Edler, C., Heumader, P., & Petz, A.: Tools and Applications for Cognitive Accessibility):

- Mainstream mobile technology based on touch/gesture interactions, which people with cognitive disabilities often use without support from formal or informal care providers, often reaches the necessary level of usability and comprehensibility by cognitive disabled people.
- Well-established website manipulation techniques can support users with cognitive impairments, for example by offering layout adaptation capabilities such as font selection, font size, line/character/word spacing, foreground/background color, as well as voice in/output. However, these are hard to find and handle for our target audience.
- Some digital content is becoming more adaptable and customizable in terms of the language level, images, symbols and videos it employs. Content and interaction personalization can be particularly useful for users with cognitive impairments.

- Content customization is well supported through the trend of enriching the web with semantic information, which allows for better personalization and cognitive support.
- Pioneering approaches to supported or automated translation into easy to read, symbol languages annotation, for language translation are available. These technologies are not yet fully reliable but show the way forward for better digitally supported cognitive accessibility and digital services.

All in all, there is knowledge about cognitive user needs and there are tools on the market which can address many of these needs. Although technology is available, many users with cognitive disabilities are not aware of their existence and therefore struggle with digital content and services.

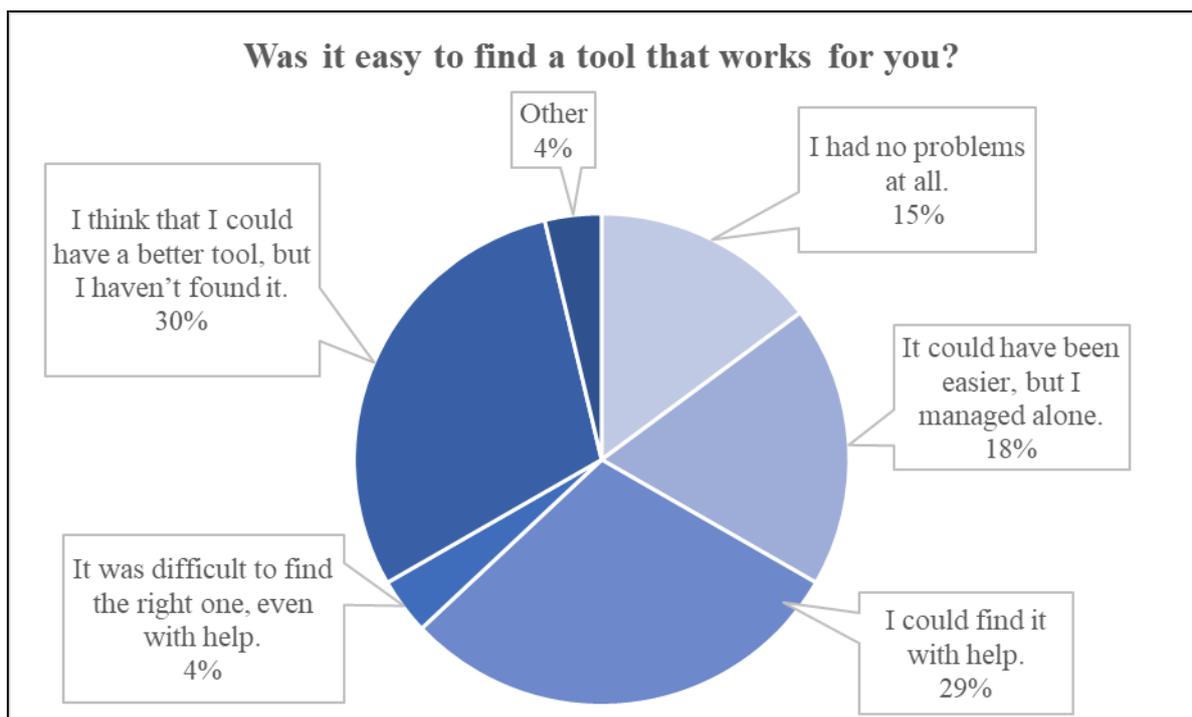


Fig. 1. Results from a User Study on Assistive Technology Usage in Sweden and Austria.

The present research started by studying how end users with cognitive disabilities discover and use AT by conducting an online survey with selected participants in Sweden, Austria, the United Kingdom, and Lithuania. 88 valid responses were received. Almost half of these participants reported that they were responding for themselves, with the remaining

ones reporting that they were filling in the survey on behalf of a cognitive disabled person (most commonly, a friend or relative). This split suggests that respondents cover a wide range of the cognitive spectrum.

One third (32%) of respondents report using AT of some type, whereas the remaining 68% do not currently employ any AT to support their needs. However, it is important to note that out of the respondents not using AT, nearly two thirds reported that they do not need it. Figure 1 shows the share of AT users according to the perceived difficulty in obtaining suitable AT for their needs. As depicted, only 15 percent of users stated that they managed to find suitable AT on their own without any problems. Over 60% of AT users needed external support to find the right technology for their needs.

These results suggest that the AT provision process has a significant gap when it comes to training, support, and maintenance. On the other hand, 64% of participants already using some form of AT reported on a subsequent question that they do not need help using it. It can therefore be concluded that the greatest barrier in AT provision (at least in the selected countries) comes from users not being able to find the proper AT for their needs, not from the AT solutions themselves.

Discussion

In order to bridge the gap between existing AT solutions and end users, this paper tackles the problem of developing a solution for simple, effective, and autonomous discovery of AT by persons with a cognitive disability. Addressing the accessibility challenges mentioned above, our approach is implemented as a repository of relevant tools (features, apps, ATs, etc.) and an Artificial Intelligence (AI) assisted recommendation system that helps users with cognitive disabilities to access online contents and services. The solution, named Buddy, is based on two main components, namely: (1) an online repository of AT entries and user profiles that stores the support categories of available tools and the abilities and

preferences of each user, and (2) an intelligent recommender that leverages the stored knowledge about users and AT entries to create personalized recommendations on suitable AT fulfilling the specific user needs.

User profile

To generate recommendations for assistive technology for a specific user, the needs and preferences of this user must be known. As a basis for eliciting the user requirements, we mapped the definition of cognitive functions and needs in the ISO guidelines for the design and development of cognitively accessible systems, products and services (ISO 21801-1:2020) against the cognitive abilities as defined in the ICF framework (World Health Organization: International Classification of Functioning, Disability, and Health: ICF). This process resulted in a list of relevant cognitive user needs. The list was also complemented by definitions of cognitive user requirements developed within research initiatives that explicitly look at requirements for the web, most notably the research conducted by the W3C COGA group (Seeman, L., & Cooper, M.: Making content usable for people with cognitive and learning disabilities).

As a result of this research, the following list of user needs for support covering the required aspects was determined:

- Reading
- Writing
- Understanding
- Calculation
- Focusing on a task or information, and keeping the focus
- Managing tasks (getting started and completing them)
- Memory
- Managing time (planning, allocating and controlling)

- Managing choices (evaluating options, deciding)

Profile generation

Individual support preferences can be set by the user with a classic multi step web-form, where each step represents a user need mentioned above. However previous projects and user involvement activities showed that people with cognitive disabilities often struggle with long forms which can be tedious and too complex to fill in. In addition, sometimes users do not know or are unable to express which types of support they need. Therefore, an innovative game-based approach has been designed, where users play mini games which detect the users' needs for support. At the moment, 6 mini games have been developed covering 7 out of the 9 support categories.

Reading game

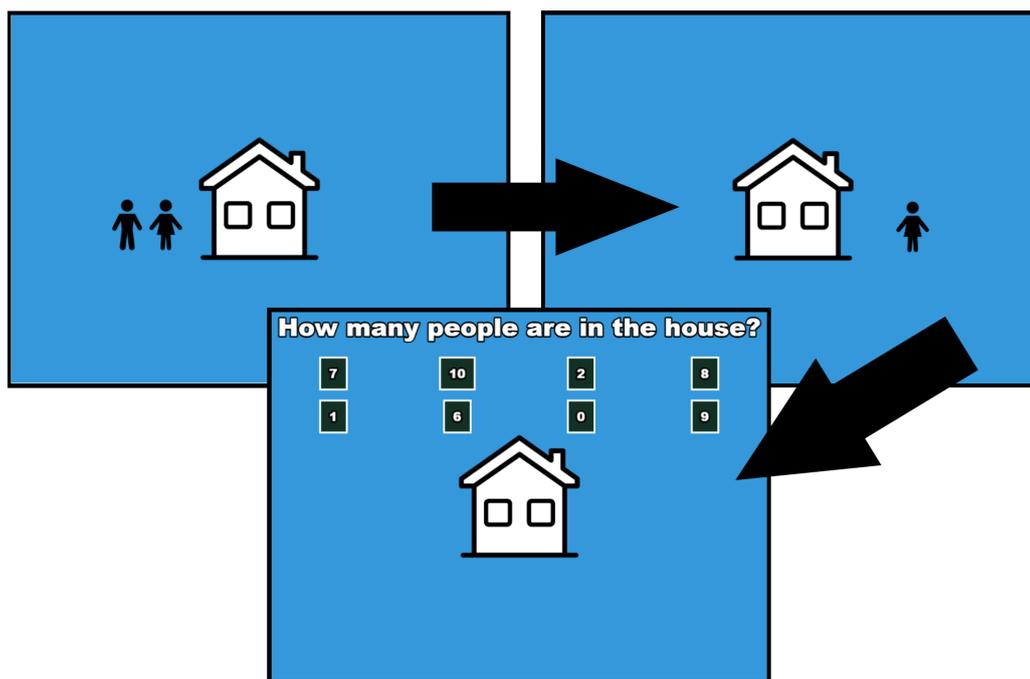
In the first step the reading and spelling capabilities of the user are determined. This is done in a three-stage quiz game. In the first stage, text is read out aloud, and users have to select the proper text for the spoken text within a set of answers displayed on the screen. In the beginning wrong answers differ greatly from the correct answer, whereas at the end of this stage they only differ in certain words. In the next step, wrong answers are derived from the right ones with the addition of spelling mistakes thus giving an indication about the spelling capabilities of the user. In the last stage of this game, users have to read a paragraph by themselves and answer a question about the paragraph.

Writing game

The next game determines the writing abilities of the user. Text is read aloud via synthetic speech, and then users are asked to input the spoken text in a text area. A keyboard listener then detects how fast the text was entered and analyzes grammar and spelling. In this manner, a basic estimation of the user needs for writing support is inferred.

Math game

This game detects the basic capabilities of math and also provides some insight into the working memory capabilities of the user. In this game, a random number of people are shown entering or leaving a house in several batches. Users have to count the number of remaining people in the house after a few batches have passed.



The game consists of several levels. In the beginning, batches move slowly and each batch consists of a small number of people. However, depending on the outcome of previous levels, the amount and the movement speed of people is increased. This game allows the Buddy system to infer the basic math capabilities of the user.

Memory game (short term):

In this game random items fall onto a conveyor belt which slowly transports them until they fall into a suitcase and disappear. Users have to remember the items that have previously fallen into in the suitcase and have to remove duplicate items before they land in the suitcase.

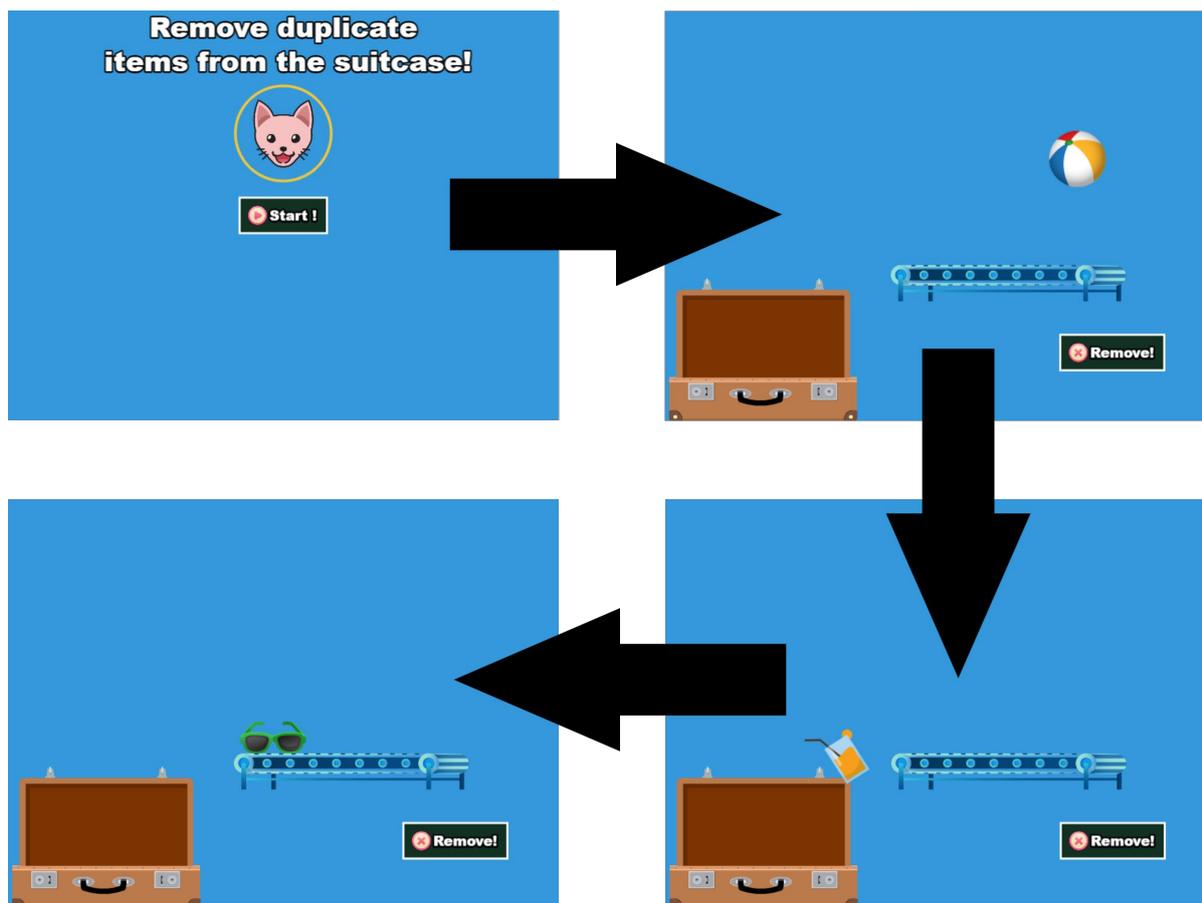


Fig. 3. Memory Game.

In this manner, a basic estimation on the needs for short term memory support of the user can be determined.

Focus game

In this game users have to follow a coin that is hidden inside a cup among a set of empty cups. These cups then get shuffled with a randomized animation. To distract the user, disturbances in the form of random, eye-catching moving figures are added. After shuffling is complete, users have to locate the cup containing the coin. Users have to play the game several times, with increased difficulty by adding more cups and distractions if they succeed, or reducing the difficulty if they fail.

Managing task and time questionnaire

The last game is a questionnaire based on the Assessment of Time Management Skills (ATMS) which was developed to measure the extent to which people actively manage their

own behavior to ensure effective management of time (Suzanne, White., Riley, Anne & Flom, Peter.:Assessment of Time Management Skills (ATMS): A Practice-Based Outcome Questionnaire). Users have to answer several questions based on the ATMS so that the basic needs for task and time assistance of the user can be determined.

Current status

In general, games were chosen based on desktop research on actual projects (Hautala J.,Heikkilä R.,Nieminen L., Rantanen V., Latvala J., Richardson U.: Identification of Reading Difficulties by a Digital Game-Based Assessment Technology) in related domains and informal interviews with psychologists. Next, these games will be tested with user tests to determine whether users understand the games and how reliable the user needs are inferred. More work will be done in order to explore whether all user needs can be covered with this approach. Informal preliminary evaluation with cognitive disabled users shows that, even if the game-based approach takes significantly longer than the completion of the traditional multi step form, all users preferred to set up their profile this way. Once the user has finished setting up his or her profile with all preferences for support, it is stored to the Buddy system and the user may start discovering suitable AT.

AI based recommendation

The second main component of the Buddy system consists in an intelligent recommender service. Its main purpose is to discover suitable ATs for specific users that may not be aware of their existence. In this manner, users are encouraged to try out new technologies that support their specific needs, thereby benefiting both end users and AT vendors. This service, designed as a distributed weighted hybrid recommender system (Burke, R.: Hybrid recommender systems: Survey and experiments), hinges on two complementary methods:

- A knowledge-based recommendation approach that matches ATs to users directly by exploiting explicit knowledge about the support needs of users and support categories of ATs in the repository. A similarity score between ATs and a given user is computed, and the highest-scoring ATs recommended to the target user. Because AT entries in the system and user profiles are underpinned by the same support categories, computing this similarity measure is very straightforward.
- Data-driven recommendations leveraging user ratings of individual ATs to discover similar users and ATs regardless of their specific profiles. This system is inspired by well-established collaborative filtering methods commonly employed in e-commerce websites. Users of the Buddy system can rate the repository entries of AT they use or have tried out in the past by choosing the corresponding score in a Likert-type scale from 1 to 5, where 5 indicates that the user is totally satisfied with the AT solution. A Likert-type scale has been selected due to its finer granularity and low cognitive demands. Users and/or ATs are represented by their aggregated scores, and similar ones are retrieved according to their similarity in data-space. In this manner, suitable ATs for a target user may be found even if partial or incorrect knowledge about them is stored in the repository.

The final recommendations offered to a user are based on a weighted mean of both scores in order to smoothen the final score while benefiting from both techniques. Initially, more importance will be given to the knowledge-based score. As more user ratings are inputted into the system, emphasis will be placed on data-driven scores.

Conclusion

This paper presents an online repository, named Buddy, that is able to recommend suitable assistive technology (AT) to individual users with cognitive disabilities, thereby bridging the existing communication gap between end users and AT providers. Buddy

benefits end users, since it allows them to discover otherwise hard-to-find AT for their specific needs. In addition, the system is also a valuable tool for AT vendors by exposing their products to a suitable audience.

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A Tangible Manipulative for Inclusive Quadrilateral Learning

Scott George Lambert - Saint Louis University - scott.lambert@slu.edu,
Brett L. Fiedler - University of Colorado Boulder - brett.fiedler@colorado.edu,
Chloe S. Hershenow - University of Tulsa - cs4376@utulsa.edu,
Dor Abrahamson - University of California Berkeley - dor@berkeley.edu,
Jenna L. Gorlewicz - Saint Louis University - jenna.gorlewicz@slu.edu

Abstract

Over the last decade, extensive growth in digital educational content has opened up new opportunities for teaching and learning. Despite such advancements, digital learning experiences often omit one of our richest and earliest learning modalities - touch. This lack of haptic (touch) interaction creates a growing gap in supporting inclusive, embodied learning experiences digitally. Our research centers on the development of inclusive learning tools that can flexibly adapt for use in different learning contexts to support learners with a wide range of needs, co-designed with students with disabilities. In this paper, we focus on the development of a tangible device for geometry learning - the Tangible Manipulative for Quadrilaterals (TMQ). We detail the design evolution of the TMQ and present two user studies investigating the affordances of the TMQ and the user strategies employed when explored in isolation and in tandem with a two-dimensional touchscreen-based rendering of a quadrilateral. Findings illustrate the affordances of the TMQ over traditional, static media and its ability to serve as an inclusive geometry learning tool.

Keywords

Blind/low vision, educational tools, mathematics learning

Introduction

Enabled by advancements in technology access and bolstered by online delivery of courses, digital formats are becoming the praxis in education. This shift to the digital space, however, introduces new challenges for students, particularly for those with blindness or a visual impairment (BVI). Acknowledging the gap between tangible and virtual learning opportunities, several research initiatives have investigated how to bring touch back in meaningful ways (Ding & Gallacher, 2018; Martinez et al., 2016). Several studies have focused on improving the efficacy of digital graphics through vibrations and audio feedback (Tennison et al., 2016) or by creating more sensory-rich interactions on touchscreens via variable friction displays (Xu et al., 2019). Others have built educational devices, leveraging kinesthetic learning in novel ways. Devices such as the Haptic Paddle and Hapkit demonstrated the efficacy of 3D printed devices to elucidate complex STEM topics that include dynamics (Martinez et al., 2019). Other systems have highlighted the importance of haptics in kinesthetic learning systems across STEM disciplines (Grow et al., 2007).

Taking these ideas further, several learning tools have been developed with a focus on inclusivity. Buzzi et al. (2015) developed a geometry learning application that leverages vibrotactile feedback on a touchscreen to display more immersive graphics for students with BVI. As learning materials transition to digital space, interest in accessible formats for digital graphics also grows. Sallnäs et al. showed the effectiveness of adding haptics via commercially available haptic devices (e.g. Phantom Omni) to interactive mathematics simulations. In an angle-teaching simulation, students preferred the haptic tool to their existing systems (Sallnäs et al., 2007). Similarly, a paired learning tool called ‘Clicks’ was developed as a modular geometry device

that connected with a tablet application to demonstrate various shapes in two and three dimensions (Adusei, Lee, 2017).

Our research centers on the development of inclusive learning tools that can flexibly adapt for use in different learning contexts to support learners with a wide range of needs, co-designed with students with disabilities. Here, we focus on the development of a tangible device for geometry learning. The learning tool will ultimately span coupled physical and digital interactive components, each consisting of an interactive quadrilateral that is extensible, allowing learners to extend and contract the sides of the object to continuously explore different quadrilaterals (e.g., parallelogram, rectangle, trapezoid, etc.), their invariant properties (e.g., angle congruence), and the relationships between them (e.g., square-rectangle definitions).

We chose to focus initially on a quadrilateral-shaped tool as it allows exploration of many shapes mentioned above and serves as a simple case to demonstrate basic geometric concepts such as parallel lines and right angles. The research team looks forward to leveraging the design acumen developed through this project toward taking on more advanced concepts in geometry curriculum. In particular, characterizing students' emergent multimodal sense-making strategies with two-dimensional shapes will inform how the team expands its technological offerings toward three-dimensional geometries of solids, which draws on perceptuomotor cognitive foundations in two-dimensional content.

The design rationale of this experimental learning tool applies theoretical perspectives from the embodiment turn in cognitive science (Newen et al., 2018) to re-motivate and implement longstanding pedagogical argumentation for multimodal interaction as the cognitive grounding of conceptual knowledge in the disciplines (Abrahamson 2014; Abrahamson et al., 2021). In particular, this perspective seeks to empower sensorially diverse STEM students by

centering their modal strengths (Tancredi et al., in press). By coupling the physical and digital components, teachers and learners will have flexible access to visual, auditory, and haptic displays and a wide range of traditional and alternative inputs, accessed with their available technology resources and adaptable to meet diverse learning needs.

Discussion

Hardware Design

This paper presents the Tangible Manipulative for Quadrilaterals (TMQ) shown in Figure 1. The TMQ is a 3D-printed reconfigurable device that allows a learner to explore the relations between different quadrilaterals through movement of the extensible sides and flexible vertices. The device can be used as a stand-alone tool for investigating relationships between quadrilaterals or as a paired device providing a tangible component to a physical/virtual coupled learning system. The envisioned experience created by the TMQ-touchscreen system is that students with BVI will be able to move back and forth between the touchscreen rendering of a quadrilateral and the TMQ itself. This leverages tangible interaction through kinesthetic learning in three-dimensional space and two-dimensional representation through digital formats that are ubiquitous and readily available.

Several design iterations of the TMQ were developed in collaboration with students with BVI. Initial prototypes tested the reception of size changes, cross-section shape, and presence of locking mechanisms. Rapid prototyping through 3D-printing allowed positive design changes to be quickly implemented into each subsequent prototype which can be printed and assembled in one day. The current device (Figure 1) is hand-held and adjustable in side length and angle, allowing a learner to create and interact with a range of four-sided shapes. Opening one angle to

180 degrees results in a limited set of triangles. The side lengths can be locked in place and tactile measurement markers are indented into the sides as reference lines (Figure 1).

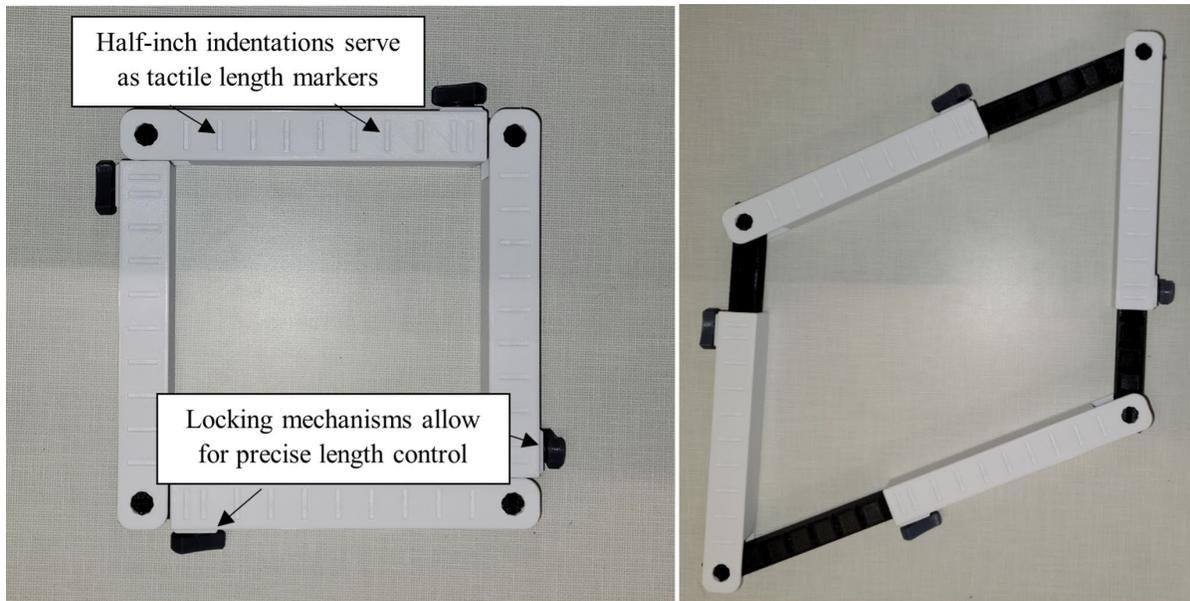


Fig. 1. The Standard TMQ Can Create Numerous Shapes and Features Length-Locking Mechanisms and Tactile Measurement Indents.

In order to connect to multiple modalities, a “smart” version of the TMQ (sTMQ) was created to enable future communications with software applications on a touchscreen tablet. This allows a learner to quickly transition between shapes as two-dimensional renderings displayed on the touchscreen and three-dimensional representations from the sTMQ. The sTMQ is embedded with length and angle sensors: four Force-Sensitive Linear Potentiometers (2730, Pololu Robotics and Electronics) and one rotary potentiometer (EVU-F2AF30B14, Sparkfun) giving a user immediate access to exact length and angle information. An Arduino Uno microcontroller was used for acquisition and calibration of sensors and connection to digital environments. Validation of the accuracy of the sensors was assessed by comparing the physical value of length and angle to the sensor-acquired value. Each length was expanded and contracted 10 times and

measured every 0.5 inches. For the angle sensors the same process was repeated at 45° increments, and the sensors demonstrated consistent accuracy within 2% of the physical values.

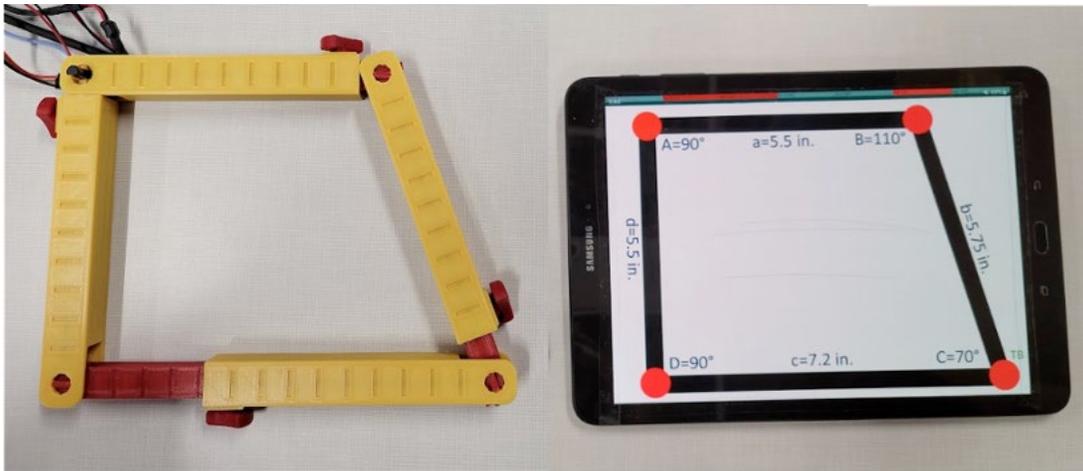


Fig. 2. The sTMQ Gives Learners Exact Length and Angle Values will Serve as a Three-Dimensional Shape Exploration Tool Alongside Two-Dimensional Graphics.

Research Study Design

The TMQ device was used to investigate two foundational research questions supporting the development of inclusive learning tools: (1) In the context of quadrilaterals, what affordances does a tangible manipulative offer over a static representation?; and (2) What core design attributes of the TMQ support user exploration and interaction? We conducted two studies: a comparative study between the TMQ and static graphics displayed on a touchscreen tablet or embossed graphics with 18 college-aged participants (16 blindfolded and 2 BVI), and an exploratory study with 7 participants with BVI aged 18-22. Informal exploration and discussion were done with 5 high school students with BVI.

Study 1

In the first study, we sought to investigate what affordances a tangible manipulative might offer over or in conjunction with multimodal, touchscreen-based renderings of quadrilaterals. To do this, 18 participants (16 sighted-hearing, blindfolded and 2 individuals who

are BVI) completed two tasks using the sTMQ and a touchscreen tablet and additionally, embossed graphics for individuals who are BVI. In consultation with an experienced teacher of students with visual impairments, embossed graphics were created using Nemeth Math Braille labeling following the guidelines from the American Printing House.

The first task was shape identification: on each medium, how accurately could participants identify the following shapes: various trapezoids, right-angle quadrilaterals, and parallelograms. Participants were given either the sTMQ set into a specific shape configuration, the touchscreen tablet displaying a shape (as shown in Figure 2, right), or embossed printouts (only participants who are BVI) of a shape and asked to identify the shape. Shapes were randomized from a library of quadrilaterals, trapezoids, and parallelograms; several configurations of each shape were created to avoid process-of-elimination answers as this task was completed three times on each medium.

The second task was shape recreation: participants were presented with a shape on the touchscreen (or an embossed graphic for participants who are BVI) and asked to replicate the geometry on the sTMQ as accurately as possible (as shown in Figure 2). Length and angle values were available as audio readouts on the touchscreen and recorded on the sTMQ via the Arduino Uno upon completion.

In the identification task, learners were about 1.4 times more successful in identifying the correct shape when using the sTMQ as opposed to the touchscreen or the embossed graphic. Parallelograms proved most difficult to identify as participants mistook slightly obtuse or acute angles as right angles, yet most successfully identified quadrilaterals. Stark differences were observed in the strategies employed by participants across mediums. While more serial exploration procedures were used to identify value readouts on the touchscreen-based graphic,

participants employed several two-handed referencing strategies when manipulating the sTMQ. Participants who are BVI differed from those blindfolded in exploration strategies on the touchscreen: participants who are BVI traced out the shapes on the touchscreen (a dominant strategy for embossed graphic exploration) while blindfolded participants hunted for value readouts. For participants who are BVI, exploration of the sTMQ was similar to that of tactile graphic explorations in that participants put both hands-on top of the device to establish a global understanding of the object through “hand scanning”. The most common strategy for blindfolded participants estimating side-lengths on the sTMQ was to use one’s thumb and another finger to estimate distance. We observed more variance in estimating angle measurements, with strategies including making “L-shapes” with the hands and comparing it to the orientation of the sTMQ.

In the shape recreation task, all participants were able to manipulate the sTMQ into a desired shape with an overall angle and length accuracy rate of 94%. Error rates by shape are further broken down in Table 1, which shows that parallelograms proved most challenging to accurately recreate, likely due to the inaccuracy of angle estimations through extended usage of “L-shapes.” New exploration strategies emerged here, such as the use of the width of a thumb, finger, or knuckle as reference measurements for adjustment estimations. Participants also began to lean into the tangible device more fully, using the space created between the adjustable lengths to determine how much they had adjusted the device. With a focus on fine-tuning individual angles and sides, we observed participants moving back and forth frequently and quickly between the touchscreen and the sTMQ to gather the correct measurements. Interestingly, when participants could not get a side or angle to match the desired touchscreen representation, they switched to the opposite side or angle, noticing that side lengths could affect angles and angles could affect line orientation.

This study validated our design approach: users were more successful in correctly identifying quadrilaterals on the sTMQ than either of the two-dimensional mediums (touchscreen and embossed graphics). Further, across 54 observations (3 shapes per participant, 18 participants), users were able to replicate quadrilaterals on the sTMQ with 94% accuracy from two-dimensional representations. Taken together, we observe several affordances the sTMQ offers: two-handed exploration and manipulation which enables users to establish relationships between changes in angles and changes in lengths, the ability to provide kinesthetic references (e.g. usage of fingers for taking measurements), and the ability to quickly create and transform between shapes which highlights their geometric relationships.

Table 1: Recreation Error Rates (%).

| Shape (total observations) | Overall | Angles | Side Lengths |
|-----------------------------------|----------------|---------------|---------------------|
| All Shapes (54) | 6 | 6 | 7 |
| Parallelogram (54) | 10 | 11 | 9 |
| Trapezoid (54) | 6 | 7 | 6 |
| Right-Angle Quadrilateral (54) | 4 | 3 | 4 |

Study 2

In the second study, we sought to investigate the exploration strategies a learner with BVI might employ when using the TMQ. The study was conducted with 7 students (ages: 18-22) who were enrolled in a program for students with vision loss. Participants were first given the tangible and encouraged to explore its functionality before being asked to create and identify shapes. We observed one- versus two-handed exploration, usage of the device on or off the tabletop, rotation of the device, and tilting strategies for angle modification: single hand stabilization or mirrored action (Figure 3). Any shapes that learners naturally made were also noted.

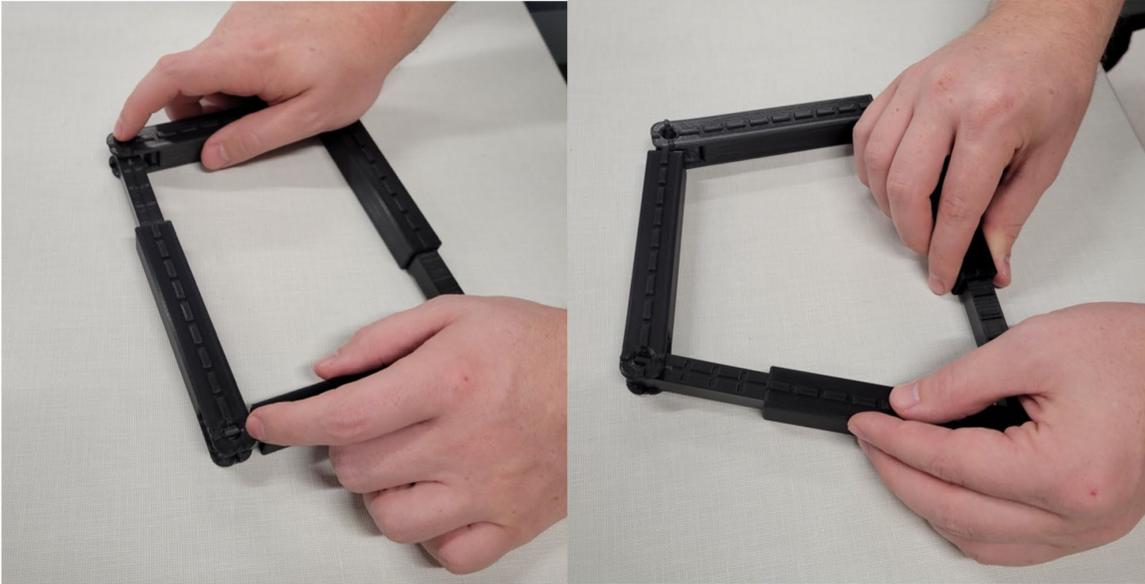


Fig. 3. Popular Exploration Strategies: Most participants utilized mirrored hand motions (left image), but in some cases used one hand to stabilize the TMQ while the other hand manipulated the shape (right image).

We learned some common strategies used by these learners and what shapes the participants made easily (such as parallelograms) and which shapes they struggled to create (such as trapezoids). Nearly all participants immediately made rectangles or parallelograms, and a few participants identified them as such without prompting. Once prompted to create and identify shapes, all participants were able to manipulate the TMQ into three or more distinct shapes. In exploration, most learners utilized mirrored motions. That is, what they did with one hand was done by the other hand, such as elongating the side lengths to create a wide rectangle. A few participants used one hand to stabilize the device while the other hand modified angles or lengths. Two-handed exploration was dominant for garnering a global understanding of the device, as well as for manipulation of the TMQ. About half of the participants explored the TMQ off the table for some part of their interview, with most preferring on-table exploration, likely

due to the lack of a locking mechanism resulting in unintentional length changes when the device was suspended above the table.

In the last part of the study, we asked participants to transform the TMQ between shapes in three different scenarios, with an emphasis on using smooth motion when possible. The first scenario was to transform from any rectangle to any parallelogram. The second scenario was mirroring the previous parallelogram without changing the side lengths. The third scenario was transforming from a small square to one twice as large. The first task was the simplest, with all participants creating a parallelogram within three attempts. Pedagogically, we found that, in the second task, parallelogram to mirrored parallelogram transformations were particularly challenging for many learners, with about half requiring further clarification on how to achieve a mirrored shape (e.g. “reverse the shape, make it point the other way.”). Most completed the mirroring task in separate steps rather than smooth motions, changing side lengths and achieving imperfect mirrored shapes. Similar actions were shown in the square scaling task: only a couple participants scaled the shape smoothly, with most expanding the left and right sides together, then the top and bottom.

Taken together, these studies illustrate the core design attributes of user exploration and interaction with the TMQ. First, the extendable side lengths were critical for participants to transform between shapes and investigate scaling. We note, however, that because the side lengths of the TMQ did not have a locking mechanism, participants preferred on-table exploration, and often had to use their hands to secure the sides at specific lengths, confounding exploration. This observation prompted the team to add locking mechanisms to the side lengths as shown in Figure 1. Future investigations will explore how individuals choose to work in the horizontal or vertical plane when able to lock the lengths. Second, we observed that most users

pushed or pulled on the side lengths of the TMQ opposed to operating at the joints. We hypothesize that this could be resultant of the tasks themselves or how participants thought out transformations between shapes. Future investigations will probe this phenomenon of side versus angle interaction to understand the methodology at which participants are approaching such transformation and scaling tasks.

These challenges in exploration suggest areas for improvement for the TMQ including leveraging other dynamic non-visual feedback (e.g. vibrotactile feedback when a right angle is achieved or audio callouts of length / angle values when desired) to assist in shape accuracy. When prompted for thoughts on the device and its potential uses, many recounted their geometry learning experiences, stating that such a device “would have been really helpful in class” and “better than shapes on a page.” Overall, users enjoyed exploring shapes using the TMQ and its ability to transform between shapes rapidly.

Conclusion

In this paper, we present an inclusive learning tool, the TMQ, which highlights the geometric relationships among quadrilaterals. Two initial investigations with sighted and BVI learners illustrate the potential affordances of such a tool, both as a stand-alone device that can be tangibly transformed and queried and as a device paired with software applications which otherwise often have limited touch interaction. This work is situated within a larger project focused on developing a set of physical/virtual coupled inclusive learning tools that support action-based embodied learning opportunities (Abrahamson, 2014). Our design efforts recognize that all students, regardless of their sensory profile, could avail of opportunities to interact with haptic–tactile models of geometric forms and, more broadly, mathematical objects. As such, we

are informed by, and eager to contribute to, a general intellectual shift in the humanities to “reclaim cognition” (Núñez & Freeman, 1999).

Future work will focus on continued iteration of the TMQ design and novel devices to represent other polygons. Expanding on this existing TMQ/virtual app coupling, we will continue collaboration with PhET Interactive Simulations (phet.colorado.edu), focusing on enabling real-time, bi-directional communication between the TMQ device and a quadrilateral virtual simulation. PhET simulations are open source and widely-used for K-12 STEM learning, with existing infrastructure for description / speech reader access and other inclusive features to support non-visual access. Additional work will focus on expansions of this initial concept into a larger suite of inclusive educational tools that promise to bring a new dimension of movement and touch to digital learning experiences to help make learning more accessible to all.

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Online Learning & COVID-19: Exploring Digital Accessibility

Justin Brown, j.brown@ecu.edu.au

Edith Cowan University, Perth, Western Australia

Ruchi Permvattana, ruchi.permvattana@sche.edu.au

Stanley College, Perth, Western Australia

Scott Hollier, s.hollier@ecu.edu.au, scott.hollier@accessibility.org.au

Edith Cowan University, Perth, Western Australia

Centre for Accessibility, Perth, Western Australia

Jason McKee, jmckee@perspectivetester.com

Perspective Tester, Philadelphia, USA

Abstract

The COVID-19 pandemic impacted nearly all aspects of life in 2020, leading to significant social, economic and technological change. Educational institutions were particularly impacted as social distancing and lockdowns precluded student attendance on-campus or in-class. Universities around the world found themselves pivoting to fully online delivery of learning content, assessments and collaboration, while striving to minimise disruption or loss to pedagogical fidelity. While universities achieved what many thought impossible, the rush away from bricks and mortar education did surface an underlying issue that while always present, had mostly been in the background. This issue was digital accessibility, a mixture of technology, policy and empathy that allows electronic content and systems to be consumed and interacted with by users of assistive technologies. This paper outlines the core precepts of digital accessibility, the standards by which it is defined, and the technologies used by people with disabilities to interact with the online world. The authors, reflecting on their own experiences of digital accessibility within the university sector propose a four-quadrant model for institutional support of accessible online learning. This model includes the role of the policy environment, accessibility awareness by faculty, accessibility support roles and the critical nature of IT procurement.

Keywords

Online learning, digital accessibility, WCAG, COVID-19, disability, model

Introduction

In 2020, the arrival of the COVID-19 pandemic saw a significant change in the delivery of courses throughout the higher education sector. While the online delivery of courses is not a new concept, the pandemic saw a notable shift in the role of the Learning Management System (LMS) and the integrated technologies that reside within (Arancibia Muñoz and Halal Orfali). The reality of learners being unable to attend bricks and mortar campuses of educational institutions worldwide during COVID-19 quickly changed the view of the LMS from a supportive role to an essential one (Dhawan; Girik Allo; WHO) making them the primary loci of curriculum and assessment.

This paper identifies a range of issues that have impacted learners with disabilities through the rapid transition to online-only learning and presents a four-quadrant model for institutional support of accessible online learning.

For people with disability to gain access to higher education, two critical things must occur.

1. People with disabilities need to have access to the assistive technologies they need on the device of their choice
2. The content being accessed through those assistive technologies is itself, accessible.

In relation to the first point, the rapid evolution of assistive technologies in mainstream computing and mobile devices has had a profound impact on the accessibility and affordability of support for people with disability in recent years (Koch). Contemporary examples include VoiceOver in Mac, iPhone and iPad, the TalkBack screen reader on Google Android and a more advanced version of Narrator on Windows including the third-party open-source screen reader NVDA (Apple; Google; Microsoft; NVDA). It should be noted that this paper will make frequent reference to visual disability in the context of digital accessibility. This choice is not

designed to marginalise the broad and complex range of specialist need that exists amongst internet users, but rather to provide a reference norm that is commonly used in the literature and general accessibility dialog.

With the first aspect largely addressed, the next challenge is the authoring of learning content in an accessible way, allowing it to be ‘visible’ to these assistive technologies. Most higher education institutions refer to the internationally recognised Web Content Accessibility Guidelines (WCAG), produced by the World Wide Web Consortium (W3C) and which at the time of writing exists as version 2.1 (W3C). The challenge for tertiary institutions trying to meet accessibility standards is one of complexity. The interrelationships between the specifics of WCAG, assistive technologies and the specific accessibility needs of learners across a range of disability types can rapidly become overwhelming for accessibility novices (Kearney-Volpe et al.; Bradbard and Peters). It is both the contention and experience of these authors that educational institutions looking to provide an inclusive digital learning experience for all students need to look beyond the specifics of guidelines and technologies and examine people and support services instead.

Discussion

Considering the challenges outlined above, the authors propose a four-quadrant model describing a cohesive, whole of institution approach in which digital accessibility standards can exist alongside online learning content and technologies to meet the needs of all students (Figure 1).

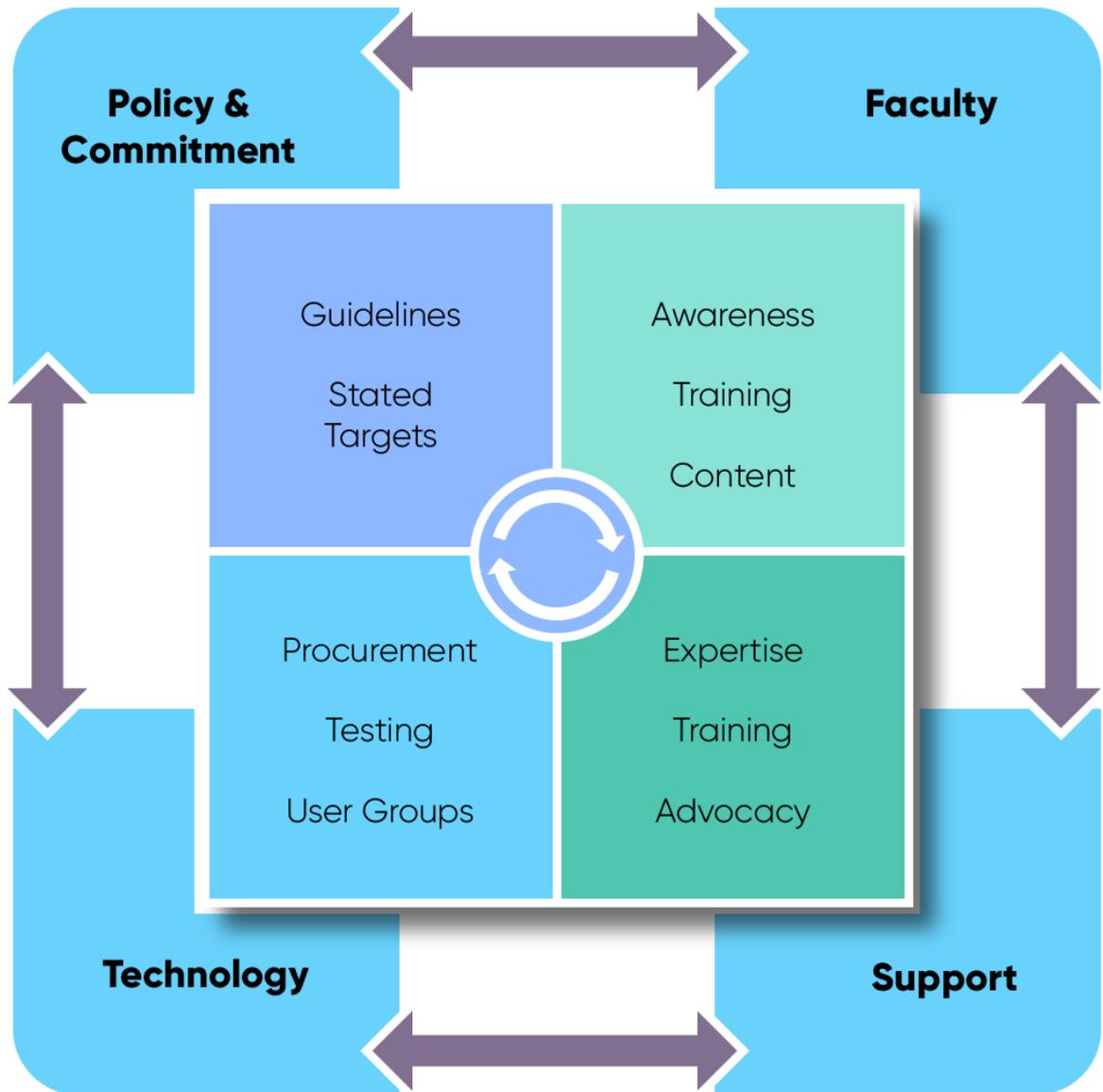


Fig. 1. Four-Quadrant Model for Institutional Support of Accessible Online Learning.

Policy & Commitment

The first and perhaps most important quadrant of the proposed model is that of policy and commitment, where an institution formally recognises the importance of digital accessibility principles and its intention to meet a pre-determined set of guidelines or standards (Axelrod; Sloan, Horton and Gregory). Policy can be a key determinant of educational organisations being

prepared to meet the broad range of skills, supports and technologies required to ensure digital accessibility is a core value rather than a future aspiration. An institution may state their goal for digital accessibility to be referenced against WCAG 2.1 at AA conformance. These accessibility targets should not be buried in policy documents that may or may not be visible to students and the public, but rather be visible on all pages of the organisation's website in the form of an accessibility statement (Olaire and Lazar). Setting specific policy goals (Lazar, Goldstein and Taylor) associated with digital accessibility is a prerequisite for surfacing the very real need for inclusive thinking across all levels and functions of educational institutions (Guilbaud, Martin and Newton).

Faculty (Awareness, Training and Content)

Faculty staff typically have a broad range of responsibilities, including teaching, research and university service. Over the past two decades faculty staff will have become accustomed to using digital technologies as part of their everyday teaching in one form or another and have some awareness of digital accessibility requirements (Michel, Pierrot and Solari-Landa; Moise, Suditu and Netedu; Popescu; Basilaia et al.) This level of awareness can vary significantly from organisation-to-organisation dependent on the focus placed on digital accessibility as part of professional development (PD). The authors of this paper currently work in or have worked in organisations where accessibility is covered through PD, focussing on both the policy expectations (Guilbaud, Martin and Newton) and the practical application of web content accessibility principles. Outside of PD, faculty staff are likely to encounter digital accessibility situations when students contact them directly or through an equity and diversity service when raising concerns about inaccessible content, platforms or teaching practices. It should be noted that the term 'equity and diversity' is broad indeed (Czerniewicz et al.), but in the context of this

paper, we are focussing on the ‘equity’ component. In most cases, these services can assist students in digital accessibility scenarios where content may need to be converted to a format suitable to individual student need. Within most organisations the equity and diversity support services have the experience, expertise and contacts to get this work done independently of the faculty teaching staff.

Training faculty to understand digital accessibility principles and apply them consistently in the development and delivery of their learning materials is a notoriously difficult task as there is far more nuance present in digital accessibility beyond just guidelines. There exist complex interactions between assistive technologies, operating systems and automated approaches to accessibility assessment. For the uninitiated, digital accessibility can become immediately overwhelming, with the outcome of faculty feeling unable to support their students in an equitable, but sustainable manner. The authors of this paper feel that a pragmatic, targeted approach to digital accessibility training for faculty staff (Arzola) should take priority over more comprehensive expectations of faculty becoming accessibility practitioners. This pragmatic approach might entail the faculty staff being trained in the following aspects of digital content creation.

1. **Use Word and PowerPoint documents:** Microsoft’s productivity suite can produce very accessible documents when used correctly, such as using the document structuring tools built into the system (ie Heading 1...6) and placing alternative text descriptions on images. Word, PowerPoint and Excel have in-built accessibility checking that will identify common accessibility issues including colour contrast, lack of alternative text on images, tables containing column headers, slides containing titles and images being in-line with text (Microsoft).

2. **Use the accessibility features of the LMS:** Modern LMS platforms have an increasing number of accessibility features built into them (though some must be purchased as aftermarket add-ons). In many cases these accessibility features are not unlike those discussed in the point above, with a focus on content structure, colour contrast, alternate text for images and analysis of document types. This kind of information is of particular importance when associated with assessment content, documentation, due dates and marking criteria.
3. **Descriptive Links:** Creating informative, descriptive hyperlinks is another accessibility skill that could be readily acquired by faculty through regular PD and applies to both productivity suits and LMS platforms alike. Teaching academics to avoid placing hyperlinks on terms such as ‘click here’ and ‘more info’ can be taught easily through the lens of writing styles for digital accessibility. Avoid verbosity for its own sake, but be specific when it will assist students with navigating to content you wish them to read.
4. **Video content:** Lecture capture technology is a common feature of both on-campus and online learning delivery, with in-class captured video being processed and then uploaded to an institutional LMS. From a digital accessibility perspective, one of the most common challenges of lecture captured content is a lack of captions available by default. A range of modern lecture capture platforms, such as Panopto and even MS Teams do have automated captioning functions, though the accuracy of these can be very reliant on sound quality and the clarity of pronunciation by the speaker. In the author’s experience, where captioning is required by a student to consume video content, that content is usually human captioned by experts. This human captioning not only takes time and money, but in most cases is used only by those students in need of this service. In an

ideal world the faculty staff member would, in the next delivery of their course, make all those captioned videos available to all students from the commencement of semester.

The suggestions listed above are by no means definitive or likely to be relevant to all institutional contexts. However, after more than a decade of these authors working in curriculum leadership and accessibility roles, it has become apparent that a more fit for purpose approach is required if faculty staff are to be capable of producing digital content relevant to the needs of all users (van Rooij and Zirkle).

Support (Expertise, Training and Advocacy)

Thus far the authors have attempted to establish the need for clear and transparent digital accessibility policy settings and the requirement for faculty staff to both be aware of this policy and incorporate it into their teaching practice. Policy on its own does not bring about the goals it was written to achieve, and in most institutions requires champions and people with expertise to help translate policy into practice (Lazar, Goldstein and Taylor).

1. **Equity and Diversity:** While this is one of the more common terms used to describe support services aimed at providing services to students with a range of specialist needs, it may also be subsumed more broadly under the banner of learner support. The staff who work in these areas typically have broad or focussed expertise within disability support and advocacy and can offer support and advice to both students and faculty. Staff in these roles can advocate for resources, provide input into policy development, and work with IT services to secure assistive technology tools. These roles typically work directly with students to develop contextualised learning plans and then with faculty to help them translate those plans into actionable outcomes (Slater et al.). The authors of this paper have found that forging collaborative relationships with the equity and

diversity staff over more than a decade has significantly improved faculty awareness of the varying needs of students and how best to accommodate these needs in curriculum.

- 2. Learning and Teaching:** Few universities would not have a dedicated training and support service tasked with the development and delivery of PD to both faculty and professional staff alike. Centres for learning and teaching typically have a strong focus on curriculum design, assessment and technology enhanced learning. It is through this lens that training in digital accessibility techniques discussed in the previous section can be most effectively leveraged (Chun and Williams).

While teaching institutions may identify these types of services by any number of labels, it is the contention of these authors that this mix of expertise is the minimum required to allow institutions to successfully achieve the digital accessibility standards they have aspired to meet (Marquis et al.).

Technology (Procurement, Testing and User Groups)

The final piece of the digital accessibility quadrant for supporting accessible online content is that of the institutions technology support area, more broadly defined as Information Technology (IT). Whether IT sits within school or faculty structures or is a centralised service, staff associated with these roles are typically tasked with the procurement of digital technology platforms that support digital content development and delivery (Marcelino, Mendes and Gomes; Pombo et al.). In an ideally collaborative organisation, senior IT figures would have input into policy settings relevant to digital accessibility, providing advice as to challenges and solutions to digital inclusivity (Turner-Cmuchal and Aitken). Of the four quadrants discussed in this model, the authors have found that influencing IT procurement and purchasing decisions around a nexus of digital accessibility can be amongst the most challenging.

A number of the authors on this paper have been involved in the procurement processes of student-facing systems ranging from small bespoke systems through to enterprise solutions. While digital accessibility in the form of WCAG 2.0 has been included as criteria in IT procurement processes for some time, until recently it has been little more than a tick box exercise. The vendors would be asked if their product adhered to WCAG 2.0 AA, they would respond yes, and that criteria would be deemed as ‘met’. Some vendors would provide evidence that compliance to accessibility guidelines was on their product roadmap, whilst others indicated it was not and never would be. For IT staff, their priorities go well beyond vendors and procurement, as they are also seeking to purchase products that integrate well with the existing IT ecosystem at the institutional level. If a product ticks all the boxes for integration, security, support, quality assurance and cost, then rejecting that product based purely on digital accessibility can be difficult to rationalise with the project stakeholders. These authors have found that over time, where external expertise can be included in the IT decision making process, and those contributions are seen to be a value add, things can change for the positive (Falloon and M. O’Reilly).

Institutional commitments to accessibility standards will be extremely difficult to achieve where student facing systems are procured without due rigor being applied to a product’s inclusive design. This issue can be particularly pervasive where internal sentiments reflect assumptions that accessibility requirements are onerous and only apply to a small number of stakeholders (Pionke). The role of IT in procuring systems that enhance rather than prevent accessibility outcomes cannot be overstated (Astbrink and Tibben).

Conclusions

This paper has outlined some of the challenges facing educational institutions in transitioning to fully online delivery in a time of crisis (Allo; Houlden and Veletsianos; Li and Lalani) and the impact on digital content accessibility. Digital accessibility is complex, multi-faceted and never a one-size-fits-all scenario. While the scope of this paper cannot hope to cover all the inherent intricacies of digital accessibility across all institutional contexts, it does propose a model of four key quadrants of activity that can enable the successful transition to a more inclusive way of thinking about online teaching and learning. Individual elements of this model are suggested in passing or covered in depth across a range of literature (Sieben-Schneider and Hamilton-Brodie) but are realised by the professional experiences of these authors in the education and commercial sectors. Some institutions are likely to be working cohesively in a structure not dissimilar to the suggested model (Lazar; Sieben-Schneider and Hamilton-Brodie; Zalavra et al.), while others may experience a level of fragmentation and dissonance that leaves the provision of accessible learning to random happenstance. While it has taken more than a decade for these authors to see these four quadrants gradually materialise in the university sector, the coming of COVID-19 has been a disrupting moment (Lazar) and has brought the issue into sharp focus. The authors feel that due to this disruption, educational institutions have an opportunity, as well as an obligation, to reshape their approach to accessible online learning to one that is transparent, collaborative and primarily focussed on a key set of stakeholders (Cooper et al.). Students.

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AI-Based and Mobile Apps: Eight Studies Based on Post-Secondary Students' Experiences

Catherine Fichten^{1,2,3,4}, Mary Jorgensen², Alice Havel^{1,2}, Christine Vo², Eva Libman^{3,4}

Dawson College¹, Adaptech Research Network², McGill University³, Jewish General Hospital⁴

catherine.fichten@mcgill.ca, mjorgensen07@ubishops.ca

ahavel@dawsoncollege.qc.ca, christine.vo@hypercube.ca

Abstract

We present eight studies dealing with artificial intelligence and mobile apps that assist post-secondary students with attention deficit hyperactivity disorder (ADHD) and other disabilities with their academic work. Study 1, based on an advisory board and on a Google search, provided glowing testimonials about AI tools. However, Study 2, a scoping review of the scientific literature, showed that research is scant. In Study 3 we explored how students with and without disabilities used AI-based intelligent virtual assistants to do schoolwork. Our findings show that students are not realizing the potential of these tools. In Study 4, we explored AI-based technologies used by 163 students with and 74 students without disabilities and in Study 5 we investigated AI-based technologies professors required students to use. These studies helped identify sustainable practices. In studies 6, 7 and 8 we explored apps for students with ADHD. Overall, the results show that students with and without disabilities use similar technologies. There will always be a place for traditional assistive technologies such as Jaws and ZoomText. However, general use technologies play an important role because the most common disabilities reported by students on post-secondary campuses include nonvisible disabilities, such as ADHD, mental and chronic health challenges, and specific learning disorders.

Keywords

AI, artificial intelligence, post-secondary students with disabilities, college, university, ADHD, Attention Deficit and Hyperactivity Disorder, mobile apps.

Introduction

Our goals in conducting the eight studies described below were to: (a) explore how useful artificial intelligence (AI) based technologies and apps are for students with disabilities, (b) discover what AI-based apps and technologies students with disabilities use to do schoolwork, (c) compare how students with and without disabilities use technologies and other apps to do schoolwork, (d) explore which technologies and apps used by college professors during COVID-19 emergency remote teaching should be retained for future face-to-face and hybrid classes, (e) explore whether students with attention deficit hyperactivity disorder (ADHD) use apps recommended for them by experts, and (f) to present evidence-based AI-based and mobile apps we can recommend for students with disabilities, access service providers and post-secondary faculty.

Artificial Intelligence (AI)

The popular press suggests that students with various disabilities, their instructors, and the professionals who provide them with assistive technology services can all benefit from the use of hundreds of AI-based apps (Martinez; Lillywhite and Wolbring). AI, used today in many technologies, has the potential to be especially helpful for students with various disabilities, not only as tools to do schoolwork, but also as assistive aids (see Martiniello et al.).

We have been unable to find a consistently used definition of AI. Here we use that of Microsoft (page 7): “AI represents a broad range of technologies that can perceive, learn, reason, assist in decision-making, and act to help solve problems. AI technology continually learns from user interactions and organizational data to provide better insights. These technologies can interpret the meaning of data from text, voice, and images, identify trends, and form conclusions.”

AI can help students access information through various modalities. For example, Zoom (“Managing”) and Microsoft Teams (“Use”) can provide live captions as well as transcripts.

Similarly, PowerPoint (“Present”) offers live captions. These are beneficial for students with

hearing impairments and second language learners. Seeing AI can convert visual information into speech (Granquist, et al. page 115), which helps students with visual impairments. Students can use dictation in Word (Whitney) and Google Docs (“How”). This is especially useful for students with hand, arm or shoulder impairments and those with specific learning disorders. Students can also use AI to assist with organization (e.g., IFTTT) to automate routine tasks (Tivers). Articles and web sites are devoted to image and facial recognition, text-to-speech, and text summarization (Martinez).

We wanted to know more about AI-based apps and technologies that could benefit post-secondary students with disabilities. So, we carried out a series of studies to explore this topic.

Study 1: Advisory board recommendations. In 2020 we convened two advisory board meetings with 38 participants, composed of post-secondary students and consumers with disabilities, faculty, post-secondary disability/accessibility service providers, and technology experts from five countries. Advisory board members were enthusiastic about the potential of AI for students with disabilities. Based on their suggestions, we prepared an annotated listing of AI-based tools and related resources (see “Canadian”) and synthesized our findings in a recent paper (Martiniello et al.). Our results, and those of a Google search, provided glowing testimonials. However, does this correspond with the scientific literature?

Study 2: Scoping review. We reviewed the scientific and gray literatures regarding AI and technologies that post-secondary students with disabilities use for schoolwork (Fichten et al., State). We searched 10 databases (e.g., ERIC, ACM Digital Library, Medline) for articles published in English between 2010 and 2020. Typical search terms used included: (*"artificial intelligence" OR "machine learning" OR "intelligent tutor" OR "smart tutor" OR "virtual assistant"*) AND (*disabilit* OR disabled OR impair* OR "special need*" OR blind* OR deaf* OR handicap**) AND (*"higher education" OR "post-secondary" OR "post-compulsory" OR college OR university OR*

undergraduate) AND (teach OR learn* OR educat* OR instruct* OR classroom OR school*).*

Our main findings indicate that (1) there is no generally agreed upon definition of AI, (2) there is a huge discrepancy between the scientific literature and the hype about AI in the popular press and, (3) scientific articles were devoted primarily to tool development. Studies reviewed also showed that the most commonly mentioned tools are intelligent virtual assistant applications, Alexa, Siri, and Google Assistant, with the focus on facilitating the ability of students with disabilities to provide oral instructions and by communicating with these apps through voice input.

We concluded that while the potential of AI-based tools for post-secondary students with disabilities seems enormous, informed research is scant and urgently needed.

Study 3: Intelligent virtual assistants. Since virtual assistants (e.g., Siri, Google Assistant, Alexa, Bixby) were most frequently mentioned in the scientific literature, we wanted to know which of these students actually used to do schoolwork, how they input information, and the tasks for which they used these tools. A quick overview of the popular press literature showed a variety of schoolwork related tasks for which students can use virtual assistants (Vo).

In 2020, using an accessible LimeSurvey questionnaire, we surveyed 172 university and college students (121 with and 51 without disabilities) who indicated using at least one intelligent virtual assistant (Fichten et al., Academic). Most students with disabilities self-reported one or more of the following: mental health related disabilities, ADHD, a learning disability, chronic medical / health problems, and neurological disorders. Least frequently reported were visual, hearing, and mobility impairments. Of the 121 students, 50% had multiple disabilities.

Overall, our findings show that students did not frequently use intelligent virtual assistants for their studies. Table 1 shows that between two percent (Bixby and Alexa) and 15% (Google Assistant) of students used virtual assistants to complete schoolwork.

Table 1. Percentage of Students with Anand without Disabilities Who Use Google Assistant, Siri, Alexa and Bixby.

| Intelligent Virtual Assistants | Students with Disabilities (n=121) | Students without Disabilities (n=51) |
|--------------------------------|------------------------------------|--------------------------------------|
| Google Assistant | 15% | 8% |
| Siri | 12% | 12% |
| Alexa | 2% | 4% |
| Bixby | 2% | 2% |

Table 2 shows that students with and without disabilities used more Apple than Android devices and more smartphones than tablets.

Table 2. Number of Students With and Without a Disability Who Used Apple and Android Smartphones and Tablets.

| Group | Any smartphone use | iPhone use | Android Phone use | Any tablet use | iPad use | Android tablet use | Any device use |
|-----------------------------|--------------------|------------|-------------------|----------------|----------|--------------------|---------------------|
| Students with a disability | 111 | 65 | 46 | 44 | 31 | 10 | 121 of 163 students |
| Students with no disability | 45 | 34 | 11 | 20 | 18 | 1 | 51 of 74 students |

We also asked students to write about the tasks for which they used the virtual assistants. Coded results show that students primarily used these for calendar alerts, Internet research, and the definition of words. Input differed across intelligent virtual assistants. For Google Assistant and Amazon Echo, most students used voice input. For Siri students relied on both voice and typing.

Overall, we concluded that students are not currently realizing the potential of intelligent virtual assistants for completing schoolwork. This led to Study 4.

Study 4: “Real-world” uses of AI-based tools by post-secondary students to do schoolwork. We surveyed 237 postsecondary students (74 without disabilities and 163 with

disabilities). Students had diverse disabilities, with the most common being mental health difficulties, ADHD, chronic medical / health problems, and neurological disorders). Students mentioned 278 apps in total (Fichten and Vo). By referring to the web description of the apps we determined that approximately 20% of these used AI (e.g., Adobe Creative Cloud, DeepL, Dragon, Dropbox, Evernote). With the exception of a few specialized apps (e.g., Seeing AI, Microsoft Lens), students with and without disabilities listed similar technologies. However, it is important to note that many of the AI-based apps are Google and Microsoft products.

This study provided insight into the AI-based tools used by post-secondary students in 2020. However, we could not identify which tools students chose versus those that professors required.

Study 5: AI-based technologies professors required students to use. In 2021 we carried out an email-based study with 24 participants (20 students with and 4 without disabilities) (Fichten et al., Digital). Of the 13 technologies listed by at least two students, as determined by the web descriptions less than ½ of these used AI. These include Zoom, Microsoft Teams, Microsoft 365, VMware Horizon, and WebEx. Coded responses indicated a series of problems related to AI and non-AI based technologies. These include software and platform issues, how professors managed their courses, problems with connectivity, classmates' computer behaviors, and equipment issues.

In this study, we identified helpful practices and solutions to problems that provide the foundation for sustainable best practices for future online, hybrid, and blended courses.

What Mobile Apps do Students with Attention Deficit Hyperactivity Disorder (ADHD) Use?

In a series of three studies, we investigated specific technologies used by one of the most prevalent groups of students with disabilities on campus, those with attention deficit hyperactivity disorder (ADHD) (Gagné and Bussières, page 11; Green and Rabiner, page 560).

Study 6: Is there an app for that? In 2020, we compiled a list of mobile apps recommended for post-secondary students with ADHD to do schoolwork (Fichten et al., Is there).

We based this list on 23 articles or items in Google and Google Scholar between the years 2017 and 2020. Key words informing our search included (“*attention deficit hyperactivity disorder*” OR “*ADHD*”) AND “*apps*” AND “*college*.” We also checked the past three years of ADDitude Magazine as well as websites and Facebook groups. This comprehensive search resulted in identification of 208 different apps (Jorgensen et al.). Often, it was only one individual, from among people with ADHD and experts, who recommended the app. We calculated how often our various sources mentioned each app and checked if these apps were available in the Apple App Store and the Google Play Store in 2020. In Table 3 we present an annotated listing of the 20 schoolwork related apps mentioned by at least two sources. Based on their web descriptions, only five of the 20 technologies mentioned by experts used AI: Asana, Evernote, Google Calendar, IFTTT, and Todoist.

Table 3. Brief Descriptions of the 20 Apps Recommended by Experts for Students with ADHD.

| App | Brief Description |
|------------------------------|---|
| Asana | Helps set goals and track progress using a Gantt chart |
| Dragon Anywhere | Dictation app for writing documents |
| Dropbox | Online file hosting that stores all files in the same place, across all devices |
| Due | ‘Auto Snooze’ automatically reschedules overdue reminders as repeat reminders |
| Evernote | Task management and note taking that keeps all notes in one place |
| Focus@Will | Focusing music subscription service; customizes music for different activities |
| Forest | Growing a virtual tree: helps to set one’s smartphone for specific time periods |
| Freedom | Focusing, distraction management app; blocks websites, apps, etc. for specific time periods |
| Google Calendar | Web based calendar and reminder that integrates with Gmail |
| IFTTT (If This Then That) | Connects apps, services, and devices to automate tasks |
| Microsoft To Do / Wunderlist | Task management app with a daily planner: breaks tasks down into simple steps |
| Mindnode 5 | Mind-mapping brainstorming tool; users can add visual tags to track progress |

| App | Brief Description |
|--------------------|--|
| Pomodoro Timer | Focusing app; sets study and break times |
| Quizlet | Study app that uses flashcards and games to facilitate learning |
| Read&Write | Provides text-to-speech, word prediction, and other literacy tools |
| Remember the Milk | Reminders by email, text, and Twitter; works across all devices |
| RescueTime | Time management app that tracks time spent on apps, websites, and specific documents |
| Time Timer | Visual countdown timer; helps notice time remaining for a task |
| Todoist | Prioritizes tasks, sets daily and weekly goals, rewards for completion |
| Voice Dream Reader | Provides text-to-speech reading aloud with synchronized highlighting |

Although we now had an idea about what apps were recommended for them, we did not know whether students with ADHD were aware of these apps and if they used them.

Study 7: Do students with ADHD know about and use the apps recommended by the experts? In 2020 we used an online LimeSurvey to ask 35 students with ADHD and 74 students without disabilities whether they used any of the 20 recommended apps and which ones they found helpful (Fichten et al., Let's). We excluded students with specific learning disorders because we did not want to confound the findings with technologies intended for students with learning disabilities. The most common comorbidity for the 35 students with ADHD was a mental health related disability ($n = 21$). We listed the 20 schoolwork related apps presented in Table 3 and asked students to check: "Which of the following apps have you tried? (Select all that apply)." Using JavaScript, we presented students with a list of apps that they indicated having tried and asked them "Of the apps that you tried, which ones did you like? (Select all that apply)."

Both groups of students were familiar with: Asana, Dragon, Dropbox, Due, Evernote, Forest, Google Calendar, IFTT, Pomodoro Timer, Quizlet, Read&Write, and Microsoft To Do / Wunderlist. Both groups liked most of these, although students with ADHD did not indicate liking

Asana, Due, Microsoft To Do / Wunderlist or Forest.

This study showed that students with ADHD and students without disabilities used the same apps and found many of the same apps helpful. Students with ADHD were familiar with approximately half of the 20 “recommended” apps and liked even fewer. To gain a more comprehensive understanding, it is crucial to find out how they use these apps and technologies.

Study 8. How do apps help students with ADHD do academic work in class and out of class? In 2021 we interviewed nine of the 35 participants with ADHD from Study 7, either via Zoom or telephone (Fichten et al., Let's). Coded responses indicate that when students were in class (face-to-face or by Zoom), they were most likely to use their smartphones' camera app to take pictures of notes and information on the board or the screen, especially when instructors did not post these online. They also used recording apps to help with momentary lapses of attention or missed classes. As with camera apps, students reported that recording was most useful when professors did not post their lectures online. Kahoot was also frequently mentioned; students used it to ask questions in class, for quizzes, and as an interactive language learning app. Students found Zoom helpful to connect with classmates.

For doing schoolwork outside the class, the most frequently mentioned app was Discord. Students utilized it to communicate with their classmates using chat and text, sharing screen shots of course slides, and asking questions that peers could answer. In addition, students found a variety of reading and writing tools helpful for getting feedback through collaboration and for screen reading. It is important to note that students frequently specified Microsoft and Google tools. Most of the apps and technologies mentioned work across several platforms. Students found the reminder feature of Google Calendar especially valuable because it facilitates time-management and scheduling daily tasks. They also liked Pomodoro Timer to schedule both study and break times.

Students also appeared concerned about their mental health: they mentioned meditation and

relaxation apps, including Insight Timer and Respirelax, as helpful.

Discussion

Artificial Intelligence Apps for Doing Academic Work

So, after five studies, what can we conclude about AI-based technologies used by students with disabilities to do schoolwork? Overall, our findings show that AI-based technologies and mobile tools have tremendous potential. However, our results also show that students are often not aware of the benefits. As increasing numbers of technologies are integrating AI into their technologies, it becomes important to identify AI features on products' web sites, including how privacy is addressed. Informed research about the efficacy of these tools is also urgently needed.

For example, Zoom, the most popular post-secondary remote teaching videoconferencing technology (Aratani) recently incorporated AI-based live captions. This is true as well of its major competitor, Microsoft Teams. Both also provide transcripts. Many colleges and universities provide free Microsoft subscriptions to their students and faculty. Free Zoom versions are available. Both work on virtually all platforms, a feature that students consider important.

The same applies to Microsoft 365 ("Get"), which recently incorporated numerous AI features. Again, many colleges and universities provide free licenses for students and faculty. Microsoft tools are interesting because of their collaboration features, which were essential during the COVID-19 pandemic, and their accessibility features for students, such as speech-to-text and text-to-speech. For faculty, there are live captions in PowerPoint ("Present") and most Microsoft 365 products have accessibility checkers ("Improve"). Other large tech companies, such as Adobe and Google are also incorporating accessibility related AI into their suites (Potoroaca; Bayern).

Although students with and without disabilities generally use the same apps, there are specialty AI-based mobile apps for students with certain disabilities, such as those visual impairments (i.e., Seeing AI, Microsoft Lens). However, it seems that operating systems, especially

those of iPhones and iPads, have excellent accessibility features, some with AI capability. It was not surprising to find that Apple smartphones and tablets were preferred over Android by students both with and without disabilities. Regrettably, intelligent virtual assistants, typically used on smartphones, tablets, and standalone devices, do not seem to be living up to their potential.

It is evident that many companies are incorporating AI related to accessibility into general use technologies, often obviating the need for expensive assistive products. Nevertheless, there will always be a place for the traditional assistive technologies such as Jaws, ZoomText, Kurzweil, and Read&Write. Such products help power users and are of enormous use to students with certain disabilities such as visual impairments and specific learning disorders. A listing of assistive technology companies and products is available (CSUN Exhibitor Directory).

Mobile Apps for Students with Attention Deficit Hyperactivity Disorder (ADHD)

Three studies later, we concluded that students with ADHD and those with no disability found the same apps helpful to do schoolwork. Most students used tools that facilitated academic work, such as Pomodoro Timer and Quizlet. Although some students with ADHD expressed concerns about the functional limitations of their disability, few reported using the apps recommended by the experts, with two exceptions: Google Calendar because of its ease of use and level of integration with Gmail, and cloud drives such as Dropbox to help with organization. Furthermore, students with and without ADHD liked apps that worked across several platforms.

The literature shows that anxiety is increasing among students in post-secondary education (Hoyt et al. page 272), especially among students with disabilities (Union). It is a well-known fact that students with ADHD have comorbid anxiety disorders (Schatz and Rostain). Therefore, as our findings suggest, some students found apps for meditation and paced breathing helpful.

Conclusions and Recommendations

Developers of AI-based tools need to consider and evaluate their usefulness as well as

potential privacy concerns. These should be indicated on their web pages. As tech companies integrate AI into more and more technologies, students with disabilities should be involved in developing and training these (Treviranus).

There will always be a place for the traditional high-end assistive technologies. But it is important to note that the post-secondary population of students with disabilities is changing, as is evident from our research. Students with non-visible disabilities such as ADHD, mental health related disabilities, chronic health challenges, and learning disabilities are more likely to be found on our campuses than students who are blind, have low vision or a mobility impairment. Moreover, over half of the students who self-identity as having a disability do not register for campus disability services (Fichten, et al., Are; Fichten et al., Academic), making them ineligible for subsidies or for assistive technology support. Thus, general use technologies have an important role to play in supporting students, necessitating a reconsideration of what is defined as assistive technology.

Poor organization, a common trait of ADHD, makes keeping track of assignments, exams, and course materials over multiple platforms exceptionally challenging. Therefore, it was not surprising to find that students with ADHD, one of the largest group of students with disabilities on campus, like to keep their documents in one place. Tools such as Microsoft OneNote, and cloud drives, such as Dropbox, OneDrive, and Google Drive, facilitate this task (Brown and Mitroff). Also, it would be helpful if institutions developed guidelines limiting the number of learning management (LMS) platforms professors use because a key source of difficulty for all students involves confusion related to the number of different LMS platforms used in their courses.

Based on our findings, we recommend that students with ADHD use Google Calendar, as it easily interfaces with Gmail to send reminders and notifications. Our findings also suggest that Pomodoro Timer is useful for scheduling study and break times. Insight Timer can be useful for finding meditation apps that can reduce anxiety, a common ADHD comorbidity.

Our findings also suggest that students appreciate when faculty upload PowerPoints and lecture videos. This practice would benefit students with attention related challenges and could obviate the need for taking photos of the screen or recording the lecture on a mobile device.

Our findings suggest that it will be easy to integrate effective teaching techniques learned during the COVID-19 pandemic into blended and hybrid courses once the pandemic ends. Post-secondary faculty (Lombardi) and students (Top) are interested in keeping certain aspects of remote teaching when classes return to normal. Peter Salovey (President) recently noted in Time Magazine that remote teaching has taught faculty to use digital tools for learning activities. He also stated that, "Recorded lectures will allow many to make the best use of class time with students and provide more learning resources. Remote teaching formats featuring transcripts and captions also increase accessibility of course content for all students." We certainly agree and add that access to asynchronous lectures can help all students, including those whose first language is not the language of instruction and those whose work schedules do not permit attending the live class.

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Teleconference Sign Language Detection

Shane Angel, Allison Tate, Christian Vogler and Raja Kushalnagar
shane.angel@gallaudet.edu, allison.tate@gallaudet.edu,
christian.vogler@gallaudet.edu, raja.kushalnagar@gallaudet.edu
Gallaudet University

Abstract

Teleconferences spotlight the active speaker, based on audio. For deaf signer accessibility, we report user evaluations of a sign-detection algorithm to spotlight the active signer.

Introduction

The pandemic led to the increased use of technologies like Zoom, which is helpful for large group meetings without additional costs, and educational institutions and companies have been using Zoom during the pandemic. (Iqbal, 2021). However, Zoom is not deaf-friendly since its spotlight feature only detects voices and doesn't have the technology to detect signers, which leads to professors having to spotlight every signer, a time-consuming task. Sign language detection [3] is defined as the binary-classification task for any given frame of a video if a person is using sign-language or not. Unlike sign language recognition, where the task is to recognize (classify) and interpret continuous signs in a video, or sign language identification, where the task is to identify which sign language is used, the task of sign language detection is to detect when something is being signed, which is easier to solve than recognizing discrete or continuous sign language detection. By reducing this to a binary classification, we can automatically spotlight any person who is signing, lessening the burden on the host, who otherwise must manually spotlight every DHH person when it is their turn to speak using American Sign Language (ASL). Apple already had sign detection technology used in FaceTime to spotlight any signers automatically, but they did not share their coding or technology with anyone else, so that leads to another current sign detection technology which Google invented. The Google app aimed to detect sign language while improving the accuracy of detecting sign language from non-sign language. We plan to use the Google app to minimize the number of errors and impact of errors by identifying which algorithms and UI can be improved or changed.

Background

A group of Google developers created a real-time sign detection application called Real-Time Sign Language Detection using Human Pose Estimation. (Moryossef et al., 2020) The goal

was to create a feature that accurately monitors the user's movement by using human pose estimation. They identified four monitoring methods and tested which method was the most successful at detecting sign language. The four monitoring methods were BBOX, Pose-Hands, Pose-Body, and Pose-All. (Moryossef et al., 2020) They used techniques previously developed by Texas A&M University to detect sign language within pixels. In contrast, the background movement and non-sign language movement were filtered out by separating the foreground and background of the video input. In the end, they decided that Pose-Body was the best method for detecting sign language in their working demo.

TensorFlow.js (TFJS) is a high-level Application Programming Interface (API) that implements both machine learning and deep learning to create an end-to-end platform that makes it possible for ASL detection applications to be built and deployed. ("Real-Time Human Pose," n.d.) As a result, TensorFlow significantly improved the development of ASL detection applications because it eliminates a large portion of the development process.

Methods

The two key goals for our testing were to determine results for accuracy and latency/lag. Looking at examples of sign videos, we hypothesize that the most challenging part of this task is to identify when a person starts signing, because a signer might initiate hand movement for other purposes, for example, to touch their face. Distinguishing this type of ambient motion from actual linguistic sign movement is not always straightforward. Although not explicitly studied on signers, people in different cultures exhibit different face-touching patterns, including frequency, area, and hand preference.

We compared our results to the Google group's results for accuracy and then compared results for latency to the other table and speech detection results. In addition, we will be using

the Google sign language detection application to determine the impact of errors and delays. Our research question is what algorithms or UI can be improved or changed to minimize errors and the impact of errors in current Sign Language Detection applications? To complete the testing, we set up a VM on Google's Cloud platform and the sign detection code.

Results

We recruited 18 deaf signers for a 30-minute evaluation, and participants were compensated a \$15 Amazon gift card. We recruited participants using word of mouth, contacting students from our peers, a few from alumni at university through email or social media, and family and friends through word of mouth. Our research question asks: What algorithms or UI can be improved or changed to minimize errors and the impact of errors in current Sign Language Detection applications?

Data Analysis

After the conclusion of our app testing, we had our participants complete a Google Form that asked them questions about their perception of our sign detection application, followed by a demographics section to gain general information about the participants that could pertain to our testing of the sign detection app. When asked to agree on whether the sign detection app was useful? As shown in Figure 1, 11% strongly agreed, 50% agreed, 27% were neutral, and only 11% disagreed.

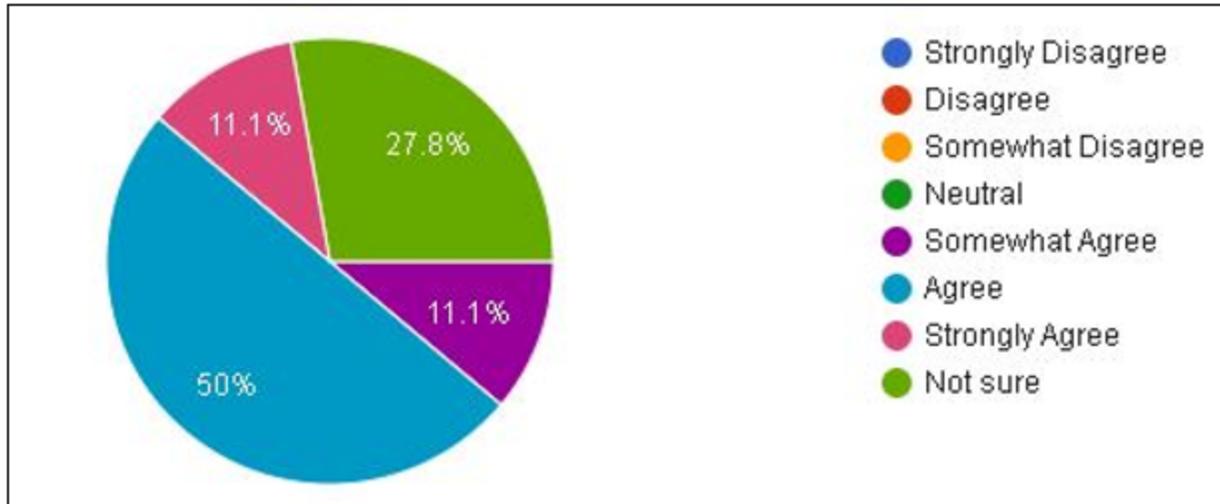


Fig. 1. How Useful is the Sign Detection App?

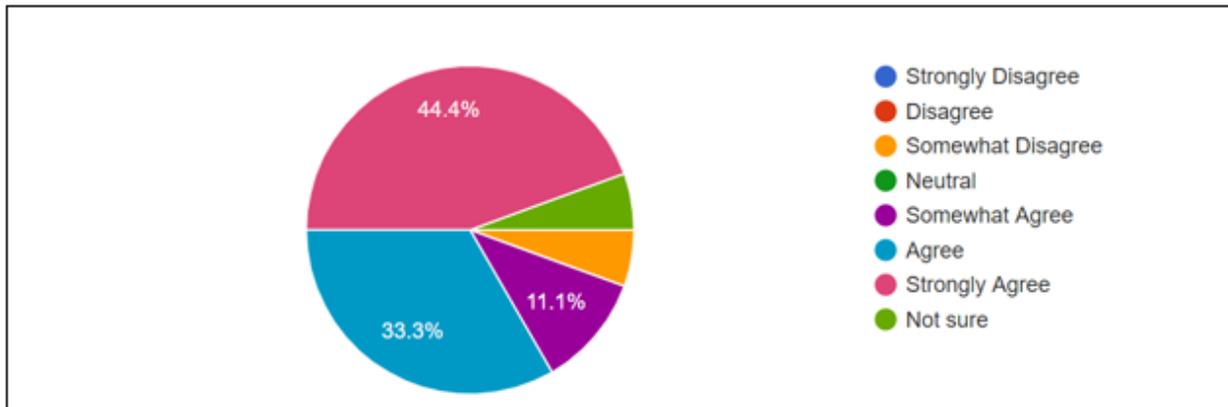


Fig. 2. How Much Do You Agree that The Gestures Will Occur Naturally?

The next question in our Google Form that had notable results was our question asking our participants if they agreed that the gestures, we had them complete would occur naturally when using a video conferencing platform. As shown in Figure 2, almost 90% of the participants either strongly agreed, agreed, or somewhat agreed that these gestures would occur naturally in a video conference platform. Based on the results, we conclude that the gestures we had our participants complete were proper and confirmed our testing procedures.

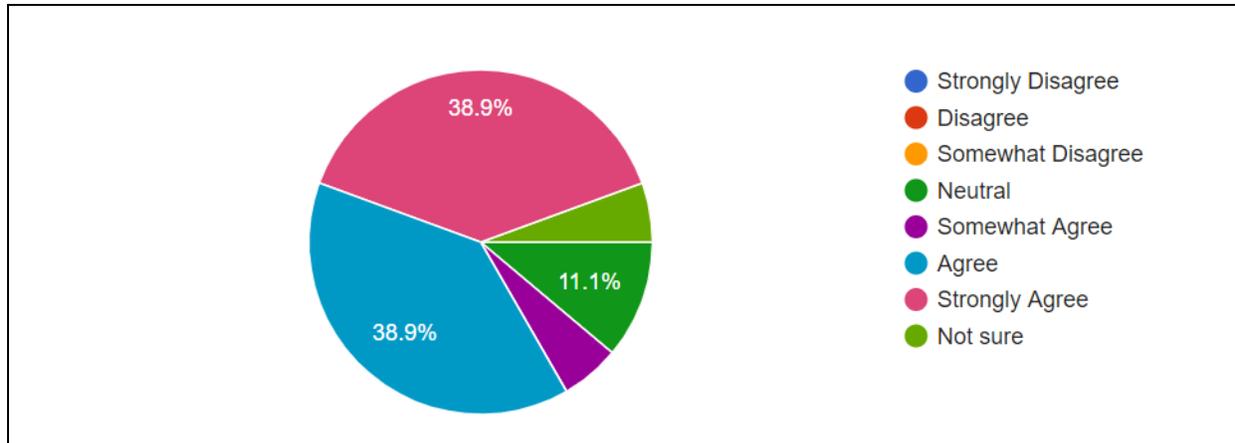


Fig. 3. Do You Agree the Lag Was Noticeable or Not?

Another question that produced significant results was the question asking if the participants agreed or disagreed that they did not experience any lag or latency while using the app demo. As indicated in Figure 3, 83.4% of our participants did not have a noticeable issue with lag or latency.

Due to FPS being different for each participant, we decided to find the averages for each group of FPS ranges. FPS was separated into the following four groups: 1-10 FPS, 11-20 FPS, 21-27, and 28+. Figure 4 below graphs the average for each group for each sign phrase/gesture.

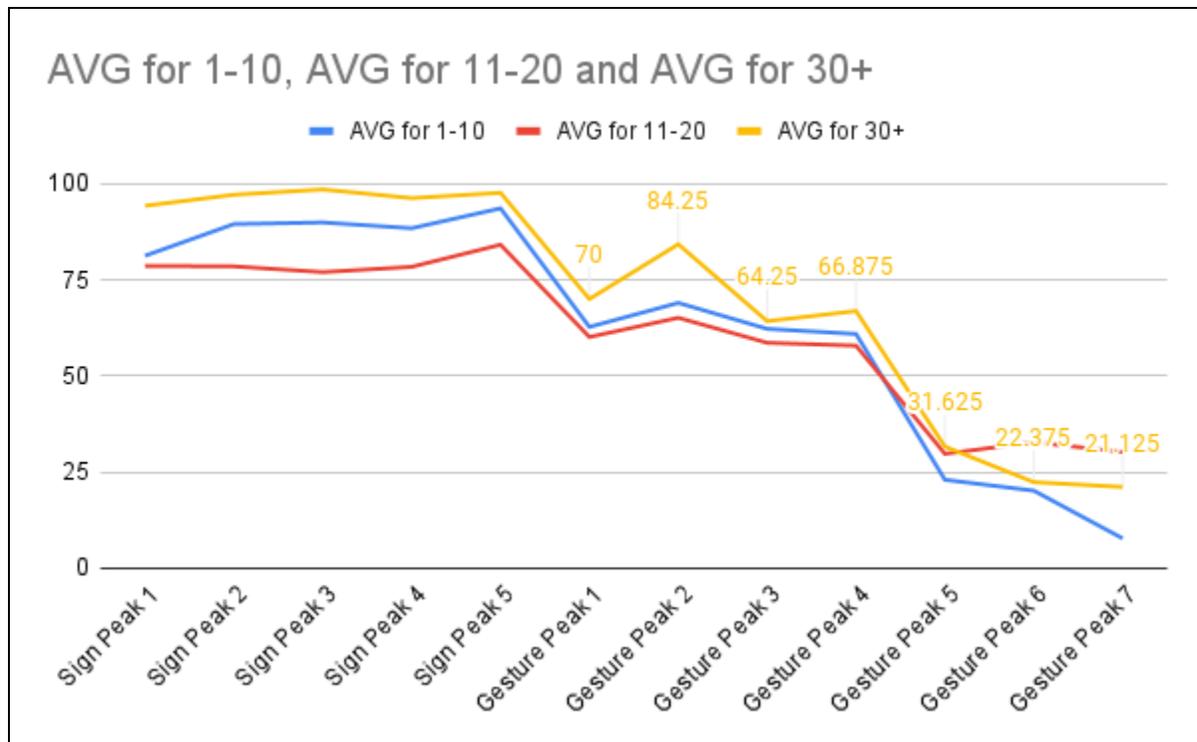


Fig. 4. A Noticeable Drop in Accuracy Below 28 FPS.

From Figure 4 above, it is evident that FPS can make a difference in the output for the users that use it. For example, 28+ FPS will typically result in higher sign detection compared to lower FPS. The main cause for higher FPS outputting a higher peak detection value is that the app detects signing by subtracting movement between frames, so by having more frames processed per second, it will cause a higher output. Likewise, as the FPS decreases, the peak sign detection will be lower compared to higher FPS computations.

Discussion

Due to being online and being unable to control what computers our participants used, cameras capture video at different FPS or at various resolutions. Given that the algorithm requires sufficient computing power to run the pose estimation system in real-time on any user's device. As we found, this proves to be challenging, as noted below that the minimum FPS requirement was not met on several participants' computers. Furthermore, as the algorithm only

looks at the input's optical flow norm, it might not be able to pick up on times when a person is just gesturing rather than signing. The authors noted that since this approach is targeted directly at sign language users rather than, the general non-signing public, erring on the side of caution and detecting any meaningful movements is preferred.

If a camera captures at an FPS below 28 frames per second, then the app will only be able to analyze the number of frames provided. This can make an impact in future sign detection applications because it will cause any improvements to account for the number of frames captured by the camera. Additionally, higher-quality cameras capture video at a higher resolution. This factors into the effectiveness of the app because with higher resolution, the app can more effectively complete body pose estimation and, in theory, would generate more accurate results.

Future Work

We have identified four areas of our app that need to be improved to potentially decrease the number of errors that occur and to improve usability for users. The app should allow for optimization throughout the processing on the client's side of the system. This change will directly benefit users because it will enable the app to process more frames per second and result in fewer errors in detection. Besides optimization, another change in the algorithms would be to recreate the machine language part of the app but with only specific sign languages and not an array of them. Lastly, we noticed that different lighting and background would seem to cause unwanted errors during testing. Therefore, we propose the addition of algorithms to minimize the impact that different lighting and background have on the application.

Conclusion

After completing our data analysis and combining our research, we were able to determine four areas of improvement for current. The proposed changes included changes in our selected app's UI and processing. Our proposed UI change would make our app's output clearer to the user. Our proposed processing changes include optimizing the body pose estimation software, training the app's machine learning process only to use American Sign Language, and adding a type of AI for better performance for different lightings and backgrounds.

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Caption UI/UX - Display Emotive and Paralinguistic Information in Captions

Joseph Mendis, Ramzy Oncy-Avila, Christian Vogler and Raja Kushalnagar
Gallaudet University

joseph.mendis@gallaudet.edu , ramzy.avila@gallaudet.edu ,
Christian.vogler@gallaudet.edu, raja.kushalnagar@gallaudet.edu

Abstract

Emotive and paralinguistic information are typically missing from conventional closed captions. To include some of this information in closed captions, we generated graphical representations of this information that is normally represented with descriptive words. We evaluate them in captions and report on how participants perceive them. These viewers then provided verbal and written feedback regarding positive and negative aspects of the various captions. We found that hard of hearing viewers were significantly more positive about this style of captioning than deaf viewers and that some viewers believed that these augmentations were useful and enhanced their viewing experience.

Introduction

Captions are the overlaid text representation of speech or sound of a video. Captions allow viewers to follow the dialogue and the action of a program simultaneously. It provides access to the spoken content for people who cannot access the audio either because they cannot hear it, or the audio is not available. Captions can also provide information about who is speaking or about sound effects that might be important to understanding a news story, political event, or the plot. The importance of closed captions cannot be understated considering the millions of people who rely on them for watching videos (Crabb et al., 2015). The demand for captions will continue to rise as video content is being produced on the internet. YouTube has seen an increase in the number of hours of videos uploaded every minute from 500 as of May 2019 from 400 hours every minute in 2015 (Tankovska, 2021). Over the years, there have been many improvements due to regulatory requirements on providing guidelines for captioning, such as the United States of America's Federal Communication Committee (FCC), or the United Kingdom's Office of Communications (Ofcom) guidelines and regulations for closed captions on television.

Closed captioning has allowed people who are deaf and hard of hearing to be included as audience members. Many of these viewers have to deal with non-speech information and identifying sound sources. These issues challenge viewers to watch video and read captions that convey sufficient aural information yet remain synchronized and readable. For example, some DHH viewers miss the point of visual gags or fail to identify who is talking in a group, as some of the audio information such as music, sound effects, and speech prosody are not usually included in captioning. Due to the lack of standardization on how to represent non-speech information, sound information is usually limited to speech representation. Emotions are

expressed through a combination of verbal communication such as speech and its prosodic modifiers and paralinguistic characteristics such as facial expressions, gestures, gaze, body positions, and movements (Wang and Cheong, 2006). Much of the semantics of television and film are conveyed through the interactions among humans on-screen, background sound, and music. The literature on primitive emotions shows that there are at least six common emotions: anger, sadness, happiness, fear, surprise, and disgust (Ortony and Turner, 1990). A previously conducted study used avatars for speaker indicators in captions, which included an image of a character and their name beneath it, indicating the speaker and their position in the video (Fels & Vy, 2009).

Another important piece of information that is typically missing from closed captions are emotions. Closed captions are text-based, so the “expressions of paralinguistic and emotive information are typically missing in video media,” (Rashid et al., 2006). Due to this, people who are deaf or hard-of-hearing are experiencing limited access to such video media.

It takes time to read and process captions, which are also subject to space and speed limitations. Viewers were generally satisfied with captioning quality for television, but were dissatisfied with missing words, spelling errors, and captions that moved too quickly caused dissatisfaction (Jensema, 1996, 1998). These studies also confirmed that reading speed and vocabulary levels limit the quantity and speed of text. There is often barely enough time and space within a caption to provide a verbatim translation of what is being said. Because of this, other non-verbal aspects central to the intended entertainment experience are omitted.

Viewers cannot simultaneously watch media and read the visual captions; instead, they have to switch between the two and inevitably lose information and context in watching the movies. In contrast, hearing viewers can simultaneously listen to the audio and watch the scenes.

Using compact representations such as graphics can help address the limited time spent on following the captions.

One of the difficulties of using graphics to convey information is deciding what information to convey and how best to convey it using the most appropriate graphics. Some solutions for this can be drawn from related fields, such as text communication. In messaging apps, such as iMessage, offer emojis, which are icons, mostly of faces that show various expressions for various emotions. Some systems allow users to add personal features to the emojis by merging a three-dimensional snapshot of their face with the emoji, which provide a personal touch to using the icon to express their emotions. Studies show that emojis have a positive effect on the ability of senders to communicate their message and of receivers to understand the message [Rovers and van Essen 2004]. Similar to using text to describe emotions in captions, using emojis to convey emotions requires a standardized lexicon.

Since there are many kinds of emotions and non-speech information, it is difficult to represent the range of possibilities with a limited set of symbols. A single non-speech sound can be captioned in multiple ways and there is no clear agreement on which one to pick. For example, a phone ringing could be represented in at least three different ways: [Phone Ringing] or as [Phone Rings Multiple Times] or [Phone rings 3 times].

Similarly, emojis and spatial information can be flexible enough to represent spatial information such as the location of the sound in a room. Attempting to express spatial information with text (as speech or in written form) is less efficient, more error-prone, and requires more descriptors and interpretations (Fels, 2001).

In this paper, we explore two simple but effective approaches to aid DHH viewers in watching movies with nonspeech audio content: emotive and paralinguistic information. Our

experiments measure students' preference and recall of captions and associated scenes in captioned media clips, by asking them to complete a survey after using each of our two tools compared to the baseline case of regular captions.

We discuss the relevant design criteria based on the feedback we received from users during our iterative design process and suggest future work that builds on these insights. The addition of compact visual information into caption can increase satisfaction and understanding of the captioned media related to traditional captions.

Methodology

The sample included 20 adult participants who are deaf or hard-of-hearing. A demographic questionnaire was designed for the study to gather information on our participants. This includes basic questions such as gender, age, ethnicity, education level, hearing level, sign language skill level, deaf identity, and their experiences using technology. Our participants all had prior experience with watching captioned movies from birth, reflecting the fact that they had grown up after the passage of the Americans with Disabilities Act. Participants that were included in our study were compensated \$15 for their time in our 30-minute study sessions. The recruiting period occurred during the months of June and July 2021 in the United States.

We tested two conditions. Condition 1 is testing the use of Apple's feature called Memoji to display emotive information in captions. Condition 2 is testing the use of text description to display paralinguistic information. In condition 1 we tested the emotive information such as sad, happy, angry, confused, and fear. For condition 2, we tested paralinguistic information such as inspiration, sarcastic, quiet, surprised, and loud.

Table 1. Lists of All Types Under Each Condition: sad, happy, angry, confused, and fear for Memoji; and inspirational, sarcastic, quiet, surprised, and loud for paralinguistic information.

| Condition 1: Memoji for Emotive Information | Condition 2: Text Description for Paralinguistic Information |
|--|---|
| Sad | Inspirational |
| Happy | Sarcastic |
| Angry | Quiet |
| Confused | Surprised |
| Fear | Loudly (screaming) |

Results

Overall, there were some differences shown between the closed captions shown with emotive and paralinguistic information and the base closed captions that did not include either emotive or paralinguistic information.

After conducting the surveys, we asked participants their thoughts on such conditions to show either emotive or paralinguistic information, if they see a benefit from using such conditions, which condition they would prefer to use, and any feedback on what improvements they would like to see. We have gathered many different responses based on the follow up questions. In the table below, it shows that hard of hearing participants see a bigger improvement in both conditions than deaf participants as hearing capability might influence these conditions.

Table 2. Compares Responses Between Base and Emotion/Paralinguistic Enhanced Captions.

| Difficulty Perceiving Emotion | Base | Condition | Difference |
|--------------------------------------|-------------|------------------|-------------------|
| Deaf | 2.96 | 2.4 | 0.56 |
| HOH | 2.92 | 2.2 | 0.72 |

| Difficulty Understanding Emotion | Base | Condition | Difference |
|---|-------------|------------------|-------------------|
| Deaf | 3.24 | 2.56 | 0.68 |

| Difficulty Understanding Emotion | Base | Condition | Difference |
|---|-------------|------------------|-------------------|
| HOH | 3.26 | 2.2 | 1.06 |

| Difficulty Perceiving Paralinguistic Information | Base | Condition | Difference |
|---|-------------|------------------|-------------------|
| Deaf | 2.74 | 1.86 | 0.88 |
| HOH | 2.62 | 2.18 | 0.44 |

| Difficulty Understanding Paralinguistic Information | Base | Condition | Difference |
|--|-------------|------------------|-------------------|
| Deaf | | 1.84 | 1.06 |
| HOH | 3.06 | 1.88 | 1.18 |

Discussion

Our results indicated that providing participants with additional information within their captioning experience can be overall beneficial. Throughout most of our participant responses we saw that there was a consistent difference between the overall difficulty our participants experienced when watching the base captioning in comparison to our condition captioning styles: Memojis and Paralinguistic Information.

Many participants found the paralinguistic condition to be helpful and gave us common feedback to improve it such as moving it to the beginning of the caption instead of the ending so participants can understand the tone before reading the captions. Other feedback was given such as giving it more variations instead of having the information in all capitals by making it italicized or mixed capitals and have it more often for other speakers.

As for the Memoji condition, many participants liked it as a speaker identification and common feedback was given about it not having a lot of variations in facial expressions and that it can be visually distracting and hard to distinguish at a far distance. While the Memoji condition is a new concept to all the participants, it would probably take some practice in

learning how to receive information and get used to this new design.

Overall, most of the participants prefer the paralinguistic condition the most as it is the easiest for them to read and understand as some of them have seen similar designs on shows or movies that they watched. Overall, there were signs of improvement for both conditions in terms of understanding emotive and paralinguistic information in captions.

Conclusion

Our study shows that deaf and hard of hearing participants show improvement to understanding emotional and paralinguistic information in captions based on our added conditions to the captions. The ability to directly perceive salient environmental information adds a new dimension to accessibility in watching media and provides a deeper understanding. . Our findings indicate that these conditions are a good possible way to include such information, while we have received numerous responses and feedback for the conditions based on the follow-up questions response. Iterations of these conditions are needed to better improve the effectiveness of including emotive & paralinguistic information in captions. While combining both conditions in the same captions can be possible but it can be too much information to process, so considering a caption design that will reduce the cognitive load and make it easier to process the information would be the next step of research. We hope with this research, we help push out other ideas of including emotive or paralinguistic information in captions and help it become an option for users to use in mainstream captioning services.

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Getting in Touch With Tactile Map Automated Production: Evaluating impact and areas for improvement

Brandon Biggs

Smith-Kettlewell Eye Research Institute and Georgia Institute of
Technology, brandon.biggs@ski.org

Charity Pitcher-Cooper, James M. Coughlan

Smith-Kettlewell Eye Research Institute

cpc@ski.org, coughlan@ski.org

Abstract

This study evaluated the impact the Tactile Maps Automated Production (TMAP) system has had on its blind and visually impaired (BVI) and Orientation and Mobility (O&M) users and obtained suggestions for improvement. A semi-structured interview was performed with six BVI and seven O&M TMAP users who had printed or ordered two or more TMAPs in the last year. The number of maps downloaded from the online TMAP generation platform was also reviewed for each participant. The most significant finding is that having access to TMAPs increased map usage for BVIs from less than 1 map a year to getting at least two maps from the order system, with those who had easy access to an embosser generating on average 18.33 TMAPs from the online system and saying they embossed 42 maps on average at home or work. O&Ms appreciated the quick, high-quality, and scaled map they could create and send home with their students, and they frequently used TMAPs with their braille reading students. To improve TMAPs, users requested that the following features be added: interactivity, greater customizability of TMAPs, viewing of transit stops, lower cost of the ordered TMAP, and nonvisual viewing of the digital TMAP on the online platform.

Keywords

Tactile, Map, Blind, Orientation and Mobility, Evaluation, Low Vision

Introduction

Maps are a critical part of everyday life (Longley et al.). While blind and visually impaired (BVI) travelers routinely use verbal directions from GPS applications, maps have been repeatedly shown to more effectively convey spatial knowledge to the user (Williams et al.; Papadopoulos, Koustriava, et al.). Siegel and White explain there are three types of spatial knowledge: route, landmark, and survey knowledge. Lack of spatial knowledge increases fear and anxiety around travel for BVIs, but maps for BVIs are difficult to obtain (Jacobson; Papadopoulos, Barouti, et al.).

Until recently BVI individuals have had almost no access to tactile maps (Butler et al.; Rowell and Ongar; Rowell and Ungar). There are two major problems with tactile maps: generating/making a usable tactile map, and viewing the tactile map (Butler et al.). Since the early 1800s, tactile maps have been custom made by sighted tactile graphic specialists and take hours to complete (Weimer; Amanuensis Braille; BANA and CBA). Tactile maps are normally created with a graphics embosser or swell paper machine with braille labels, and are often simplified with limited or abbreviated information (BANA and CBA; Brock et al.).

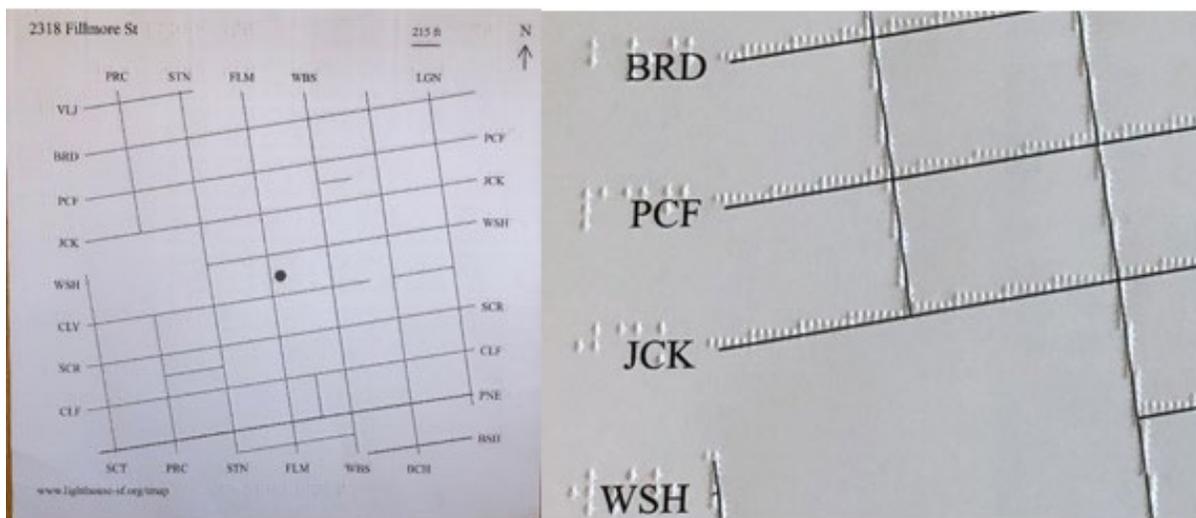


Fig. 1. Picture of Two TMAPs: One zoomed out and the other zoomed in.

To remove the need for an expensive transcriber to create a generic map of a neighborhood, the Tactile Map Automated Production system (TMAP) was developed by Joshua Miele at the Smith-Kettlewell Eye Research Institute (SKERI), and transferred to the MAD Lab at the San Francisco LightHouse for the Blind and Visually Impaired for production and future development in 2017 (Miele et al.; Lighthouse; *LightHouse for the Blind and Visually Impaired of San Francisco*). The TMAP system accepts an address from the user, and outputs a standardized SVG tactile map that can be embossed on a tactile embosser or swell paper machine. TMAP uses data from OpenStreetMap (OSM) (*OpenStreetMap*) and shows any combination of streets, walkways, and buildings. The view that is presented is often around five or six city blocks wide, depending where the address is located (see Fig. 1a). TMAPs standardizes many elements of the map, such as shortening street names to two or three letters (e.g., Jackson Street may be shortened to JCK, see Fig. 1b). Streets are represented with a solid line, walkways are represented by a dashed line, buildings are represented by a filled-in shape of the building on OSM, and a circle representing the address of the user is shown at the center of the map. A key for both the tactile features and the abbreviations is given as a second page with the map.

There are currently two methods for obtaining and viewing a tactile map: 1) The online Adaptations store at the LightHouse sells TMAPs both online and over the phone. These maps come with two zoom levels, one level that is zoomed in with buildings shown, and a second map that is zoomed out with no buildings shown. It often takes between 1-6 weeks to obtain a TMAP, depending on shipping preferences. 2) LightHouse has an online web application that individuals can use to generate, download, and emboss their own maps. This study evaluated the effect

TMAPs has had on both its BVI and orientation and mobility specialist early adopters and obtained suggestions for improvement.

Orientation and mobility specialists (O&Ms) teach BVI individuals “to utilize their remaining senses to determine their position within their environment and to negotiate safe movement from one place to another” (*Certified Orientation and Mobility Specialist (Coms®)*). O&Ms often teach tactile map literacy, and can use TMAPs in their lessons.

Study

The goal of this study was to find the impact TMAPs has had on its existing users, and how TMAPs can be improved. A mixed-method study was performed on existing TMAP users through both a coded semi structured interview, and an analysis of the online system usage logs. Although the questions were similar between BVIs and O&Ms, responses were very different. There were a total of 13 participants, 6 BVIs, and 7 O&Ms. All 25 TMAP users as of March 2020 from both the order system and online application with an email address, and who had ordered or downloaded 2 or more TMAPs, were contacted.

Table 1. BVI Participants.

| Label | Total number of y responses | P1 | P2 | P3 | P4 | P5 | P6 |
|------------------------------|------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| I am a Braille reader | 6 | y | y | y | y | y | y |
| See Light perception or less | 6 | y | y | y | y | y | y |
| Age to become Blind | | 4.5 | 0 | 0 | 0 | 0 | 0 |
| Age | | 31 | 35 | 52 | 25 | 37 | 39 |
| Gender | | m | m | m | m | f | m |
| I use a cane | 5 | y | y | y | y | n | y |
| I use a dog | 1 | n | n | n | n | y | n |
| Location | | U.S. | UK | U.S. | U.S. | U.S. | U.S. |
| Interviewed March 2020 | 6 | y | y | y | y | y | y |

Table 2. O&M Participants.

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 |
|--------------------------------------|------------------------------------|-----------|-----------|-----------|------------|------------|
| Age | | 34 | 29 | 48 | 55 | 64 |
| Gender | | Nonbinary | f | m | f | m |
| Years teaching O&M | | 10 | 6 | 3.5 | 22 | 6 |
| I mostly teach Adults 18+ | 5 | y | n | y | n | y |
| I mostly teach Children Birth-age 22 | 2 | n | y | n | y | n |
| Location | | U.S. | U.S. | U.S. | U.S. | U.S. |
| Interviewed March 2020 | | y | y | y | y | n |
| Interviewed Dec 2020 | 4 | 34 | 29 | 48 | 55 | 64 |

The hour-long interviews were held over video conference or telephone, and were recorded. Participants received \$30 an hour, and IRB approval was given through SKERI. The recording was then transcribed using Otter.ai, then coding was performed on the transcript. Usage logs from the online TMAPs system from March 2019-March 2020 were obtained and compared with the responses in the interview on map usage.

Each transcript was coded utilizing an inductive thematic analysis (Braun and Clarke; Campbell et al.; Caulfield). There were 5 steps to the process: 1) The transcripts were coded for important statements, such as “I don’t use tactile graphics other than braille”; 2) Codes were grouped into labels that represented the general sentiment of all the codes, such as “TMAPs is the only tactile graphic I use”; 3) Labels were sorted into six categories (demographics, creation, map history, feature requests, usage, and problem; e.g., the label in step 2 would be placed in “usage”); 4) The number of responses for each label were counted and the sums were sorted for BVIs, O&Ms, and total; and 5) An analysis was performed on the data, which is presented below. In the analysis, “n” (for “no”) designates that the user did not have the code in their interview, it does not mean they disagreed with the statement, and since the codes and labels

were developed inductively from a semi structured interview, not all participants talked about the exact same topics. There were 118 unique labels.

One researcher coded all thirteen interviews, and a second collaborator coded three randomly selected interviews, and intercoder reliability was obtained (Campbell et al.). This process involved both collaborators initially coding the three interviews individually, and comparing the codes for each interview. The final inter-coder reliability was 99.58%. To sort the codes into labels, one collaborator performed the initial label creation and categorization, and two other collaborators reviewed the list of labels, codes in each label, and reviewed the list of codes for each interview to check for missing codes in a label or to see if a new label should be added.

Results for BVI Users

Table 3. BVI Map History.

| Past Usage | Total number of y responses | P1 | P2 | P3 | P4 | P5 | P6 |
|---|------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Got or produced less than one map a year before TMAPs | 5 | y | y | n | y | y | y |
| Obtained last TMAP less than a month ago | 3 | n | n | n | y | y | y |
| Use other tactile graphics than TMAPs | 3 | n | n | n | y | y | y |
| Obtained first TMAP before 2019 | 3 | n | n | n | y | y | y |
| Have embosser at home | 3 | n | n | n | y | y | y |

Table 4. BVI Generated TMAPs.

| Generated TMAPs | P1 | P2 | P3 | P4 | P5 | P6 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|
| Obtained last TMAP less than a month ago | n | n | n | y | y | y |
| Number of Online Generated TMAPs | 0 | 18 | 0 | 11 | 28 | 16 |
| Number of TMAPs they said they embossed at Home or Work | 0 | 0 | 0 | 18 | 84 | 24 |
| Number of TMAPS they said they ordered from Lighthouse in the last year | 2 | 0 | 2 | 0 | 0 | 0 |

| Generated TMAPs | P1 | P2 | P3 | P4 | P5 | P6 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|
| Number of TMAPs they said they ordered from an external embossing center in the last year | 0 | 2 | 0 | 0 | 0 | 0 |
| Total Number of Said Obtained TMAPs in the last year | 2 | 2 | 2 | 18 | 84 | 24 |

Table 5. BVI Usage of TMAPs.

| Label | Total number of y responses | P1 | P2 | P3 | P4 | P5 | P6 |
|--|------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Use TMAPs to go on trips | 6 | y | y | y | y | y | y |
| I use TMAPs to understand layouts of streets and intersections | 5 | y | y | n | y | y | y |
| I use maps to build an understanding of a location | 5 | y | y | y | n | y | y |

Table 6. BVI Identified Problems.

| Label | Total number of y responses | P1 | P2 | P3 | P4 | P5 | P6 |
|---|------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| TMAPs are too difficult to obtain without an embosser | 6 | y | y | y | y | y | y |
| TMAPs are not dynamic enough | 4 | y | n | y | y | y | n |

Table 7. Feature Requests from BVIs.

| Label | Total number of y responses | P1 | P2 | P3 | P4 | P5 | P6 |
|--|------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Want to view transit stops | 5 | n | y | y | y | y | y |
| Would like interactivity | 5 | y | y | y | y | y | n |
| I would like if clients or I could print TMAPs at home, because being able to emboss at home is critical | 5 | y | y | y | y | n | y |
| I would like a lower cost tactile only TMAP | 4 | y | n | y | y | n | y |
| Would like way to view map online non-visually | 4 | n | y | n | y | y | y |

Results for O&M Users

Table 8. O&M Map History.

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|------------------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| Used handmade maps / Swell paper before TMAPs | 6 | y | y | y | n | y | y | y |
| I use other tactile graphics than TMAPs | 6 | y | y | y | y | y | n | y |
| Students map reading level is beginner | 5 | y | y | y | y | n | n | y |
| I got/produced more than 7 maps a year before TMAPs | 5 | y | n | y | y | n | y | y |
| Obtained first TMAP before 2019 | 5 | n | y | y | n | y | y | y |
| Obtained last TMAP between 1-6 months ago | 4 | n | y | n | n | y | y | y |
| Used last TMAP more than a month ago | 4 | n | n | n | y | y | y | y |
| Most students are not braille readers, or TMAPs are too advanced for their tactile diagramming skills | 4 | y | n | n | y | y | y | n |
| Students have found TMAPs to be helpful | 4 | n | n | y | n | y | y | y |

Table 9. O&M TMAP Generation.

| Generated TMAPs | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|-----------|-----------|-----------|------------|------------|------------|------------|
| Number of Online Generated TMAPs | 4 | 2 | 0 | 2 | 6 | 4 | 0 |
| Number of TMAPS they said they produced in the last year | 10 | 10 | 0 | 0 | 6 | 0 | 0 |
| Number of TMAPS they said they ordered from LightHouse in the last year | 0 | 0 | 2 | 3 | 0 | 5 | 6 |
| Total number of said obtained TMAPs | 10 | 10 | 2 | 3 | 6 | 5 | 6 |

Table 10. O&M TMAP Usage.

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|------------------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| I use both the tactile and visual elements of TMAPs | 7 | y | y | y | y | y | y | y |
| I like multiple zoom levels | 6 | n | y | y | y | y | y | y |

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|--|------------------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| I use TMAPs to understand a Local area like my neighborhood | 6 | y | y | y | n | y | y | y |
| I use maps to build an understanding of a location | 5 | y | n | y | n | y | y | y |
| I use TMAPs to understand layouts of streets and intersections | 5 | y | n | y | y | y | n | y |
| I like how current tactile features are represented on the map | 5 | y | n | y | y | y | y | n |
| I like to see the buildings | 5 | n | y | y | y | y | y | n |
| I like TMAPs is customizable | 5 | y | y | n | n | y | y | y |
| I use TMAPs to understand Features around where I am going on a trip | 4 | n | n | y | n | y | y | y |
| TMAPs are Difficult to Understand | 4 | n | n | y | y | y | n | y |
| I like online interface | 4 | y | y | n | n | y | y | n |
| TMAPs give a good overview of an area | 4 | n | n | y | n | y | y | y |

Table 11. O&M Problems Around TMAPs.

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|---|------------------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| Paying for TMAPs is difficult | 5 | y | y | n | y | y | n | y |
| TMAPs are too difficult to obtain without an embosser | 5 | y | y | y | n | y | n | y |
| Buildings make the map difficult to understand | 4 | y | y | y | y | n | n | n |
| TMAPs are not dynamic enough | 4 | n | n | y | n | y | y | y |

Table 12. O&M Feature Requests.

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|--|------------------------------------|-----------|-----------|-----------|------------|------------|------------|------------|
| Would like interactivity | 7 | y | y | y | y | y | y | y |
| Would like to add and remove tactile features, like particular buildings | 7 | y | y | y | y | y | y | y |

| Label | Total number of y responses | P7 | P8 | P9 | P10 | P11 | P12 | P13 |
|--|-----------------------------|----|----|----|-----|-----|-----|-----|
| I would like a drag and drop interface to create custom tactile features, like building, dots, spiky bushes... | 6 | y | y | y | n | y | y | y |
| Would like ability to add or remove different interactive features | 5 | y | n | n | y | y | y | y |
| Would like to add multiple points on a map | 5 | n | y | y | n | y | y | y |
| Would like a refreshable tactile display that can show TMAPs | 5 | y | n | y | n | y | y | y |
| Would like ability to change the look/feel of each feature | 5 | y | y | n | y | y | n | y |
| Would like more ability to change the scale | 5 | y | n | y | y | n | y | y |
| I would like a lower cost tactile only TMAP | 4 | n | y | y | y | y | n | n |
| want maps of college campuses | 4 | y | y | n | y | n | n | y |
| Would like turn by turn directions | 4 | y | y | n | n | y | n | y |
| Would like natural features and off-grid features | 4 | y | y | y | n | n | n | y |
| Would like to change line thickness and height | 4 | n | y | n | y | y | n | y |
| Would like a super simple map | 4 | n | y | n | y | y | y | n |
| Want to have more training materials on TMAPs | 4 | y | y | n | n | n | y | y |
| I would like if clients or I could print TMAPs at home, because being able to emboss at home is critical | 4 | n | n | y | n | y | y | y |

Discussion

The goal of this study was to find the impact of TMAPs on its existing users, and how TMAPs can improve.

BVI Users

The most important effect shown in this study was that five blind participants went from getting less than 1 map a year to getting at least two maps, with those who had an embosser generating on average 18.33 TMAPs in the last year from the online system and saying they

embossed 42 maps on average at home or work. The online system usage data was obtained by counting the number of times a participant downloaded a map from the platform. The participants with an embosser mentioned that it sometimes takes multiple tries of changing the settings and downloading a map before it is correct, and once a map has been downloaded, it could have been embossed multiple times, which does not show up in this data. P5 mentioned they frequently generate maps for other people, so re-embossing the same map, or using another account to generate the map could explain their significantly higher estimate of 84 vs the 28 downloaded from the platform. This means that increasing availability and reducing the cost can completely transform map usage among blind individuals. The overwhelming sentiment was that despite the lower cost TMAP, it is still difficult to depend on the external TMAP production process, and having an embosser at home or work will increase map usage further.

The current usage of TMAPs is to view new locations while going on trips, including streets and intersections, but the biggest feature request was to add interactivity such as through Coughlan et al. One participant explained: “If I had a tactile map, I could have a picture in my head, and confidently go outside, on the streets, by myself”. Another participant said “I feel like I’m more empowered and I have more comfort level when I’m visiting a new place if I have a map”. On using GPS instead of a map, P5 explained: “When you read things in GPS as plain text, you may know kind of in theory, what streets are connected. But being able to get that bird’s eye view and understand exactly how things intersect and understand scale is really transformational.” Interactivity could allow a significant number of features to be shown, such as transit stops and building names, without increasing the tactile map complexity. With a digital aspect of the map, the utility of TMAPs could increase from just showing intersections and streets, to providing spatial guidance between two locations on the map. If GPS was also

integrated, it could also show users their current position on the map as they are physically navigating. P1, who was also an O&M, provided one hesitation in describing their older BVI students: “Many clients don’t have a smartphone and don’t want one.” A possible solution P1 proposed was building a single purpose device that was extremely easy to use, without the complexity or negative experiences older users may have around a smartphone. Adding utility may increase the amount users are willing to pay for a map, but enabling users to view TMAPs before sending the TMAP to an embossing center may also reduce the map production cost.

The researchers interviewed the MAD Lab about their experiences with TMAPs, and the most expensive part of TMAP production is positioning the map to optimize space and minimize complexity. Although much of the TMAPs system is automated, positioning the frame and selecting features still requires a small amount of time from the MAD Lab staff. Every BVI user who had used the online system requested a method to digitally view the TMAP before printing. Having an online auditory view, such as Biggs et al., or the digital tactile display described in Biggs, would enable blind users to view the map on their computer or smartphone before ordering or printing the map. If users could position their map independently before ordering, it may help reduce the time, and hence the cost, of producing a TMAP.

One theme that was very clear from the responses is that having a map is not a replacement for the turn-by-turn directions provided by a GPS, instead, the directions from the GPS are used to supplement data from the map. This “picture” and “layout” participants have in their head after viewing a TMAP may be the survey knowledge from Siegel and White. With the anxiety and fear blind users often face when walking outside, having this extra level of spatial knowledge may facilitate more independent travel, increase positive emotions around travel, and

increase community participation, as BVIs may be more willing to leave their house (Williams et al.; Jacobson).

O&M Users

O&M users utilized TMAPs as just one tool in their toolbox. The advantage that it had for them was quick generation of maps they didn't need a transcriber for. P8 described that "before TMAPs I would just use home-grown maps, lots of time spent with puff paint, Wheatley kit, the tactile drawing kit, and Wikki Stix". The main difficulty the O&Ms had was not being able to customize it for the extremely basic tactile diagram reading skills of their students. P10 admitted "we stopped using it [TMAPs] because his [their student's] tactile diagramming skills just weren't fine enough". Intersections were also very important to show with the TMAP: "We used TMAPs to figure out when intersections were coming up and the layout of intersections, because that information was not conveyed in GPS". P13 explained: "TMAPs is the first step in spatial awareness and orientation". The feature requests mostly focused around customizing the features so these students could have a map that was less complicated and easier to read. This could be done through an online map editing interface, similar to geojson.io or a paint tool (geojson.io). In general, TMAPs was very good at showing intersections and an overview of neighborhoods, and now O&Ms would like a more advanced and customizable mapping tool.

One question the researchers had in undertaking this study concerned the use of TMAPs with low vision students. P1 (the blind O&M) and P7 didn't think their low vision students would find TMAPs useful because of its minimal detail and the use of braille labels. P8, who worked with children, said they did use TMAPs with one low vision student: "My student who is unable to read braille, because she's got quite a lot of vision, she is able to see the map and is able to understand just like general layout of which street is which and where her destinations

are... I find she pays more attention to the map when she has her hands on it.” P13 also explained: “A lot of braille readers are low vision and like the high contrast”. More research needs to be done on low vision users directly to make TMAPs something they would find useful.

Conclusions

The TMAP project has made a significant impact on map usage for its blind users, and has been a useful tool for its O&M users. Now that TMAPs has increased tactile map availability, 11 of the 13 participants wanted to see those efforts continued through more financial support and lower cost TMAPs. 12 of the 13 participants wanted to see TMAPs become interactive and expand the level of accessibility for non-braille readers and add detail on the map without increasing complexity. For BVI users, increasing the utility of TMAPs and allowing online viewing and creation of TMAPs should make maps easier to obtain. Allowing O&Ms to completely customize the map through an online visual editor should encourage O&Ms to use TMAPs more in their lessons. Ideally, there will be a higher resolution and portable digital tactile display that can show TMAPs, or portable virtual reality gloves that can communicate details at sufficiently high (e.g., 1 mm) resolution, but the technology needed for these has a way to go before this will be possible (*Size and Spacing of Braille Characters*; Durham; *HaptX | Haptic Gloves for Vr Training, Simulation, and Design*). TMAPs has enabled BVIs and O&Ms to obtain a relatively inexpensive tactile map, and these early adopters of the system want to see TMAPs continue providing less expensive, interactive, and more customizable maps.

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Crowdsourcing Annotating Storefront Accessibility Data Using

Jiawei Liu^{1,2}, Hao Tang¹, William Seiple³, Zhigang Zhu^{2,4}

¹Department of Computer Information Systems, CUNY BMCC, New York

²Department of Computer Science, CUNY City College, New York

³Department of Computer Science, The Graduate Center, CUNY, New York

⁴LightHouse Guild, New York

jliu021@citymail.cuny.edu, htang@bmcc.cuny.edu,

wseiple@LighthouseGuild.org, zzhu@ccny.cuny.edu

Abstract

The storefront accessibility can substantially impact the way people who are blind or visually impaired (BVI) travel in urban environments. Entrance localization is one of the biggest challenges to the BVI people. In addition, improperly designed staircases and obstructive store decorations can create considerable mobility challenges for BVI people, making it more difficult for them to navigate their community hence reducing their desire to travel. Unfortunately, there are few approaches to acquiring this information in advance through computational tools or services. In this paper, we propose a solution to collect large-scale accessibility data of New York City (NYC) storefronts using a crowd-sourcing approach on Google Street View (GSV) panoramas. We develop a web-based crowdsourcing application, *DoorFront*, which enables volunteers not only to remotely label storefront accessibility data on GSV images, but also to validate the labeling result to ensure high data quality. In order to study the usability and user experience of our application, an informal beta-test is conducted and a user experience survey is designed for testing volunteers. The user feedback is very positive and indicates the high potential and usability of the proposed application. DoorFront has been successfully launched and can be accessed at: <https://doorfront.org>.

Keywords

Crowdsourcing, Storefront Accessibility, Independent Travel, Visually Impaired,
Open-Source Data

Introduction

In the United States, the number of blind or visually impaired (BVI) people continues to increase. According to the report by the CDC organization, approximately 12 million people 40 years and over in the United States have vision impairment, including 1 million who are blind, 3 million who have vision impairment after correction, and 8 million who have vision impairment due to uncorrected refractive error (CDC, 2021). Visual impairment can have a profound effect on their quality of life, affecting them physically and psychologically and interfering with their daily activities, especially traveling, which is identified as the most stressful event in their lives (Nadine Donaldson, 2017).

For BVI people, how and where to go can be a significant challenge. Localizing the entrance of a store or facility is a difficult task for BVI people. Additionally, improperly designed staircases and obstructive store decorations are still common barriers for BVI people. In New York City (NYC), for example, although the Mayor's Office for People with Disabilities (MOPD, 2021) requires businesses to provide equal access to goods and services for customers with disabilities in an integrated environment, most small businesses do not follow this principle. As a result, monitoring compliance that relies on owner self-inspection is clearly challenging as thousands of small businesses in NYC still have physical barriers (stairs) at store entrances. Neither organizations that serve people with BVI (American Council of the Blind et al.), nor software developers have identified appropriate storefront accessibility data to use as travel guides. The existing accessibility information is mainly concerned with sidewalk situations such as defective curbs and problems caused by tree roots (DOT, 2021), and there are few emphases on the accessibility of storefronts. Moreover, studies indicate that most of the sidewalk assessment is conducted through physical audits (May et al, 2014, Law et al, 2018), but in-

person audits are not only costly and time-consuming but also lack timeliness (Rundle et al, 2011).

To further support the independent travel of the blind and visually impaired and reduce their stress in travel planning, we propose a solution that uses an approach integrating online crowdsourcing and online map imagery (e.g., Google Street View images) to gather a large amount of storefront information that can be used as reference guide materials. Our ultimate goal is to create a large-scale open-source database of NYC storefronts accessibility data with a close community engagement. In this paper, we focus on developing a crowdsourcing web application that enables volunteers to remotely label storefront accessibility data on Google Street View (GSV) images. Volunteers can virtually “walk through” New York city streets via the function of the GSV and select a cropped image of a specific storefront from a custom volunteer’s perspective in order to label our required targets. The novelty and contributions in this work include:

- (1) A web-based application *DoorFront* that provides a user-friendly interface and interactive tool combined with Google Street View for volunteers to annotate storefront information.
- (2) A volunteer contribution credits system that allows students, especially high school students, to acquire community service credits or certificates by annotating storefront accessibility data using the *DoorFront*.

While this paper mainly focuses on a data collection approach using crowdsourcing, we anticipate future work will include georeferencing the collected image labels and deposits of the data into the NYC Open Data platform (NYC Open Data, 2021). With our storefront accessibility data, technical companies can develop more flexible applications to assist the visually impaired. For example, imagine a mobile app that provides BVI people a turn-by-turn

navigation to enter a facility based on our accessibility data, or automatically recommends a travel site or a restaurant with an accessible entrance.

Related Work

Local and state governments often need to collect street-level accessibility data, but it is challenging to acquire a complete set of data at the city scale. We believe that the use of crowdsourcing methods will make data collection more efficient and economical due to the omnipresent Internet and convenient mobile technologies. Many studies have indicated that the use of online crowdsourcing plays a significant role in supporting urban mobility and public transportation (Krajzewicz, 2010, Marzano, Gilberto, et al, 2019). The solutions most relevant to our work are those that can combine Google Street View (GSV) images and online crowdsourcing to collect street-level accessibility data. For example, Bus Stop CSI (Crowdsourcing Streetview Inspections) allows people to remotely label bus stop landmark locations with GSV images (Kotaro Hara et al, 2013). Sidewalk accessibility data is important to people with mobility disabilities, hence some work has focused on collection of sidewalk data using crowdsourcing (Saha, Manaswi, et al, 2019) or machine learning approaches (Weld, Galen, et al, 2019). However, they emphasize the problem related to sidewalks and their contribution to the mobility disability community. Other approaches have collected massive urban image-based datasets such as LabelMe (Russell, Bryan C., et al, 2007) and Places (Zhou, Bolei, et al, 2018), using computer vision algorithms.

In this work, inspired by the previous crowdsourcing platforms (Kotaro Hara et al, 2013, Saha, Manaswi, et al, 2019), we propose a solution that combines online crowdsourcing and GSV images to collect large-scale accessibility data of NYC storefronts.

Discussion

User Study

In this project, our ultimate desire is to collect a large amount of data at the city scale that is useful to the visually impaired. Although we have predefined four important storefront accessibility objects, namely doors, doorknobs, stairs and ramps, we still want to find out the usefulness of the information we collect. In addition, we would like to know if there are other important storefront accessibility data for BVI people that we have not collected. In order to gain a more comprehensive understanding of the challenges and needs of the visually impaired during their independent travels, we conduct informal interviews with six blind adults to learn about what challenges they might encounter during their independent travels.

In the series of interviews, we learned that most of the participants were daily commuters prior to COVID-19. Based on their descriptions, we found that they encountered many challenges when traveling, such as keeping walking straight, determining current location and localizing store entrances. Most relevant to this paper is that most participants experienced difficulty in finding the exact location of the main entrance of their desired store or facility. For instance, one participant claimed that finding a store entrance would be the second biggest challenge in his daily life. He often needs to spend a considerable amount of time to find the location of the door. Sometimes, he will also ask volunteers for help, but these people usually only tell him that the store is in front of him but do not provide him with the exact location of the store entrance. Even those having guide dogs state that being informed in advance of the storefront accessibility of their destination store can significantly reduce the time it takes to find the entrance. According to the interviews, guide dogs can only distinguish doors but cannot tell if a door is the entrance to the destination store. Therefore, knowing the entry location of a store in

advance enables them to better instruct the guide dog. In addition, most participants indicated that the information of doors and door knobs (both types and locations) help them to easily enter buildings. This information would help them make more effective judgments.

In summary, most participants felt that having information about store accessibility in advance, especially the type of entrance (door, ramp or stair) and entrance location, would greatly reduce their stress in getting around. In addition, stairs, ramps, the types of doors and door knobs would be very beneficial to them.

Application Design and Development

Our web-based crowdsourcing application, called DoorFront, is designed to allow volunteers to label the NYC storefronts' image data with predefined accessibility categories (doors, stairs, ramps, and doorknobs). Our goal is to provide a user-friendly platform to collect a completed city-scale image dataset of storefront accessibility information with annotations. In order to achieve our goal, we have separated our application requirements into two tasks.

- First, we develop an interface that combines GSV to allow volunteers to virtually walk through the city and choose specific scenes based on their own perspectives.
- Second, we propose a solution to manage the volunteers and increase their engagement.

Crowdsourcing and Annotation Interface

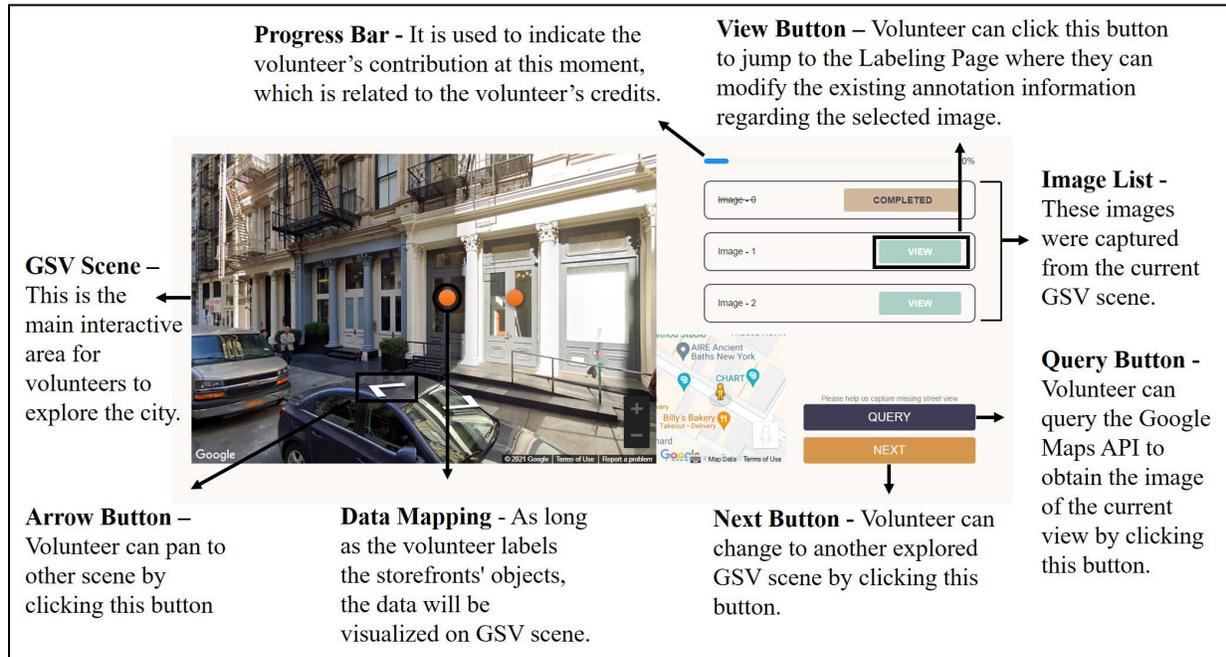


Fig. 1. The Interface of Exploration Page.

The primary goal of the project is to create a volunteer-based platform that provides an interactive labeling tool to collect street-level accessibility information of NYC storefronts. Our labeling tool can be mainly divided into two parts that were designed as two web pages, namely the Exploration Page, and the Labeling Page. On the Exploration Page (Fig. 1), a GSV scene is displayed as the main interactive area that allows volunteers to virtually turn around to view the 360-degree views of the scene and to essentially walk through the city by clicking the "Arrow" button embedded in the GSV scene. Regarding the Labeling Page (Fig. 2), it offers a tool for volunteers to label storefront accessibility objects with a user interface design inspired by *LabelBox* (LabelBox, 2021). In addition, we created a validation tool with the same interface as the Labeling Page, allowing volunteers to contribute to the validation of existing annotated images, which can improve the quality of our data.

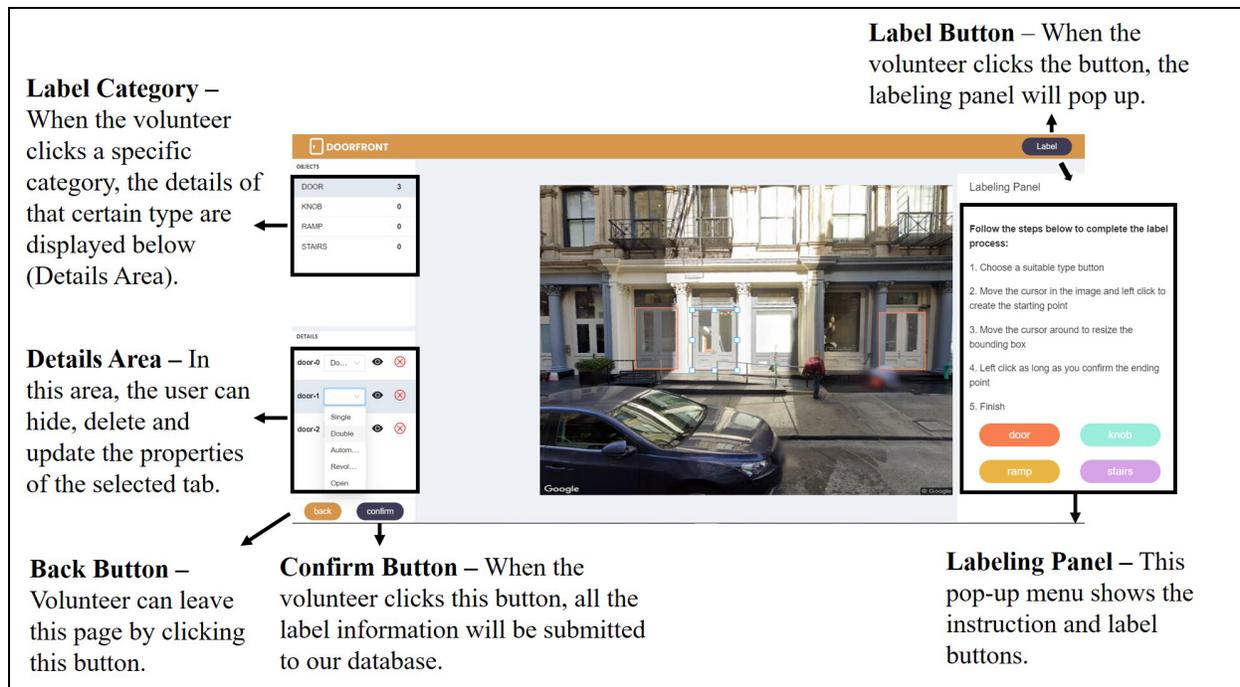


Fig. 2. The Interface of Labeling Page.

When volunteers enter the Exploration Page (Fig. 1.), they will be randomly dropped in a GSV scene that has been labeled by other volunteers. Within the Exploration Page, there are two approaches for volunteers to change the GSV scene. The primary approach is to use the built-in panning feature of GSV by clicking the embedded “Arrow” button to change the GSV scene, which allows volunteers to virtually “walk through” NYC. While the other approach is to click the "NEXT" button to reload another explored GSV. If the current GSV scene has not been labeled yet, volunteers can adjust the view direction by spanning the panorama to select the image with an appropriate view for labeling. When the volunteer presses the “QUERY” button, our application will automatically query the Google Maps API to get the corresponding image display in the current view, based on the current camera’s location and heading direction. In order to avoid storing the wrong image data and to ensure proper use of cloud storage space, a pop-up preview window appears when we get the cropped image of the current scene and asks the volunteer to confirm the selected image. Our application will only save those images that are

confirmed by volunteers so that the wrong image data would not take up our cloud storage space. When the image confirmation process is complete, the page will automatically jump to the Labeling Page (Fig. 2), where volunteers can categorize the storefront accessibility objects and select the appropriate subtype if one exists, e.g., various door types and doorknob types. Once the volunteer finishes the labeling process, the data of storefront accessibility objects will be saved in our database and displayed on the original GSV scene with a color marker on the labeled object. Our tool will automatically adjust the marker's position based on the current viewport and field of view (FOV), which means the markers stick on the labeled object accurately, even though they are not part of the GSV. When the image list appears, which indicates that the current GSV scene has been labeled, the volunteer can verify whether the storefront accessibility objects of the current scene have been fully identified by looking at the markers on the GSV. Moreover, if volunteers find an incorrect annotation, they can click on the "View" button in the image to fix the incorrect annotation.

Volunteer Engagement

The participation of volunteers is a significant factor in this project. To increase volunteer engagement, we dedicate a contribution credit system for the volunteers. Our ultimate goal is to encourage volunteers, especially high school or college students, to give back to their local community. Students can gain community service credits or certificates by annotating storefront accessibility data using the proposed web application. For the credit system, we design an incentive mechanism that gives extra credit as a reward when volunteers label a certain number of images. On the Exploration Page, we created a progress bar (percentage format) to show the number of images that the current volunteer has labeled. For example, 10% means that the

volunteer has labeled one image, and if volunteers continuously label ten images (reaches 100%), they will be rewarded with extra points.

Evaluation

In order to study the usability and user experience of our application, we conducted an informal beta-test and designed a user experience survey for testing volunteers. A total of 13 student volunteers participated in the test and completed the survey. In this test, with the help of the 13 participants, we collected 234 images in total, including 676 labels with four predefined categories (doors, stairs, ramps, and doorknobs). The number of labels for each specific category is shown in the following table (Table 1).

Table 1. The Number of Labels for Each Category.

| Category | Amount |
|-----------------|---------------|
| Door | 358 |
| Doorknob | 283 |
| Stair | 33 |
| Ramp | 2 |

To assess the label accuracy, we manually inspected 50 out of 234 images (20%), including 112 labels. During this inspection, we found 7 incorrect labels: 3 out of them were labeled with incorrect category and 4 out of them had inaccurate bounding boxes, such as oversized and misplaced. Based on the data, the accuracy rate is approximately 93.75%. We realize that this result is not statistically significant since only a limited manual inspection was performed. Therefore, we anticipate future work will design and implement a robust cross-validation mechanism that allows volunteers to evaluate the collected labels.

Table 2. The Survey Questions and Answers.

| Questions | Answers |
|--|---|
| 1. How do you like the way we collect data through Google Street View? (Please rate from 1 to 5) | 1: 0% 2: 0% 3: 15% 4: 31% 5: 54% |
| 2. Do you like the interface of our application? (Please rate from 1 to 5) | 1: 0% 2: 15% 3: 15% 4: 23% 5: 47% |
| 3. What is the average amount of time you spend on each scene (panorama)? (In general, there are two sidewalks in each scene where volunteers can label the storefront accessibility data) | 1 - 2 minutes: 46% 3 - 5 minutes: 23% 5 - 8 minutes: 23% 8 - 10 minutes: 8% |
| 4. What is the average number of images you have queried (Click Query Button) in each scene (panorama)? | 2: 23% 3: 8% 4: 8% 5: 15% More than 5: 46% |
| 5. What is the average time for labeling one image? | Less than 1 minute: 54% 1 - 2 minutes: 31% 3 - 5 minutes: 15% More than 5 minutes: 0% |
| 6. How long are you willing to spend on each volunteer time? | Less than 5 minutes: 15% 5 - 30 minutes: 54% 30 - 60 minutes: 31% More than 60 minutes: 0% |
| 7. How many scenes are you willing to explore during each volunteer hour (panorama)? | Less than 10: 31% 10 - 20: 39% 20 - 30: 15% More than 30: 15% |
| 8. Would you like to introduce this app to your friends to help us collect storefront accessibility data? | Yes: 92% No: 8% |

| Questions | Answers |
|--|--|
| 9. Would you prefer to label random areas or label specific areas selected by yourself? | I prefer to label random areas: 54% I prefer to label selected areas: 46% |
| 10. Would you prefer to label an area close to your home? | Yes: 85% No: 15% |
| 11. Would you be interested in volunteering more time to label if a badge or credit mechanism is introduced to the platform? | Yes: 100% No: 0% |

In terms of the user experience survey, those questions as listed in Table 2 were designed with three main objectives in mind. First, we aimed to evaluate the usability of our application through volunteer ratings. Second, we intended to evaluate the labeling feature and understand the user experience by analyzing the average labeling time. Third, we wanted to evaluate user engagement by analyzing the volunteering time of volunteers and labeling areas. The answers to the survey listed in Table 2, especially regarding the usability and user experience (Q1, Q2, Q5, Q7 and Q8 in Table 2), received a positive response with more than 50% of the votes, as we expected. In addition, we restricted the labeling areas to central Manhattan in this beta test, but 7 out of 13 (54%) participants claimed that they would like to be free to choose a place (Q9 in Table 2). Moreover, 11 out of 13 (85%) people preferred to label the area near their homes (Q10 in Table 2). With these feedbacks, we plan to add new functionality that will allow volunteers to enter addresses to flexibly explore the desired areas.

Through this survey, not only did we receive important feedback on user interface designs and app usability, but we also received positive and encouraging reviews about our idea and the app. One volunteer said that it was a fun volunteer experience, and she was very happy and satisfied with the clear user interface of our app where she could virtually navigate NYC and

contribute to the community. Another volunteer also emphasized he understood how important the storefront accessibility data is and looked forward to seeing more and more applications using our collected data in the future. These reviews testify to the high potential and usability of our application.

Conclusion

In this paper, we have designed a crowdsourced web application, *DoorFront*, to collect large-scale storefront accessibility data in New York City. We conducted a pilot user study with 13 student volunteers and received positive and encouraging feedback. To encourage more students to contribute to this large-scale crowdsourcing project, we have developed a credit system to increase volunteer engagement. The ultimate goal of this project is to make the data available on the NYC Open Data platform (NYC Open Data, 2021). The informal survey indicated the high potential and usability of our application.

The current online crowdsourcing framework faces the following limitations. Though GSV has provided massive street-level images, some of them cannot be used for the following reasons: (1) Some storefront GSV images are incomplete due to occlusions by vehicles or constructions; (2) GSV images are often updated once every few years, hence our image data may be out of date. To address the above problem, we will develop an in-situ mobile app to allow volunteers to collect those missing data if they identify such cases.

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Are Blind People Considered Scientific Knowledge Producers? An Accessibility Report on the Top 10 SCIE Journal Systems Using a Tripartite Evaluation Approach

JooYoung Seo¹, Soyoung Choi²
University of Illinois at Urbana-Champaign
jseo1005@illinois.edu, soyoung@illinois.edu

Abstract

The purpose of this study was to report and discuss the current accessibility status of scientific journal sign-up and submission systems for blind or visually impaired professionals. Although there has been active discussion in the past decade about making scientific documents accessible for blind people as end users, relatively little attention has been paid to science accessibility for blind professionals as knowledge producers. We obtained the 2021 Science Citation Index Expanded (SCIE) publisher list from the Clarivate Analytics Web of Science Core Collection. We selected the most prolific top 10 publishers, based on the number of active journals, as well as one journal for each top 10 publisher using stratified random sampling. For the data analysis, we adopted a tripartite (three-level) accessibility evaluation strategy: (1) automated testing, (2) non-visual manual testing, and (3) visual manual testing. We examined the overall accessibility impact levels and detailed WCAG 2.1 rule violations within the sign-up and submission pages, respectively. Our findings include descriptive trends and statistical results depicting current accessibility issues across the 10 target scientific journal systems.

Keywords

Accessibility, journal systems, blind, WCAG 2.1

Introduction

While it remains a challenge, science, technology, engineering, and math (STEM) content is becoming increasingly accessible for blind and visually impaired (BVI) people, thanks to exponentially advancing digitalization and assistive technologies. For instance, Web Content Accessibility Guidelines (WCAG; Caldwell et al.) and continuously improving awareness of document accessibility (e.g., tagged PDF, Word, presentation slides) have opened new doors for BVI people to explore massive scientific information on and offline, using screen readers, which would otherwise not be readily accessible using analog techniques, such as hard-copy braille and human readers. Growing advancements in Math Markup Language (MathML) (Hagler), along with accessible libraries and plugins (e.g., MathJax; MathPlayer), have also propelled math readability for BVI people with and without braille literacy (Bouck and Meyer; White). Furthermore, enhanced optical character recognition (OCR) and image detection technologies are empowering BVI individuals to explore untagged documents or analog objects in various STEM contexts (Punith et al.).

Although there has been active discussion in the past decade about making scientific documents accessible for blind people as content consumers, relatively little attention has been paid to science accessibility for blind professionals as knowledge producers. This gap is due, in part, to the limited number of blind professionals in STEM disciplines (Chhabra; Greenvall et al.) and the resulting low demand for blind people as knowledge producers. In fact, as Greenvall et al. noted in their article, while the existing literature on STEM accessibility often highlights challenges and solutions for blind students, the situation of blind STEM educators remains underexplored. In a previous article in this journal, as one of the few blind scientists and educators, the first author of this paper also highlighted the need for research and development to

allow more blind individuals to go beyond content consumption and become knowledge producers in STEM disciplines by introducing accessible authoring tools for scientific documents (Seo and McCurry).

This paper further contributes to the literature on this underserved, yet important, research agenda—accessibility for STEM professionals and knowledge producers who are blind or visually impaired—by reporting and discussing the current accessibility status of scientific journal sign-up and submission systems for BVI professionals. This study inquiries into the following underexplored research questions: (1) How accessible are scientific journal systems for blind and visually impaired professionals when signing up for accounts and submitting manuscripts? (2) What are some common WCAG 2.1 violations of popular scientific journal systems? (3) What design considerations can contribute to more accessible journal sign-up and submission systems? Because journal publication is the crux of knowledge production and sharing communication among scientists and practitioners across academia and industry in STEM fields (Xie et al.; Yildirim), it is not just fundamental but imperative for the science community to investigate the current accessibility of such journal systems to pave the way for existing and future BVI knowledge producers in STEM. In what follows, the two authors of this paper (one is blind; the other is sighted) will detail how we examined the suggested research questions and share the study results.

Discussion

Data Collection

The target scientific journal systems were obtained and selected in the following manner. For our data source, we focused on the Science Citation Index Expanded (SCIE) for this study scope, given its impact on STEM disciplines. The SCIE has covered over 9,200 of the world's

most impactful journals across 180 scientific disciplines since 1964 (Liu and Li). We obtained the 2021 SCIE publisher list from the Clarivate Analytics Web of Science Core Collection (<https://mjl.clarivate.com/collection-list-downloads>). Among a total of 9,581 retrieved data entries, we selected 8,477 English journal systems for this study. For the subset data, the most prolific top 10 publishers were identified by the number of active journals, and one journal per top 10 publisher was selected using stratified random sampling. An online appendix at https://jooyoungseo.github.io/scie2021_a11y/ discusses the reliability and reproducibility of this procedure.

Data Analysis

We adopted a tripartite (three-level) accessibility evaluation strategy for the collected data. As the first-level evaluation, we conducted an automated web accessibility test. Automatic assessment tools have been widely used to evaluate web accessibility. Some researchers have utilized these tools to determine whether their software or online services meet web accessibility guidelines (Kumar et al.; Manez-Carvajal et al.). We employed Deque's axe™ DevTools Chrome extension (<https://www.deque.com/axe/>) as an assessment tool that can identify 76–84% of accessibility issues on a web site. For the second-level testing strategy, the first author (a blind scholar and a Certified Professional in Accessibility Core Competencies) conducted non-visual manual testing using screen readers and refreshable braille displays to complement the machine-generated results. For the third-level assessment, the second author (a sighted scholar) undertook visual manual testing with the first author to check the visual accessibility (e.g., color contrast, mouse hover) and GUI usability.

The tripartite accessibility evaluation method was mainly proposed to minimize the errors of the automatic evaluation tool. Specifically, the feedback from the evaluation results produced

by the first author was used to refine and validate the identified accessibility issues.

In addition to the three-level accessibility testing, we also performed Pearson's Chi-squared test to confirm whether there was an association between journal system type and accessibility impact level.

Findings

The sampled target journals were *Microelectronics Reliability* (Elsevier), *European Journal of Trauma and Emergency Surgery* (Springer), *Genesis* (Wiley), *Applied Artificial Intelligence* (Taylor & Francis), *Nursing Science Quarterly* (Sage), *American Journal of Surgical Pathology* (Lippincott Williams & Wilkins), *Quarterly Journal of Mechanics and Applied Mathematics* (Oxford University Press), *Alzheimer's Research & Therapy* (BMC), *IEEE Transactions on Sustainable Energy* (IEEE), and *ANZIAM Journal* (Cambridge University Press). Interestingly, we found that our top 10 sampled journals used one of the following three journal management systems: "Editorial Manager®" by Aries Systems Corporation (5 out of 10); "ScholarOne™ Manuscripts" by Clarivate (4 out of 10); and "Open Journal Systems" by the Public Knowledge Project (1 out of 10). While Editorial Manager® and ScholarOne™ Manuscripts are two major commercial solutions, Open Journal Systems is a free open-source framework. Table 1 summarizes the sampled top 10 journals, along with their management systems.

Table 1. The top-10 Publishers and Target Journals.

| Publisher | Number of Journals (English-only) | Target Journal | System |
|------------------|--|--|-------------------|
| Elsevier | 1,147 | Microelectronics Reliability | Editorial Manager |
| Springer | 1,019 | European Journal of Trauma and Emergency Surgery | Editorial Manager |

| Publisher | Number of Journals (English-only) | Target Journal | System |
|-------------------------------|--|--|-----------------------|
| Wiley | 899 | Genesis | ScholarOne Manuscript |
| Taylor & Francis | 585 | Applied Artificial Intelligence | Editorial Manager |
| Sage | 248 | Nursing Science Quarterly | ScholarOne Manuscript |
| Lippincott Williams & Wilkins | 206 | American Journal of Surgical Pathology | Editorial Manager |
| Oxford University Press | 204 | Quarterly Journal of Mechanics and Applied Mathematics | ScholarOne Manuscript |
| BMC | 202 | Alzheimer's Research & Therapy | Editorial Manager |
| IEEE | 162 | IEEE Transactions on Sustainable Energy | ScholarOne Manuscript |
| Cambridge University Press | 98 | Anziam Journal | Open Journal Systems |

Table 2. Overall Accessibility Impact Levels.

| Procedure | Impact | n | % |
|------------------|---------------|----------|----------|
| Sign-up | Moderate | 971 | 51 |
| Sign-up | Critical | 690 | 36 |
| Sign-up | Serious | 236 | 12 |
| Sign-up | Minor | 1 | 0 |
| Submission | Moderate | 1,589 | 54 |
| Submission | Serious | 669 | 23 |
| Submission | Critical | 343 | 12 |
| Submission | Minor | 316 | 11 |

As all 10 target journals required account sign-up for manuscript submission on their portals, our findings include accessibility reports for both the journal sign-up and manuscript submission systems. Table 2 illustrates the overall accessibility impact levels found in the journal account sign-up and manuscript submission pages. Figure 1 and Figure 2 highlight detailed WCAG 2.1 rule violations within the sign-up and submission pages, respectively. Half of the common issues were due to moderate violations (51% in sign-up pages; 54% in submission pages), such as a lack of aria landmark regions and ill-structured heading semantics. In fact, most of the journal systems did not conform to WCAG guidelines 1.3 “adaptable” and 2.4 “navigable” in the sign-up and submission pages.

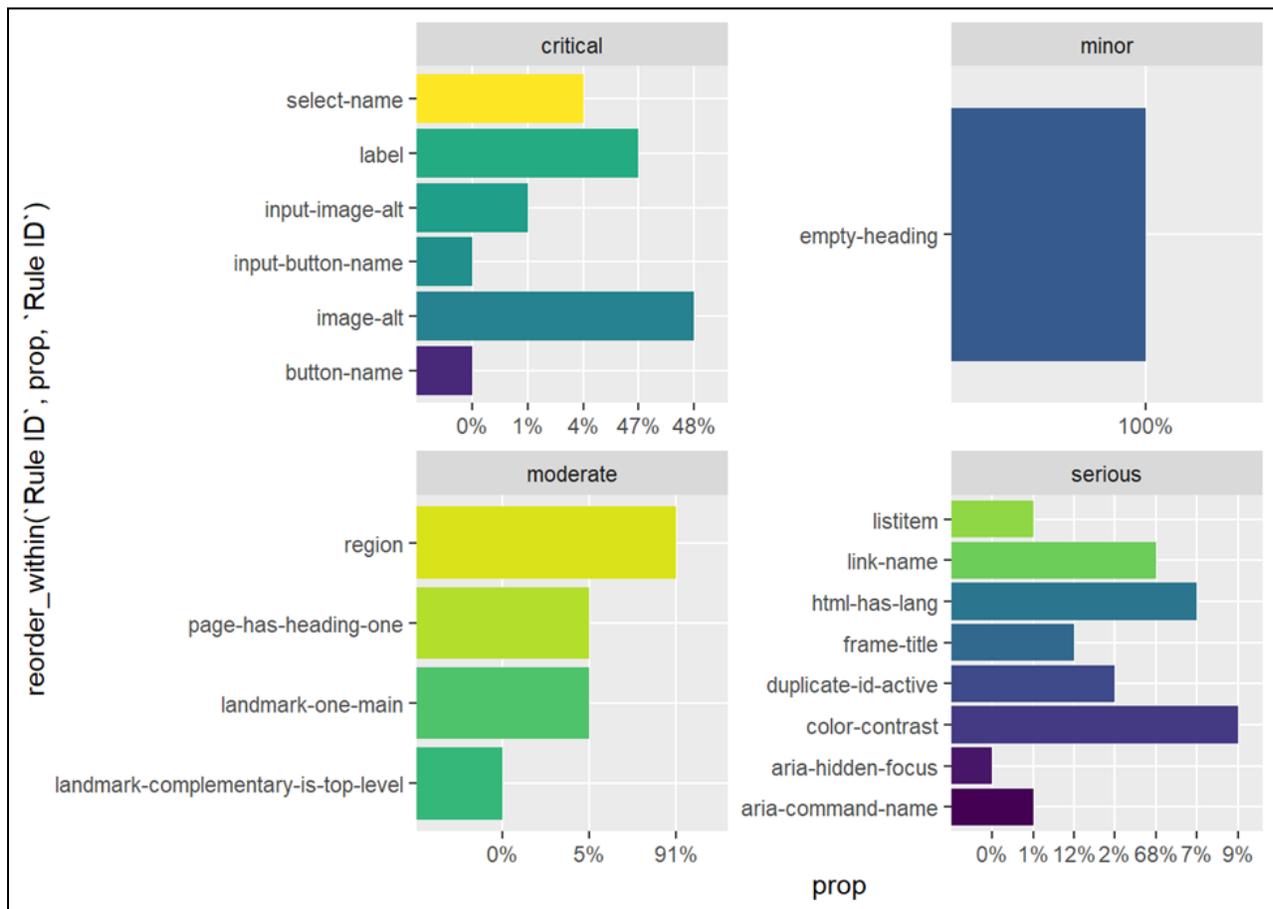


Fig.1. Sign-up Issues.

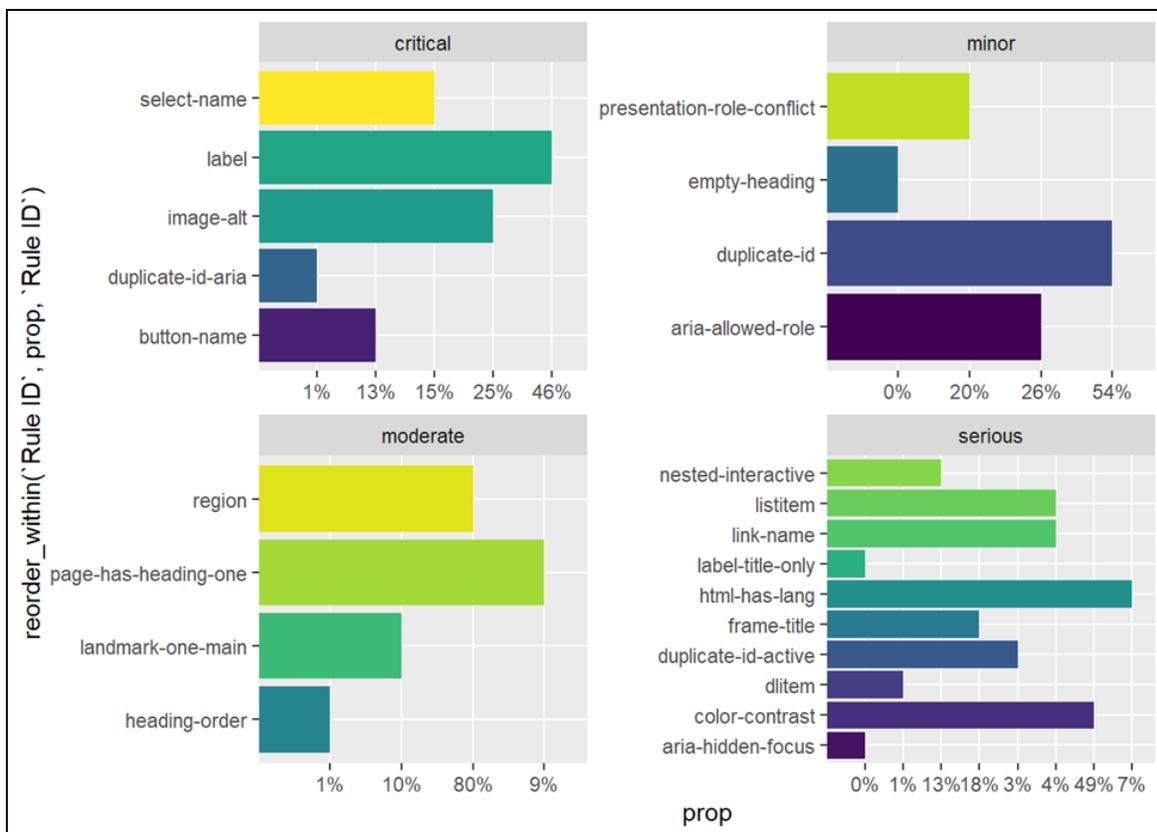


Fig.2. Submission Issues.

Although these accessibility problems are commonly found in general web pages and are categorized as moderate violations because they are easily corrected, the impact of this inaccessibility is far-reaching. For example, screen reader users often press single-letter navigation keys (e.g., in JAWS 2021, “H” for the next section heading, “R” for the next landmark region) to efficiently navigate and understand page structure and content. Ill-structured or lacking semantic landmarks interfere with basic keyboard navigation by BVI people in web pages, demanding much more time to interact with the content.

In general, it was much more challenging for screen reader users to set up an account than to submit a manuscript because most issues other than the common moderate semantic barriers concerned “critical” violations (36%) in sign-up pages, such as missing alt text for non-decorative images and unlabeled inputs and buttons. These violated the WCAG first principle of

“perceivable.” The first author had difficulty creating journal accounts by himself using screen readers owing to inaccessible elements and often required the second author’s direct help. This revealed that the scientific journal systems presented fundamental and crucial barriers from the outset to BVI individuals who would otherwise have been able to participate in knowledge creation more easily and independently. In addition to moderate issues, the manuscript submission systems also had “serious” issues (23%) (Table 2); however, they were more related to visual aspects, such as visual structure, color contrast, and text size, rather than critical semantic barriers. Nevertheless, although not impossible, it was still very challenging to submit manuscripts in the selected journal systems using screen readers.

To confirm whether there was an association between journal system type (Editorial Manager®, ScholarOne™ Manuscripts, Open Journal Systems) and accessibility impact level (critical, serious, moderate, minor), we also performed Pearson’s Chi-squared test. The results suggested that there was a statistically significant relationship between them ($\chi^2[6, n = 4815] = 952.25, p < .001$). This indicates that accessibility impact levels may differ by journal system type (Figure 3). This statistical finding also aligned with our automated and manual testing results. For example, we found that *ANZIAM Journal* (Cambridge University Press), which used Open Journal Systems, was the most accessible for screen reader users across the sign-up and submission pages. Images and buttons were properly labelled, and semantic structures were relatively well formed. As shown in Figure 3, most Open Journal Systems issues were minor violations (48%). By contrast, *Nursing Science Quarterly* (Sage), which used ScholarOne™ Manuscripts, was the least accessible for screen reader users. He was unable to create an account because most issues were critical, such as focus traps and unlabeled buttons and images.

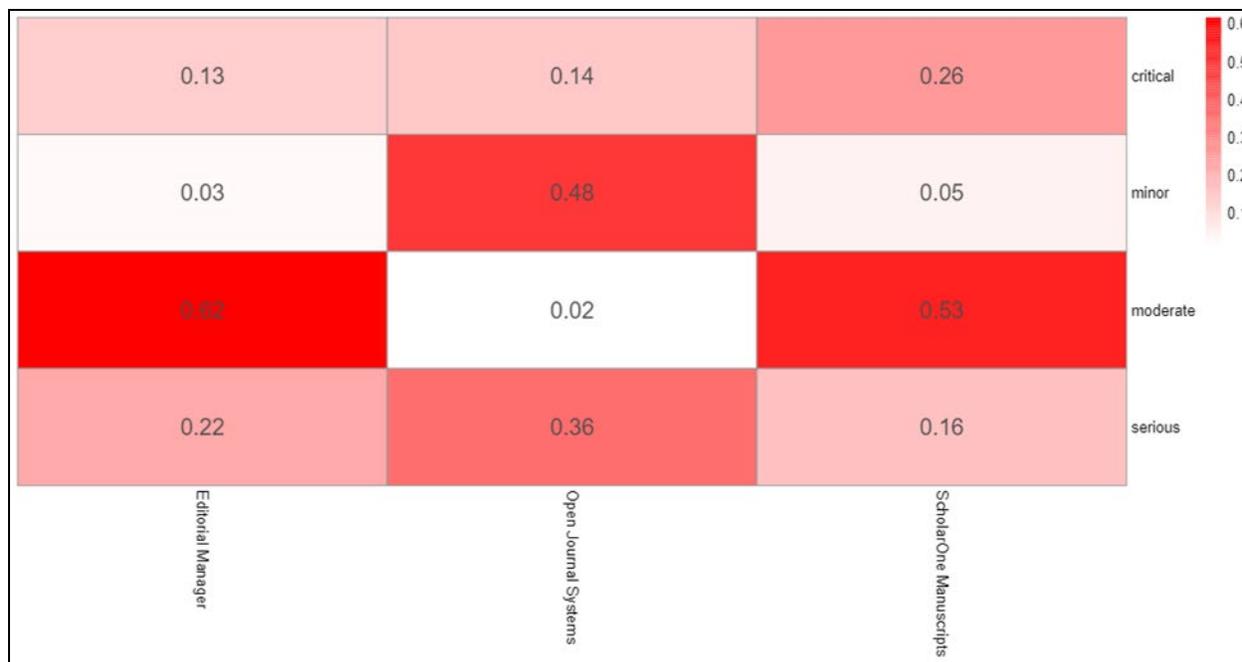


Fig.3. Heat Map Visualization Based on Column Margins.

Taken together, based on our three-level evaluation results, the journals that used ScholarOne™ Manuscripts were found to have more critical violations than those that used the other two systems: Editorial Manager® journals had some systems that were usable by (but not fully accessible for) screen reader users through trial and error, while Open Journal Systems journals provided the most pleasant access usability and accessibility for BVI people (Figure 3).

Conclusion

This paper reported and discussed the current accessibility status for blind or visually impaired (BVI) professionals of certain scientific journal sign-up and submission systems. We performed a tripartite (three-level) evaluation of the journal systems' accessibility: (1) automated testing was conducted using Deque's axe™ DevTools Chrome extension; (2) non-visual manual testing was carried out by the first author (a blind scholar and Certified Professional in Accessibility Core Competencies) using screen readers and refreshable braille displays to complement the machine-generated results; and (3) visual manual testing was undertaken by the

second author (a sighted scholar) with the first author to check the visual accessibility (e.g., color contrast; mouse hover) and GUI usability. The Pearson's Chi-squared test was performed to determine the relationship between the journal system types and the accessibility impact levels.

Our findings suggest the following: (1) as a high-level takeaway, most of the major SCIE journal systems seemed to have more than moderate accessibility violations, which may discourage BVI professionals from easily creating an account and submitting a manuscript (Table 2); (2) as a general tendency, sign-up pages seemed to have more critical barriers than submission pages, which may create another rudimentary barrier for BVI authors (Table 2; Figures 1 and 2); and (3) as a technical aspect, the two major commercial journal management systems (i.e., ScholarOne™ Manuscripts; Editorial Manager®) appeared to pose more critical accessibility issues than Open Journal Systems (Figure 3).

The limitations of this research were that the number of evaluated target journals was small, and the scope of the samples was limited to SCIE journals. Further studies are needed using larger samples to uncover other potential accessibility issues nested within journal submission pages. Despite these limitations, the study findings are expected to contribute to improving awareness of accessibility among scientific journal publishers of the need to lower barriers for blind science citizens in the knowledge product community. Specifically, the web site developers of scientific journal publishers should consider the highlighted accessibility problems when they design the system structure.

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Outdoor Navigation Assistants for Visually Impaired Persons: Problems and Challenges

Renato Busatto, Richard Harvey

University of East Anglia, School of Computing Sciences, Norwich, United Kingdom

r.busatto@uea.ac.uk, r.w.harvey@uea.ac.uk

Abstract

This article explores the problem of building outdoors navigation assistants for persons with visual impairment (NAVI). A review of the state-of-the-art solutions and frameworks of navigation assistants for persons with visual impairment shows that, although several solutions have been proposed, the functionality of such systems is often limited to obstacle detection and navigation assistance based just on satellite positioning information presented to the user in limited forms. Navigation assistants available to final users are basically the same Global Navigation Satellite System (GNSS) widely available to everyone else, adding little to meet the necessities of users with visual impairment. We present the requisites of building a NAVI system running on smart glasses integrating all journey stages and exploiting the current technology to its full potential. Accordingly, we identify key technology gaps and areas that need further research to deliver a system with such features.

Keywords

Visual impairment; Blindness; Wayfinding; Smart Glasses; Computer Vision; Electronic Mobility Aid

Introduction

Persons with visual impairment are one of the most affected by the lack of accessibility. Approximately 2.2 billion people with visual impairment in the world (World Health Organization 2021) have difficulties in engaging in activities that involve social relations, which affects their process of socialization (Slade and Edwards 2015). Transportation is one of the greatest barriers and a major challenge for persons with visual impairment. Only a minority of the persons with visual impairment report being confident using public transport according to The Royal National Institute of Blind People UK (RNIB) (Pavey et al. 2009). Autonomous mobility is affected not only by transport availability, but also by difficulties in walking outdoors, including crossing streets and locating the final destination. People commonly stumble across road signs and architectural barriers (Pavey et al. 2009).

Wayfinding is a complex and interwoven task that must be broken down to be fully understood. The British RNIB Wayfinding Project (Worsfold and Chandler 2010) defines the journey stages as walking, catching a transport (bus, train, tube, ferry, plane), and navigating within a building. Walking is the most important stage that binds the other journeys stages together, yet it is the one with the least amount of information or assistance. These stages are further refined into activities and actions following four principles of wayfinding: getting information and using it, orientating within the environment, navigating within the environment, and entrance and exit identification.

Historically, canes and guide dogs are the most widely used tools for detecting obstacles by persons with visual impairment (Pavey et al. 2009). Nonetheless, both options fail to detect obstacles over the knee level or beyond a 30 cm to 60 cm range. Such obstacles cannot be detected before they are dangerously close to the person. Some other tasks, such as identifying

buildings, shops, buses, entrances, signs, and written information, are hardly possible without the assistance of an electronic device or a person with no visual impairment.

Many studies have been conducted to develop equipment and technology to assist autonomous navigation of persons with visual impairment. Navigation Assistance for Visually Impaired (NAVI) refers to systems that guide or assist persons with vision loss through sound commands (Aladrén et al. 2016). Table 1 describes the main systems available, primarily focusing on their equipment, features and limitations. Most of the systems found in the literature focus on the detection of obstacles. Few solutions have been proposed to improve the outdoors mobility and safety of persons with visual impairment. In general, the user needs to carry complex hardware systems and, in some cases, the environment where the navigation must be accomplished also has to be prepared beforehand. The most comprehensive solutions involve connecting users to remote agents (Wiberg 2015; Kanuganti 2015). Although remote human assistance can be versatile, disclosing what users are seeing or doing to remote agents can be undesirable and embarrassing. Users report that they do not feel safe to disclose where they are going to strangers, neither in person nor in a video call (Avila et al. 2016; Williams et al. 2013). It further raises privacy and legal concerns since agents and users may be in different jurisdictions with different mores. For these reasons, we do not consider using remote human assistants as viable for autonomous navigation.

Table 1. Overview of NAVI Systems Including Main Features and Equipment Used.

| System | Equipment | Obstacle detection | Object identif. | Indoor path | Outdoor path |
|-------------------|--|---------------------------|------------------------|--------------------|---------------------|
| (Kanuganti 2015) | Smartglasses, smartphone, camera, GNSS, remote human agent | Yes | Yes | Yes | Yes |
| (Wiberg 2015) | Smartphone, camera, remote human agent | Yes | Yes | Yes | Yes |
| (Ran et al. 2004) | Computer, GNSS, Wi-Fi, sonar | Yes | - | Yes | Yes |

| System | Equipment | Obstacle detection | Object identif. | Indoor path | Outdoor path |
|--------------------------|---|---------------------------|------------------------|--------------------|---------------------|
| (H.-C. Wang et al. 2017) | RGBD camera, computer, haptic | Yes | Yes | - | - |
| (S. Wang et al. 2014) | RGBD camera | Yes | Yes | - | - |
| (Li et al. 2016) | Tablet, RGBD camera | Yes | - | Yes | - |
| (Dreamwaves 2021) | Smartphone, GNSS, camera | Yes | - | - | Yes |
| (Katz et al. 2012) | Computer, GNSS, stereoscopic camera, motion tracker | Yes | - | - | Yes |
| (Mayerhofer et al. 2008) | Computer, mobile phone, GNSS, infrared, dead reckoning device | Yes | - | - | Yes |
| (Koley and Mishra 2012) | GNSS, sonar | Yes | - | - | Static |
| (BlindSquare 2012) | Smartphone, GNSS, compass, Bluetooth | - | - | Yes | Yes |
| (Wayfindr 2017) | Smartphone, Bluetooth | - | - | Tube | Tube |
| (Agrawal et al. 2017) | Sonar, GNSS, GSM | Yes | - | - | - |
| (Aladrén et al. 2016) | RGBD camera, infrared, RFID | Yes | - | - | - |
| (Float 2016) | Smartphone, camera | Yes | - | - | - |
| (Ifukube et al. 1991) | Sonar | Yes | - | - | - |
| (Ju et al. 2009) | Computer, camera | Yes | - | - | - |
| (Kanwal et al. 2015) | RGBD camera, infrared | Yes | - | - | - |
| (Kulyukin et al. 2005) | Computer, RFID, sonar | Yes | - | - | - |
| (Mahmud et al. 2014) | Sonar | Yes | - | - | - |
| (Mandal 2018) | Sonar, infrared | Yes | - | - | - |
| (Nandhini et al. 2014) | GNSS, RFID, sonar | Yes | - | - | - |
| (Tapu et al. 2014) | Camera | Yes | - | - | - |
| (Wahab et al. 2011) | Sonar, water detector | Yes | - | - | - |
| (OrCam 2013) | Wearable camera | - | Yes | - | - |

| System | Equipment | Obstacle detection | Object identif. | Indoor path | Outdoor path |
|--|---|---------------------------|------------------------|--------------------|---------------------|
| (Ahmetovic et al. 2016) | Smartphone, Wi-Fi, Bluetooth | - | - | Yes | - |
| (Chaccour and Badr 2015) | Smartphone, Bluetooth, Wi-Fi, surveillance cameras, head marker | - | - | Yes | - |
| (Fusco and Coughlan 2020) | Smartphone, camera, gyrocompass | - | - | Yes | - |
| (Jain 2014) | Smartphone, RFID | - | - | Yes | - |
| (Mehta et al. 2011) | RFID, Bluetooth, compass | - | - | Yes | - |
| (Nassih et al. 2012) | RFID | - | - | Yes | - |
| (Öktem et al. 2008) | RFID, compass | - | - | Yes | - |
| (Right-Hear 2015) | Smartphone, Bluetooth | - | - | Yes | - |
| (American Printing House for the Blind 2013) | Smartphone, GNSS | - | - | - | Yes |
| (Brusnighan et al. 1989) | GNSS | - | - | - | Yes |
| (Ciaffoni 2011) | Smartphone, GNSS | - | - | - | Yes |
| (Espinoza and González 2016) | Smartphone, GNSS, compass | - | - | - | Yes |
| (EveryWare Technologies 2013) | Smartphone, GNSS | - | - | - | Yes |
| (Garmin 2011) | Smartphone, GNSS, compass | - | - | - | Yes |
| (Humanware 2017) | GNSS | - | - | - | Yes |
| (Kaminski et al. 2010) | Computer, GNSS, compass, gyrocompass, keyboard | - | - | - | Yes |
| (Kirkpatrick and Lilburn 2004) | Smartphone, GNSS | - | - | - | Yes |
| (Liu et al. 2015) | Smartphone, GNSS | - | - | - | Yes |
| (Loomis et al. 2005) | Computer, GNSS, compass | - | - | - | Yes |
| (Novartis Pharmaceuticals 2014) | Smartphone, GNSS | - | - | - | Yes |
| (OsmAnd 2010) | Smartphone, GNSS, compass | - | - | - | Yes |

| System | Equipment | Obstacle detection | Object identif. | Indoor path | Outdoor path |
|-------------------------------------|--|--------------------|-----------------|-------------|--------------|
| (Petrie et al. 1996) | Handheld computer, mobile phone, GNSS, compass | - | - | - | Yes |
| (Pielot et al. 2010) | Smartphone, GNSS, compass | - | - | - | Yes |
| (Sendero Group 2002) | GNSS | - | - | - | Yes |
| (Sendero Group 2013) | Smartphone, GNSS | - | - | - | Yes |
| (Snigle 2016) | Smartphone, GNSS, compass | - | - | - | Yes |
| (Swis Federation of the Blind 2012) | Smartphone, GNSS | - | - | - | Yes |
| (Transition Technologies 2013) | Smartphone, GNSS | - | - | - | Yes |
| (Lakehal et al. 2020) | Smartglasses, smartphone, GNSS | - | - | - | Static |
| (Tashev et al. 2018) | Smartphone, camera | - | - | - | Static |
| (Dharani et al. 2012) | RFID | - | - | - | - |
| (Gulati 2011) | GNSS | - | - | - | - |
| (Hub and Schmitz 2009) | Tablet, GNSS, RFID, inertial sensor | - | - | - | - |

The motivation for this paper arose from open discussions with persons who are blind or visually impaired. It became evident that, despite a large number of NAVI systems presented in the literature, for most people they were unviable (Real and Araujo 2019; Griffin-Shirley et al. 2017). Thus, systems were being created to solve problems that did not exist. There is still a need for a solution that integrates all outdoors journey stages. Therefore, we posit a model of NAVI system for outdoors navigation exploiting the current technology to their full potential. In this way, we can understand the pitfalls involved in developing such a system.

Discussion

We first present the desired features and user interface of a NAVI system for outdoors navigation. Next, we consider the equipment and sensors currently available that could make it

possible to build a system with such features. This leads us to identify key technology gaps and areas that need further research.

Features and User Interface

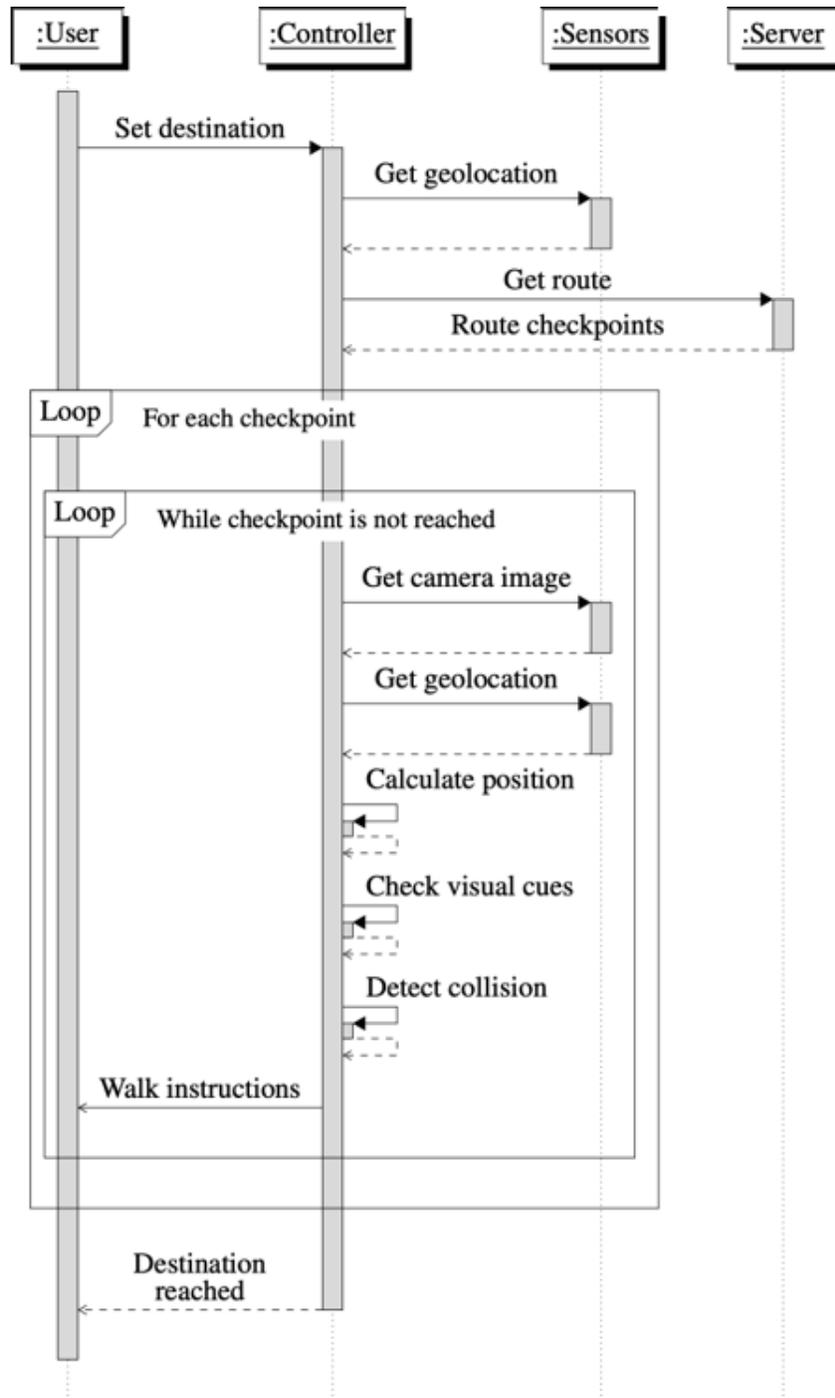


Fig. 1. Model of NAVI Systems.

Figure 1 shows a sequence diagram for the tasks of outdoors visual navigation. First, when the user requests assistance to reach a destination, the system (controller) must retrieve the user geolocation and request a route to the online server. An internet connection allows making use of more complex algorithms and access to services such as the Google Directions API and the Apple WebKit for up-to-date information about maps, roads, sidewalks, and available routes (Google Inc. 2021; Apple Inc. 2021). Nevertheless, local processing is preferred when possible.

The evaluation of possible routes must consider: (1) time and length of journey, (2) accessibility and safety of the path, well signposted and paved, (3) easy access to public transport like bus, tube, train, and tram, and (4) roadworks and closed ways. The route retrieved from the server is segmented, and checkpoints need to be reached in sequence to arrive at the destination.

The route segments and checkpoints need to be carefully chosen. A segment that involves crossing a street, for example, must be broken down into more specific steps: “approach the pedestrian crossing,” “activate pedestrian traffic light,” “cross the street” and “reach the sidewalk.” These steps are usually implicit for persons with sight, yet they are essential to allow autonomous journeys of persons with visual impairment. It is not just about giving more instructions; the quality of instructions is essentially different. Even when the same route is followed by persons with and without visual impairment, the instructions must consider the individual necessities of each user.

For each checkpoint on the route, the system guides the user by audio and keeps estimating the user position in real-time, evaluating whether they are on track or the route needs to be recalculated. The camera allows identification in real-time of obstacles and assesses imminent collision risk. In a scenario of crossing a street, for example, the camera allows the identification of pedestrian crossings, traffic lights, cyclists and cars to decide when it is safe to

cross. The system also identifies and prioritizes recognized text to announce relevant information considering the context. A big sign far away may be less relevant than a small street sign near the user. With no priority classification, the user may be overwhelmed by irrelevant announcements.

The walk instructions are given both by spoken and audible signals. The audio feedback must not block signals from external sources, which helps in keeping the safety of users. With the use of smart glasses, users may receive audio instructions to aim their head towards locations where they expect important visual targets. In this way, there is no need to train users beforehand. A heads-up display may be used by persons with low vision, enabling announcements both by audio and on the display. Yet, the use of a display is secondary and is not in any way essential.

The use of non-visual references is fundamental when giving navigation instructions. Simple instructions such as “walk 20 m” are hard to follow because it refers to a measure not easily verifiable in such a situation. Alternatively, saying “walk twenty steps” is more intuitive and easily verifiable. Although it is not as accurate, checking the user’s position in real-time allows route correction and follow up instructions such as “walk two more steps” or “you have reached the street corner, turn left now.”

When the destination is finally reached, the system learns the user’s preferences considering the journey actually undertaken. The more people use it, the better it would get at suggesting convenient routes to everyone.

Equipment and Sensors

Localization technology is the backbone of navigation systems. Currently, the Global Navigation Satellite System (GNSS) is the main technology used for outdoors navigation. GNSS is a general term for any satellite constellation providing positioning and navigation services on a

global or regional basis. While the United States' GPS is the most prevalent GNSS, other nations have also fielded their systems to provide independent or augmented services: GLONASS (Russia), BeiDou (China), Galileo (European Union), NavIC (India) and QZSS (Japan).

Although GNSS is a global solution for geolocation, there are some challenges to using them on NAVI systems. Their horizontal accuracy of approximately 10 m (U.S. Air Force 2014) makes it impossible to safely guide a pedestrian with acceptable precision. The error range increases when the GNSS signal is blocked by large objects such as trees, bridges and buildings. In places with many obstructions, such as metropolitan areas or inside buildings, these structures can block satellites' signals to an extent that the receiver is not able to calculate its position.

Some methods have been proposed to increase the accuracy of GNSS receptors, including Differential GPS (DGPS), Assisted GNSS (A-GNSS) and satellite-based augmentation systems (SBAS). Nonetheless, these augmented solutions are currently restricted to niche applications for reasons of practicality and cost.

Digital cameras are cheap, compact, easy to maintain, and widely available on smartphones and laptops. When associated with computer vision algorithms, it becomes possible to perform tasks such as reading signs, labels, texts, identifying color information, objects, people, or cash. Although distinguishing between close and far objects with a single camera is possible, this task is not trivial. Usually, other devices are used to accomplish this task, e.g., stereo or RGBD cameras; ultrasonic, Bluetooth or infrared sensors.

Computer vision algorithms have been advancing since the last decade. Complex algorithms can now run in real-time on smartphones and wearable devices. Computer vision algorithms are easier to reproduce and less biased on interpreting real scenes when compared to humans. Nevertheless, the current error rates are still higher than that made by humans with

sight, which becomes a large practical problem posed by using computer vision to interpret the visual environment. As a result, the user interface of any NAVI system needs to accommodate the inevitability of such errors.

Few solutions exploit the potential of computer vision algorithms. OrCam (2013), for example, aims to recognize labels, products, text, and other objects close to the user. Images captured by the camera may be combined with GNSS information to not just precisely localize the user in real-time, but also to know what direction they are heading to. In 2019, Google announced a Visual Navigation System incorporated on Google Maps app available on selected locations (Reinhardt 2019). Although it is not specifically designed to have persons with visual impairment in mind, they use computer vision algorithms to match images taken in real-time from the user's smartphone with a data set to improve their geolocation estimation. The path is then shown on the screen using augmented reality.

Computer vision algorithms rely on visual appearance to detect obstacles and objects. Therefore, they are sensitive to factors that change visual appearance, e.g., illumination, point of view, artefacts, and occlusion. Internal factors as processing power and trained model also affect accuracy. Some classes of objects are well studied and present a high detection accuracy, but some others need more study and large image data sets for training purposes.

Ultrasonic sensors are common components on outdoors NAVI systems. Sound propagation is used to measure the distance to objects in a short-range from 2 cm to 400 cm (Adafruit Industries LLC 2020). They are cheap components that do not need the preparation of the environment in advance. Although ultrasound pulses propagate in three dimensions, the distance information is unidimensional. It is possible to combine sensors pointing in different directions, but this approach can be problematic for tasks other than roughly detecting obstacles.

Yet, it is still not possible to detect long-range distances or the shape of objects. When used on NAVI systems, ultrasonic sensors help to avoid obstacles but need to be somehow attached to the main processing device, as it is not usually embedded on laptops, smartphones or smart glasses.

Other sensor components, such as Bluetooth and infrared beacons, are undesired for outdoors use because they require preparation of the environment beforehand.

Technology Gaps

Table 2. Features of the NAVI Model for Outdoors Navigation.

| Feature | Development | Solved? |
|--|---|----------------|
| F1: Localize user with high accuracy | Current accuracy is approximately 10 m with GNSS (U.S. Air Force 2014). Maximum required error is 0.5 m | Partially |
| F2: Calculate the best route to reach a point of interest | Pedestrian routing is freely available on smartphones map apps (Apple Inc. 2021; Google Inc. 2021) | Yes |
| F3: Define micronavigation instructions | Further studies needed on Human Computer Interface (HCI) (Budrionis et al. 2020) | No |
| F4: Recognize public transport vehicles | Solved by Computer Vision detection and classification algorithms | Yes |
| F5: Locate doors and entrances | Solved by Computer Vision algorithms with 97.96 % accuracy (Othman and Rad 2020) | Yes |
| F6: Recognize relevant signs and labels | Partially solved by Computer Vision detection, classification and OCR algorithms (OrCam 2013) | Partially |
| F7: Identify the sidewalk | Solved by Computer Vision segmentation algorithms (Olvera et al. 2020) | Yes |
| F8: Access collision risk | Solved by Computer Vision algorithms | Yes |
| F9: Perform visual navigation | Further studies needed on Computer Vision (CV) | No |
| F10: Interact with the user in a natural and intuitive way | Further studies needed on Human Computer Interface (HCI) (Budrionis et al. 2020) | Partially |

Table 2 summarizes the desired features of an outdoors NAVI system mentioned so far and highlights their current development status reported in the literature.

The first task in Table 2 is to localize the user with high accuracy (F1). Although there are some subtleties in certain scenarios, it is a standard task, so we have marked it as such. Although GNSS provides only around 10 m accuracy, that is either sufficient for many purposes (e.g., ship navigation) or can be combined with tracking models to give improvements. For example, in autonomous vehicle navigation, systems assume that the vehicle is located on the road using an up-to-date map. Thus, cross-track errors can be zeroed. Pedestrian navigation is more challenging because people roam off streets, but with good tracking and with newer GNSS components such as Galileo and SBAS systems such as WAAS and EGNOS, it is reasonable to assume that determining outdoor pedestrian geolocation might be solved to within 1 m. Indoor navigation will either require significantly greater antenna gain at the receiver using larger and more complex receptors, or widescale deployment of indoor GNSS augmentation systems. Both seem unlikely within the next ten years. Hence are other “partially” ratings.

Calculating the best route (F2) can be considered solved for outdoors pedestrian navigation. Google and Apple services provide pedestrian routing freely available online and with vast documentation (Apple Inc. 2021; Google Inc. 2021). These services consider factors such as time, walking distance, accessibility, and roadworks. Defining the micronavigation instructions (F3), on the other hand, remains a challenging open problem. The route segments retrieved from online routing services must be broken down into more specific segments. Navigating in large open spaces, in a park for example, is hardly a problem for persons who are sighted. Persons with visual impairment may get lost or go astray without accurate navigation

instructions and constant rerouting assessment. Furthermore, there is every reason to think that instructions need to be personalized since visual disabilities are diverse.

Recent advances in computer vision make viable the recognition of vehicles (F4), doors (F5), signs (F6) and sidewalk (F7) with high accuracy. Recognition of labels using Orcam MyEye and Seeing AI, for example, is reported to achieve greater than 95% accuracy in text recognition for flat, plain word documents (Granquist et al. 2021). Recent research has been conducted on detecting signs specifically for navigation of persons with visual impairment (Cheraghi et al. 2021). When the recognition is associated with the tracking of objects, it becomes possible accessing collision risks in real-time (F8) with no need for extra sensors.

Despite notable improvements in visual recognition, performing visual navigation (F9) remains a very significant problem for NAVI systems. Current solutions involve building 3D maps a priori (Dong et al. 2020), which is not desirable in outdoors navigation. Even if the user position could be calculated with enough accuracy, the information retrieved by the camera and processed by computer vision algorithms still needs to be classified and organized into instructions to the user. This is the basis for naturally interacting with users (F10).

It is important to recognize that this paper is written from the traditional research perspective, which focuses on the lower Technology Readiness Levels (TRLs 0 to 4). It goes without saying that to be useful, all research needs pushing to higher TRL levels, which requires commercial or government investment.

Conclusions

In this article, we explored the problem of building outdoors navigation assistants for persons with visual impairment. A review of the state-of-the-art solutions and frameworks of navigation assistants for persons with visual impairment showed that, although several solutions

have been proposed, the functionality of such systems is often limited to obstacle detection and navigation assistance based just on GNSS. Navigation assistants available to final users are the same satellite navigation system widely available to everyone else, adding little to meet the needs of users with visual impairment.

We presented the requisites of building a NAVI system running on smart glasses integrating all journey stages and exploiting the current technology to its full potential. Finally, we highlighted the areas that need further research and the problems that need to be solved to make such a system viable. In subsequent work, we will zoom in on these technological lacunae and show how a NAVI system could soon be a practical reality.

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The Decentralized Education of Digital Accessibility for Technologists

Dana Frayne

Oxford Internet Institute at the University of Oxford

Accessibility@danafrayne.com

Abstract

While research exists on the inaccessibility of the Internet, there is little discussion about the norms that are specific to digital accessibility practices in the technology industry. The aim of this research paper, derived from the author's unpublished dissertation at the University of Oxford, is to address this knowledge gap by gathering data on the norms that directly affect how digital accessibility practices are adopted in the technology industry. In particular, this research paper focuses on the educational aspect of digital accessibility by investigating how technological practitioners, particularly engineers and designers, learn about digital accessibility practices. Through a series of ten interviews with digital accessibility experts and technological practitioners, the researcher collected qualitative evidence of a decentralized educational process for engineers and designers who want to learn about digital accessibility. These findings illustrate a need for centralized educational options so that accessibility education becomes mainstream information for the next generation of technologists.

Keywords

Digital accessibility, assistive technology, accessibility practices, academic inclusivity.

Introduction

“The power of the Web is in its universality. Access by everyone regardless of disability is an essential aspect.” – Sir Tim Berners-Lee, 22 October 1997 (W3C)

Take a moment to consider how you used the Internet today. You may have used it to access your email account, look up an article, or even read this research paper. For the 15% of the global population that has a disability (World Health Organization, 2011), the ability to access information on the internet is often not a simple task (Goggin et al., 2019). The most frustrating aspect of this dilemma is that a plethora of assistive technology already exists for the purpose of making Internet more accessible, such as screen readers, voice-to-text software, and electronic Braille (Smith et al., 2018; Alper & Raharinirina, 2006). However, these assistive technologies only work when Internet-based products and services follow accessibility guidelines (Goggin & Newell, 2003; Cooper et al., 2012).

To address this challenge of non-conformance to digital accessibility guidelines, the aim of this research paper is to investigate the processes by which technologists are educated about digital accessibility guidelines, either through formal training or informal industry experience. A key point of clarification is that this research does not evaluate the educational materials that teach digital accessibility, but instead focuses on the processes by which technology practitioners are exposed to the practices of digital accessibility in the industry. Therefore, the aim of this research paper is to answer the question, “How is digital accessibility knowledge attained by practitioners in the technology industry?” This research question aims to bridge the burgeoning gap between digital accessibility policies and practice with this intentionally broad research question, as it allows for creative exploration of a topic that has little existing research.

Discussion

Method

This section discusses the procedures used for the semi-structured interview method. The interview method was chosen as the primary data collection practice because it has been a longstanding tradition in the social sciences that has proven to be efficient at gathering anecdotal evidence (Goldstein, 2002). The interview questions were designed to be intentionally broad, covering areas such as background in accessibility, accessibility expertise, and experiences with accessibility education. While the majority of interviews were conducted via audio or video calls, some were conducted via email, and the questions were slightly adjusted before each interview based on the field of expertise of the participant.

The criterion for inclusion in this research was that the participants must either be experts in the field of digital accessibility, with the term “expert” being subjective and applicable to multiple areas, or a technological practitioner, either through the role of an engineer or designer. The purpose for this broad selection criterion was the fact that digital accessibility is an interdisciplinary concept that covers many realms, and therefore, a narrow set of recruitment requirements would have greatly limited the research output. Furthermore, a point to draw attention to regarding recruitment is the rationale for presenting findings from a relatively small sample. While a collection of ten interviews is generally considered an unrepresentative sample in most social science research (O’Reilly & Parker, 2013), this is actually a significant number when considering the context of the broader accessibility field. This sample size represents how few accessibility experts exist in the field, which is an even smaller number when considering the obstacles related to conducting research with technologists, including non-disclosure agreements, lack of time, and lack of compensation for accessibility work. Future iterations of

this research could be improved with an expanded sample size.

To ensure the University of Oxford's ethical requirements for social science research were met, the researcher applied for and received ethical approval from the Central University Research Ethics Committee. The audio files of the calls were recorded and promptly saved to the researcher's university Nexus 365 account on the researcher's local computer. The researcher proceeded to transcribe the audio files with the assistance of the Trint transcription software. Once the initial transcription cycle was completed, the researcher uploaded the transcript into the MaxQDA data analysis software to develop a cyclical coding diagram (Saldaña, 2013).

Findings

A recurrent theme in the interviews was that the educational offerings for digital accessibility are not universal nor robust, particularly in comparison to other skills offerings for designers and developers. In fact, about half of the interview participants noted that their most relevant accessibility education was gathered almost through on-the-job trainings or experience, leading to questions about the gaps that exist in the process of obtaining a digital accessibility education. The significance of obtaining an accessibility education was emphasized in a research interview with Alastair Campbell, the co-editor of the Web Content Accessibility Guidelines (WCAG) 2.1 and a digital accessibility consultant for over twenty years:

One of the biggest, biggest problems for accessibility is the education of designers and developers in general, because there's no one particular route. Whenever I run training, I start off with how many people have done any accessibility training before. The answer's usually about 10 percent...that's terrible, frankly.

This reflection, particularly coming from an accessibility expert, emphasizes the challenging reality that engineers and designers face when putting accessibility policies into practice.

Without a centralized training of the key techniques of digital accessibility, it is difficult for engineers and designers to apply digital accessibility practices to their work. These findings are divided into two primary sections: first, an overview of experiences with accessibility education at the university level, and second, a discussion of the educational offerings at the industry level.

Digital Accessibility Education in Universities

These findings provide an overview of the digital accessibility educational options that are available to engineers and designers prior to entering the industry. The engineers and designers interviewed for this research obtained their discipline-specific skills in either an educational setting, such as a university or a skill-specific training course, or through on-the-job training in their profession. In a traditional university setting, the options for learning about digital accessibility are highly dependent on the university and appear to be up to the discretion of instructors of user experience design. The existence of the Teach Access grant, which provides funding grants to professors who incorporate accessibility teaching in their courses, is an example of how digital accessibility practices are incorporated into American university curriculum (Teach Access Curriculum Development Awards, 2021). A software engineer who pursued an undergraduate degree in electrical engineering and computer science noted:

One of my classes in college was a UI/UX design class that covered digital accessibility.

The class covered diversity of ability and the different kinds of impairments that might affect access to software and hardware... Additionally, the class covered current forms of assistive technology like screen readers, speech recognition, and eye trackers.

Therefore, there is evidence that digital accessibility education does exist at the university level as a subtopic of broader design courses. This sentiment was echoed by another designer who pursued a liberal arts degree and took design and computer science courses, “At my school, there

were no courses focused specifically on digital accessibility. However, accessibility was a subtopic in several of my design and computer sciences classes.”

Therefore, a trend in the research was that digital accessibility is covered as a subtopic in a user experience design class, which indicates an increased awareness about digital accessibility topics. However, there was no findings of a standalone digital accessibility course, and some practitioners indicate that they did not learn about digital accessibility until entering the technology industry. Therefore, there is evidence that digital accessibility education does exist at the university level in America, but it is highly dependent on the educational setting and appears to be at the discretion of the university professors to decide whether the topic should be included.

Before transitioning to a discussion of digital accessibility educational processes in the technology industry, a key issue to address is how digital accessibility education in a formal educational setting is often sidelined as a relatively less important topic. Accessibility scholar Gerard Goggin noted this risk of digital accessibility knowledge being limited to literature in a research interview:

There's a literature of increasing sophistication. And because of the growth of different kinds of research techniques and data gathering techniques, you can actually get really fine-grained and really sophisticated measurements of web accessibility. But it seems to me in some ways they stay in the literature.

The risk of digital accessibility information staying in the classroom and not being brought into the industry represents a significant threat to the broader digital accessibility movement, as it is critical that engineers and designers have access to knowledge of digital accessibility when they are first acquiring their technical skillset. The evidence from this research suggests a broader trend of decentralization in digital accessibility education at the university level, which poses

further questions about why digital accessibility education is not more commonplace in traditional educational systems. This question is also relevant to the next section of findings, in which there is a discussion on the options available to engineers and designers learning about digital accessibility in the technology industry.

Digital Accessibility Education in Industry

This section presents an overview of the educational options available to technologists working in the technology industry. The key finding is that, similar to the educational options for technologists at the university level, the educational options at the industry level are also highly situational. Contextual factors, such as the resources of a particular technology company, are indicators of whether engineers and designers can acquire information about applying digital accessibility standards to the product development process. Larger technology companies tend to have more accessibility resources available than smaller companies, as evidenced by a designer's reflection on their experience with digital accessibility:

When I interned at large tech companies like Microsoft and Google, there were extensive internal resources on digital accessibility. Products launched needed to satisfy a number of accessibility requirements, and there were dedicated teams within these companies that were exclusively focused on accessibility.

This same designer noted that, in contrast to large technology companies, the discussions of accessibility is less prominent at mid-size and small companies, including start-ups:

Since starting my career as a full-time designer, I've worked at a mid-size startup (~150 employees) and an early startup (~20 employees). Neither of these employers have provided digital accessibility training or guidelines. Although it's acknowledged that accessibility is important, I would say that accessibility initiatives are often unfortunately

relegated as lower priority than product initiatives due to business goals.

However, this reflection does not mean that all startups and relatively smaller technology companies are unconcerned with digital accessibility education. Matthew Pierri, founder of the technology startup Sociability, emphasized his company's ongoing dedication to ensuring that their technology team was trained in digital accessibility practices:

Within this idea of translating theory into practice, it is really fundamental to engage with people's lived experience and to get them involved in a very central way in the process of designing and iterating and improving. So, not just having one disabled person at the start give some thoughts and then going off and doing whatever you want because you've got their endorsement ... [accessibility should be approached] in a very sincere and ongoing manner, rather than the all-too-common: 'we did it once, and that should be sufficient.' [Accessibility] will evolve because it's based around people, and people evolve and their preferences change.

These reflections provide a foundation of preliminary evidence to support the notion that digital accessibility educational options for technologists are highly dependent on the resources and priorities of technology companies.

A risk associated with this situational nature of accessibility education at the industry level is that there is a decentralized path to providing digital accessibility education. One possible pathway within a company is that an individual who is knowledgeable about digital accessibility advocates for increased accessibility within a team. This was identified as a common pathway in interviews, but is not sustainable in the long-term because this advocacy work is often undervalued. The other pathway identified within companies was accessibility teams, in which there are groups of accessibility experts who are both advocates and educators

within the company. In contrast to these internal resources, there are also external resources in the forms of third-party consultants and external courses that are utilized by companies to develop their accessibility educational programs. It is not uncommon for a company that is invested in ensuring the accessibility of their products to employ a variety of these resources.

Therefore, similarly to the formal educational options available prior to entering the industry, the options for digital accessibility education in the technology industry are highly situational. As identified in Figure 1, there are multiple pathways that currently exist for digital accessibility education, and it is up to companies to decide how they are going to employ these options. While companies that are proactive about adherence to digital accessibility standards can maintain long-term educational options for their employees, this decentralized educational landscape illustrates the challenges that technologists encounter when they are not formal educational systems in place to teach digital accessibility.

Conclusion

Regarding the initial research question concerning how digital accessibility knowledge is attained by practitioners in the technology industry, the overarching finding is that the educational pathways for practitioners are highly dependent on situational factors. At the university level, opportunities for learning about digital accessibility skills is limited and linked to whether a professor decides to incorporate digital accessibility into their curriculum. This results in an uneven distribution of the digital accessibility skillset throughout the technologist population. Once individuals enter the technology industry, the situational context is also highly variable due to the different options that technology companies have for educating their technologists about digital accessibility. Therefore, if a company is committed to the education

of digital accessibility, then their technologists are likely to encounter multiple forms of digital accessibility trainings and educational opportunities. On the contrary, if a company is not committed to digital accessibility, the opportunities for technologists to learn about digital accessibility can be extremely limited. This decentralized educational system results in a technology industry that has a vast range of educational levels for digital accessibility skills. In order for there to be universal practices for digital accessibility, it is necessary to look at the educational options available to technological practitioners and consider how this decentralization causes inequitable backgrounds in digital accessibility.

The thesis from which this research is based on addressed additional norms of digital accessibility, including digital accessibility policies and social norms in the industry. The research presented in this paper is meant to serve as a preliminary starting point for further investigations into the educational landscape for technologists learning about digital accessibility. This research could be improved with an expanded sample size, as well as a more detailed emphasis on sectors of digital accessibility education. Future research can build upon these findings by studying the education of digital accessibility in countries other than the United States, as well as specific industry sectors that present significant challenges to digital accessibility, such as artificial intelligence.

These findings investigate the educational norms that operate within the field of digital accessibility with an emphasis on how technologists learn about digital accessibility at the university and industry levels. Through a series of interviews with digital accessibility experts and practitioners, this research highlights the pressing need for a centralized educational pathway for technologists learning about digital accessibility. A departure from the decentralized educational system that results in this uneven landscape will improve outcomes for people who

utilize assistive technology, as well as the technologists who are building these products. This overview of the existing educational system is meant to present a starting point for further research on how technologists can be better prepared to build products that can be used by anyone, regardless of ability. By developing a more equitable educational system through the process of centralization, it is more likely that the goal of universal adherence to digital accessibility standards will become attainable for the broader technology industry.

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Design of Augmented Tactile Books for Blind Children

Dominique Archambault¹, Solène Negrerie², Sophie Blain²

¹Université Paris 8 Vincennes Saint-Denis, France

²Les Doigts Qui Rêvent (LDQR), Tallant, France

Abstract

We present the design of the first prototypes of augmented tactile books. These books not only play sounds but also engage the children by proposing original digital models of interaction based on recent research in the domain of sensorimotor psychology. The prototype books were designed using rich tactile material to be touched on the pages as well as miniaturized electronic components – embedded in the pages themselves – to detect several different gestures on the page such as the action of simulating walking with two fingers. Here we describe and then informally test three prototypes. After receiving encouraging feedback, we continued this project by designing a small series of 12 prototypes to perform a formal evaluation with two types of users: professionals and blind children.

Keywords

Tactile books, blind, children, interactive books, literacy.

Introduction

Tactile books are especially important for the development of blind children as well as children with partial sight or various other disabilities, although they can also be interesting for any child. These books not only help them develop tactile skills but also provide them with fun and pleasure, as books do for any child. Tactile illustrations are images that can be perceived in the same way as graphical illustrations in normal books. Nevertheless, blind children have major difficulties in recognizing what is actually depicted by tactile illustrations produced using standard techniques (e.g., relief drawing with swelling paper or wax strings, thermoformed illustrations). Several reasons may explain this difficulty, the main one being that this kind of drawing does not correspond to their primary perception, as images correspond to a projection of sight, even when they are schematized in the case of a simple drawing. Therefore, a tactile image must be read analytically and reconstructed mentally. Indeed, this process is incomparable to the immediate pleasure of a sighted child upon discovering a graphical illustration (Valente 2).

To make the tactile reading of images easier, more intuitive, and fun, the tactile illustrations need to be linked to interactive elements and sounds, which are not only enjoyable but also guide the reader. These elements make the tactile discovery more intuitive and enjoyable for children and require less mediation from the adult; they also entail less cognitive overload. Authors have been working together for over 20 years on projects combining these interactive elements with tactile illustrations (Casson et al., Archambault et al.). LDQR (literally “Daydreaming Fingers”) is an associative editor of tactile books for blind children.

Valente proposed simulating actions through a set of gestures performed by two fingers (5-7) such as using them as legs to walk on a page or to caress, scratch, rub, or tap. Previous

studies (Valente et al.) have shown that these inclusive gestures help blind and sighted children to identify the represented objects, and that they are highly inclusive.

Recent progress in the miniaturization of electronic components – especially sensors – and processors means that we can embed them inside the books instead of simply overlaying them over the tactile zones like buttons. The idea is to provide children with a more immersive reading experience using scenarios in which they can trigger the verbal components (recorded voices read by actors) and non-verbal elements (music, sound effects) with their hand gestures. Various kinds of sensors are inserted into the page and connected to a processor that is located in the cover and communicates with an external component to implement the scenario and play the audio components. In this respect, this process involves adapting a visual illustration in relief with added sounds and then augmenting it with original digital models of interaction, thus moving from somesthetic to gestural touch.

The project “*Livres Tactiles Augmentés*” (Augmented Tactile Books) began after we realized that we could use this technology to integrate some of the gestures proposed by Valente into books in order to encourage younger readers to manipulate and experience the body using two fingers.

Page Prototype Design

Two students enrolled in the Master of Electronics at University of Burgundy, Farooq and Amene, worked on page prototypes using various kinds of cheap and modular sensors to detect the gestures. These prototypes were based on the Arduino ecosystem, including hall-effect sensors, touch capacitive sensors, conductive fabrics, and so on. The system can detect the following gestures on a page:

- tapping on different kind of fabrics;

- simulating walking on a page with two fingers;
- climbing up several steps;
- opening a door or window;
- touching a textile flower;
- moving a “boat” on a page;
- rotating a “planet” on a page.

The pages were made of cardboard, with the cables stuck down using adhesive tape; active components like hall-effect sensors, and in some cases, conductive material like copper tape were also fixed onto the page. All sensors were wired to an Arduino Nano controller located in the back cover of the book. Cables went through the binding as shown in Fig. 1 and were soldered onto a printed circuit board (PCB) on which the controller and a few necessary electronic components were also soldered. The power came from the USB cable plugged into the controller and connected to a computer. Indeed, in these early prototypes, the software was located on a computer, which ran the scenario and played the sounds according to the touch events sent by the book via the controller. In future prototypes, we will discard the need for a computer, as will be discussed below.

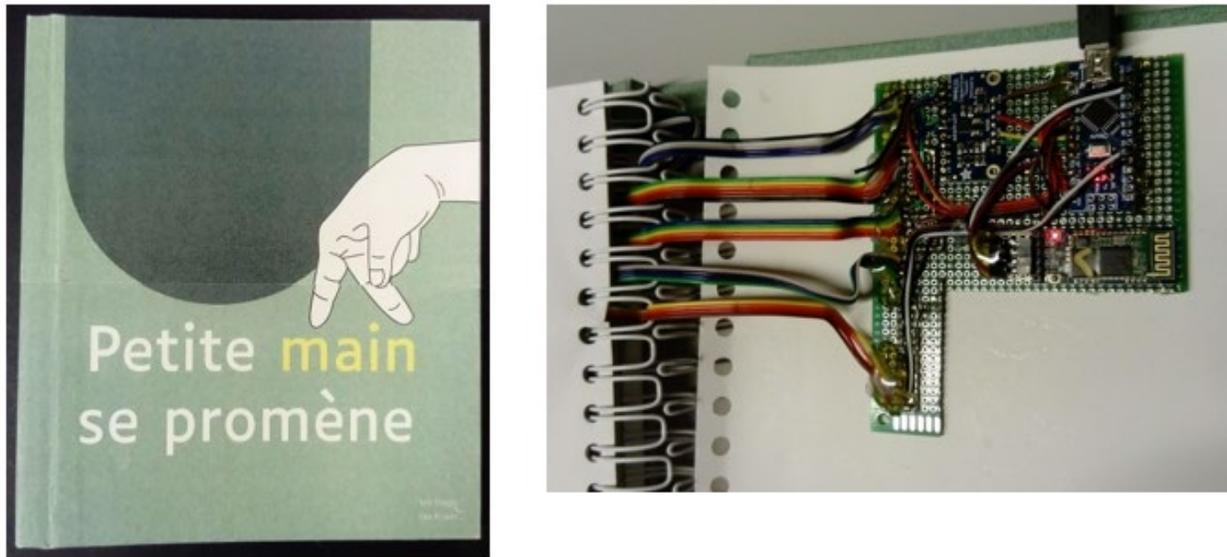
Prototype 1 – “Petite main se promène”

Fig. 1. Prototype 1 “Petite main se promène”: Cover and Electronic Board.

The prototype book designed by Farooq was based on a short story called “*Petite main se promène*” (“Little hand goes for a walk”) in which the child simulates walking with two fingers on the four pages of the book. Fig. 1 illustrates the prototype cover on the left, showing the gesture of simulated walk with two fingers, and on the right, the electronic board located on the cover of the book.



Fig. 2. Prototype 1 “Petite main se promène”: Page 1 (three steps), Page 2 (three flowers) and Page 4 (mouse needs to hide).

On the first page, three steps can be climbed by our character represented by two fingers to simulate walking. The steps are covered with copper, and they are about 1 mm high, as we are limited in terms of the height of the illustrations given the necessity to be able to turn the pages. The capacitive effect is used and implemented on the Arduino board, which detects the touch of the child's finger on one of the steps. A "footstep" sound is then played.

On page 2, the child is invited to touch some flowers made from conductive fabrics. Different sounds are played when the contact of a finger is detected. Page 3 presents a door that can be opened. The hinge is made from fabric with electrical resistance that changes proportionally when folded. Finally, page 4 shows a small mouse hooked onto the page with Velcro. The child is asked to hide it from the cat. On the page, there is a small curtain covering another Velcro piece where the child can attach the mouse. The system recognizes if the mouse is under the curtain using a Hall effect sensor and a small magnet placed inside. Pages 1, 2, and 4 are presented in Fig. 2.

Hall effect sensors are also used to detect which page is open. There are four magnets embedded in the four pages at different levels along the book hinge with four corresponding sensors in the back cover at the same levels. When a page is closed, its magnet is situated near the corresponding sensor, while it is far away when the page is open. These sensor values thus indicate which page is open.



Fig. 3. Prototype 2 “Mes Chemins”: Page 1 (simple path), Page 2 (path with coating) and Page 4 (path with a river to cross).

Another prototype book was designed by Farooq during his Master to explore the technical possibilities of simulated walking with fingers as shown on the cover presented in Fig. 1. The four-page book is entitled “*Mes chemins*” (“My paths”) and the characters of the story walk along a path. On each page, the path is presented vertically, and the reader has to walk along it with the fingers. On the first page, only the path is shown; the reader subsequently encounters different coatings and additional items (e.g., a river to cross). Pages 1, 2, and 4 are shown in Fig 3. The system used for the pages was identical to the precedent prototype, and the book was also connected to the computer for reading the story and playing the sounds. The main technical problem was the limited number of usable pins on the microcontroller.

If two fingers simultaneously touch a conductive material, the controller will only detect one zone. So, when the child walks with the fingers, one finger should be lifted before the second finger touches the book. However, this is not easy to do, or otherwise, it gives the impression of jumping or running instead of walking. It was therefore necessary to make small conductive zones around 24 mm wide by 20 mm long (spaced 1-2 mm apart). Each zone had to be

connected to a pin of the controller, and in this case, the path was 4 cells wide by 10 cells long, with a total of 40 cells. An Arduino Nano as 13 digital pins. A multiplexer or an Arduino Mega could be used, but this would result in a larger electronic board and more expensive hardware, which would still be insufficient if we wanted to cover the whole page (about 20 cm x 20 cm).

The chosen solution was to connect together a few conductive zones and ensure that the contiguous zones were not linked. We set up an arrangement so that the distance between two different zones was at least 20mm (see Fig. 3). We used conductive ink for this test: the zones were painted with conductive ink, and copper tape connected them to the wires in the cardboard page.

Prototype 3 – Entitled

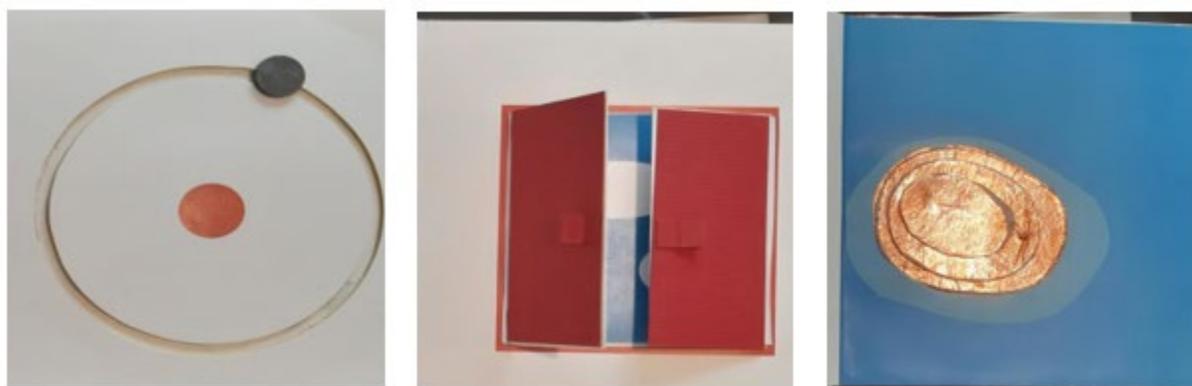


Fig. 4. Entitled: Page 1 (planet orbiting), Page 2 (window) and Page 5 (island).

These prototypes were shown to a children's book author Lucie Felix for her to test the types of gestures that we were able to detect. The author also worked on a scenario for a new prototype with a real story. The third prototype book was designed by Amene during his Master research. On page 1, a planet orbits around the sun, and on page 2, the reader can open the window and hear the sound of the surroundings. One-page features three puddles, and another

has an island surrounded by a beach. This prototype book was created using the same techniques as the precedent prototypes (capacitive touch, hall effect, etc.).

Prototype Tests

Before carrying out a proper evaluation, these books were tested informally with specialists working with blind children as well as several blind children. The preliminary conclusions were that the children liked the book and that the technology worked correctly to simulate the desired effect. Unfortunately, the device was too fragile for the children.

Despite these encouraging results, we could not carry out proper tests with the children using these prototypes, because they did not function for the duration of the evaluation. In particular, the conductive ink was far too fragile, although, admittedly, we did not test different conductive inks, so more tests could be done.

Discussion

The development of these three prototypes allowed us to create several techniques to implement a set of hand gestures to be used with an interactive book. We can simulate several actions such as walking with two fingers, jumping, or running, opening a door or windows, and moving objects by detecting their positions with magnets. We can also replicate different environments such as footsteps walking on a hard path, through dead leaves in a forest, or in shallow water.

The initial feedback from children and professionals was enthusiastic, but the tactile books need to be studied more formally, which is the next step in our research. As the first prototypes were not solid enough, they could not be used for a proper evaluation. Indeed, the planned evaluation will include around 12 copies of a prototype book, which will be sent to professionals throughout France who work in different kinds of establishments (e.g., special

schools for the blind, support centers). These professionals will conduct experiments with blind children and then complete questionnaires. As the developers will not be available to repair the books, the second step of this project will be to develop more solid prototypes using the same electronic effects. The scenario of the third prototype was slightly revised by the author, and a second version entitled "*Kapi Capitaine*" (Captain Kapi) was prepared with a small electronic company to create a more solid version. Further, the workshop of LDQR, which has over 20 years of experience in making tactile books, built the tactile parts.

An issue was raised at the start of the project about whether or not to use a computer. The three first prototypes as well as the Kapi prototypes all use a computer, because in addition to the implementation of the story, we wanted to record data about the use of the book. Log information is stored and later analyzed with the questionnaires. For the future books to be distributed schools or children's families, it will be better not to use a computer, as it would prevent the children from independently using the books and require the use of a computer nearby. Another idea would be to use a smartphone. The book could communicate via Bluetooth or WIFI with a smartphone, which is capable of implementing the scenario. Speakers can be connected (wired or via Bluetooth) to the smartphone. This solution is convenient, because it does not require a specific device, as smartphones are widely used nowadays. However, this system still has a drawback: even though smartphones are less cumbersome and easier to connect without a cable than a computer, the children would need their parents or professionals to set up the phone, thus making it unavailable for other uses. Another solution would be to create a specific device like an accompanying box, which would contain a cheap computer (e.g., Raspberry Pi), a speaker, and a battery. This box would implement the story and play the sounds with minimal commands (on/off, volume) and be inexpensive to produce. We also considered putting the computer and

battery in the cover and hinge of the book, but this would need to be integrated into every book. By contrast, the external box could be used for several books.

Conclusions

We presented the first part of an ongoing research project to design several prototypes of augmented tactile books in which child readers become engaged in the story using hand gestures. The first prototypes were successful as a proof of concept, although their solidity was insufficient to perform a formal evaluation. The children's reactions were encouraging and motivated us to initiate the second phase of the study, which was briefly summarized in the discussion above: the development of a series of more solid prototype books and a formal evaluation. This second phase was in progress at the time of writing this article.

On the technical side, further studies are needed to be able to develop a series of books without implementing all the software from scratch each time (including the microcontroller software). We expect to propose a model with several pages, including the normalization of the wiring, protocols for the communication between the pages and the controller, and between the controller and the device implementing the story (i.e., computer, smartphone, or external box), and a method for the identification of the pages.

Acknowledgments

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Video Game Trends Over Time for People with Disabilities

Sarah Mosely¹, Raeda Anderson^{1,2}, George Usmanov¹, John Morris¹, Ben Lippincott¹

The Shepherd Center¹

Department of Sociology at Georgia State University²

sarah.mosely@shepherd.org, raeda.anderson@shepherd.org,

gusmanov1@gsu.edu, john.morris@shepherd.org,

ben.lippincott@shepherd.org

Abstract

This study examines patterns of recreational video gaming from 2017-2021 for adults with disabilities. Analysis of video gaming trends was completed using data from a self-administered online survey of US Adults with disabilities (N=1,106) to understand patterns of gaming across disability types and demographic groups. 45.9% of respondents play video games. Of respondents who play video games, 62.4% play on a console, 68.4% play on their phone, and 57.9% play on their computer. People in three disability groups play video games more than people who have different disabilities: people with anxiety, people who have upper extremity limitations, and people with fatigue and limited stamina. Conversely, people who have limitations seeing or are blind play video games less than people with other types of disabilities. Males and younger adults with disabilities report playing video games less than females and older adults with disabilities. People with a graduate degree report playing video games less than people with lower levels of education.

Keywords

Video games, disability, gaming over time, video games and disability

Introduction

Video games are ubiquitous in the United States (U.S.). A substantial majority of adults in the United States (67%) play video games (2021 Essential Facts: About the Video Game Industry). Among those who play video games in the general population, 57% reported playing games on their smartphones, 46% on dedicated consoles, and 42% on their personal computer. Mobile gaming has gained significant popularity worldwide, representing a larger market share than console and PC gaming combined (State of Mobile Gaming). Casual games like Tetris, Among Us, and Candy Crush were by far the most popular genre of game (2021 Essential Facts: About the Video Game Industry; Leading Video Game Types Worldwide 2021).

Making video games accessible has been a notable focus for game developers (Brown and Anderson 702). Organizations like The AbleGamers Charity have worked to identify barriers to accessibility in video games and create resources for video game developers to make their games more inclusive (Cairns et al. 65). Some game developers have begun to integrate more accessibility settings geared toward players with specific disability types. For example, the creators of *The Last of Us Part II* included settings that would allow players who were blind or had low vision to navigate towards objectives or objects using sonar like audio cues (Link). In recent years, efforts have also been made to make gaming platforms themselves more accessible. In 2018, Microsoft released the Xbox Adaptive Controller, allowing players with more significant motor limitations to create their own custom solutions for gaming access (Gajanan). Despite these technological advances, however, disabled gamers continue to lack equitable access to mainstream video games.

While research has examined the use of video games as therapy for people with disabilities (Banskota and Ng; Hocking et al. 770) fewer studies have examined general patterns

of gaming for people with disabilities (Thompson, et al. 157). A qualitative study by Cairns et al. (262) indicated that motivations for individuals with disabilities to engage in gaming may extend beyond addressing therapeutic or rehabilitation goals. This study found motivating benefits of recreational gaming included feelings of enablement and social connection. Tabacof and colleagues (1202) explored the effect of introducing individuals with spinal cord injuries to eSports and providing them with the adaptive tools needed to access these games. Participants in this study reported increased feelings of social connectedness and decreased isolation when engaging in mainstream gaming.

To support the efforts to make mainstream gaming more accessible for all, it is important to establish a better understanding of the trends, platform preferences, and demographic characteristics of gamers with disabilities. Thus, this study examines patterns of recreational gaming from 2017-2021 for adults with disabilities.

Data and Methods

Data were collected from August 2017-August 2021 via the online self-administered entry survey of the Accessibility User Research Collective (AURC). The AURC is managed by researchers at Shepherd Center. Membership requirements include self-identifying as having a disability or functional limitation, being 18 or older, and living in the United States of America. A total of 1,106 AURC members' data are analyzed in this study.

Disability is measured with a series of seven dichotomous indicators: anxiety, dexterity limitation, walking limitation, fatigue and limited stamina, learning disability, low vision and blind, as well as low hearing and deaf. Respondents self-identified into disability groups. Most disability categories are measured through a single response option to the question "*Which, if any, of the following challenges or limitations do you have?*": anxiety via "*frequent worrying,*

nervousness, or anxiety”, walking limitation via *“difficulty walking or climbing stairs”*, fatigue and limited stamina via *“difficulty with fatigue/limited stamina”*, learning disability via *“difficulty learning, or a learning disability”*, low vision and blind via *“difficulty seeing”*, and low hearing and deaf via *“difficulty hearing”*. Dexterity limitation was measured by collapsing response options from *“difficulty using your arms”* and/or *“difficulty using your hands and fingers”* to the aforementioned question.

Demographic measures include sex, race, ethnicity, education, and age. Sex is measured through a single indicator of *“What is your sex?”* on the screener used from 2017-2020 and *“What is your gender?”* on the screener used from 2020-2021. Race and ethnicity are measured through a check all that apply question of *“What is your race/ethnicity?”*. Education is measured through a single indicator of *“What is the highest level of education you have completed?”*. Age is measured by taking the respondent’s answer to *“What year were you born?”* from the year that they completed the screener.

Gaming measures include playing video games and gaming platforms. *Playing video games* is measured via a single indicator, *“Do you play video games?”* and their response options were yes and no. *Gaming platforms* are measured through collapsing a series of variables. Respondents were asked *“Which of the following platforms do you play video games?”* with a myriad of response options. For computer games, respondents who identified playing games on a Mac, games on a PC, and/or games played online via a web browser were coded as a 1 and all other respondents were coded as a 0. For phone games, respondents who identified playing games on an Android mobile phone and/or Apple iPhone were coded as a 1 and all other respondents were coded as a 0. For platform games, respondents who identified playing games on a Nintendo, Super Nintendo, Nintendo 64, Nintendo Wii, Nintendo Wii U, Nintendo Switch,

Nintendo Gameboy, Nintendo DS, PlayStation 1, PlayStation 2, PlayStation 3, PlayStation 4, PlayStation Portable, PlayStation Vita, Xbox, Xbox 360, and/or Xbox One were coded as a 1 and all other respondents were coded as a 0.

Analyses within this study include descriptive statistics, χ^2 (chi-squared) for testing statistically significant differences between groups, Φ (phi) for testing the relationship between dichotomous measures (Fleiss and Berlin 239), and Γ (gamma) for testing the relationships between ordinal variables (Frankfort-Nachmias and Leon-Guerrero 385). Descriptive statistics used include percent (%) and count (N). Pearson's product moment chi-squared is used in this analysis as the data are parametric and the sample size is large enough to support the assumptions of the chi-squared. Analyses are conducted using pair-wise deletion as there are item non-response on some study measures (Weaver and Maxwell 145). For all statistical analyses, p values below 0.05 are reported as statistically significant (Frankfort-Nachmias and Leon-Guerrero 358).

Analysis

Table 1 includes descriptive statistics of all study variables. 45.9% of respondents play video games. Of respondents who play video games, 62.4% play on a console, 68.4% play on their phone, and 57.9% play on their computer. There is notable variation across the percent of respondents who have different types of disabilities: anxiety 20.9%, dexterity limitation 18.5%, walking limitation 23.3%, fatigue and limited stamina 17.9%, learning disability 22.2%, low vision and blind 41.6%, and low hearing and deaf 16.7%. Slightly less than half (41.6%) of respondents are female. 72.0% of respondents are white, 10.0% are African American, and 7.2% are Hispanic. Overall respondents are well educated: 9.4% highest education level was a high school diploma or less, 21.9% with some college (no degree), 7.5% Associate degree, 34.4%

Bachelor's degree, and 26.7% Graduate degree respectively. Age of respondents varies with an average age of 44.99 (SD=15.53) with 17.5% being 29 and younger, 24.5% being 30-39, 20.8% are 40-49, 16.3% are 50-59, and 20.9% are 60 are older. Respondents could have joined the study anytime between 2017 and 2021. 23.9% joined the AURC in 2017, 34.7% joined in 2018, 8.8% in 2019, 23.7% in 2020, and 9.0% in 2021.

Table 1. Study Variable Summary Statistics (N=1,106). Source: AURC, 2017-2021.

*Of participants who are gamers

| Study Variable | Percent | N |
|---|----------------|----------|
| Plays Video Games (Yes) | 45.9% | 503 |
| Gaming Platform: Console | 62.4% | 314* |
| Gaming Platform: Phone | 68.4% | 344* |
| Gaming Platform: Computer | 57.9% | 291* |
| Disability Type: Anxiety | 20.9% | 231 |
| Disability Type: Dexterity limitation | 18.5% | 205 |
| Disability Type: Walking limitation | 23.3% | 258 |
| Disability Type: Fatigue and limited stamina | 17.9% | 198 |
| Disability Type: Learning disability | 22.2% | 245 |
| Disability Type: Low vision and blind | 41.6% | 458 |
| Disability Type: Low hearing and deaf | 16.7% | 185 |
| Sex (Female) | 45.2% | 500 |
| Race and Ethnicity: White | 69.8% | 772 |
| Race and Ethnicity: African American | 9.1% | 101 |
| Race and Ethnicity: Hispanic | 5.3% | 59 |
| Race and Ethnicity: Other | 15.7% | 174 |
| Education: High school diploma or less | 9.4% | 98 |
| Education: Some college, no degree | 21.9% | 230 |
| Education: Associate degree | 7.5% | 79 |
| Education: Bachelor's degree | 34.4% | 361 |
| Education: Graduate degree | 26.7% | 280 |
| Age: 29 and younger | 17.5% | 182 |

| Study Variable | Percent | N |
|-------------------|---------|-----|
| Age: 30 – 39 | 24.5% | 255 |
| Age: 40 – 49 | 20.8% | 216 |
| Age: 50 – 59 | 16.3% | 169 |
| Age: 60 and older | 20.9% | 217 |
| Year: 2017 | 23.9% | 264 |
| Year: 2018 | 34.7% | 384 |
| Year: 2019 | 8.8% | 97 |
| Year: 2020 | 23.7% | 262 |
| Year: 2021 | 9.0% | 99 |

Figure 1 reflects the percent of people who said they play video games each year. While 45.9% of all respondents play video games, this percent varies year to year with 46.2% in 2017, 38.3% in 2018, 67.0% in 2019, 50.0% in 2020, and 43.4% in 2021.

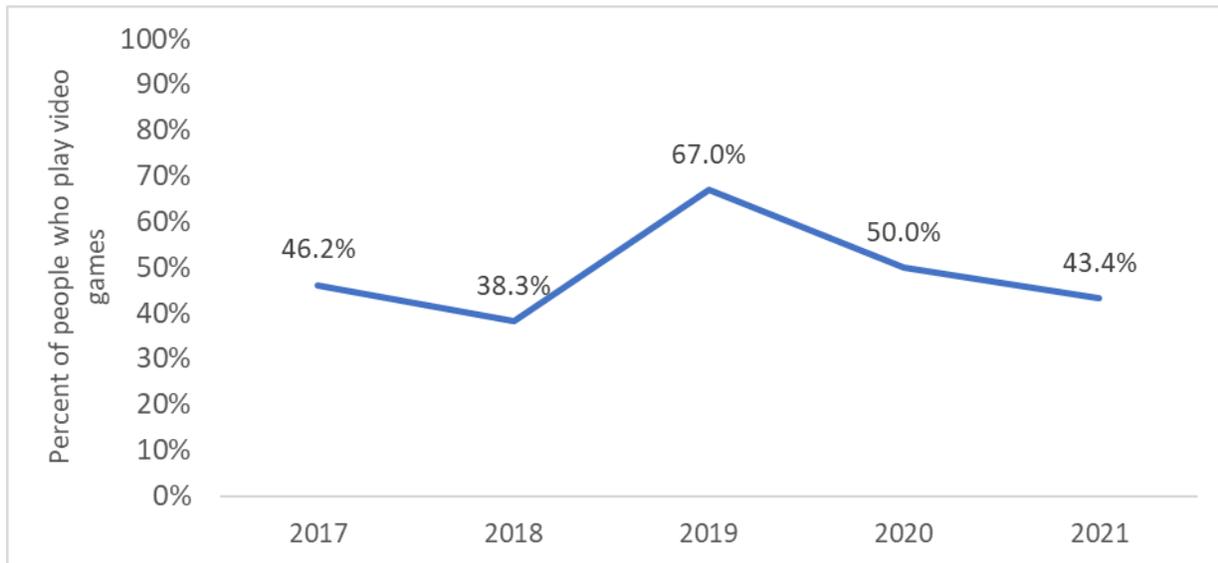


Fig. 1. Percent of Respondents with Disabilities Who Play Video Games by Year.

(Source: AURC, 2017-2021)

Figure 2 plots the percentage of respondents who are gamers for each year by disability type. All disability groups have a small decrease in gamers from 2017 to 2018. Akin to figure 1,

there is a notable peak from 2018 to 2019 with an increase for most disability groups. Testing of variability between disability groups each year is reported in table 2.

Table 2. Video Game Playing and Disability Type by Year. (Source: AURC, 2017-2021)

| Disability Type | Year | Φ | p value | Significance |
|------------------------------------|----------------|--------------|------------------|---------------------|
| Learning Disability | Overall | 0.046 | 0.128 | |
| Learning Disability | 2017 | 0.063 | 0.304 | |
| Learning Disability | 2018 | -0.082 | 0.109 | |
| Learning Disability | 2019 | 0.163 | 0.108 | |
| Learning Disability | 2020 | 0.075 | 0.233 | |
| Learning Disability | 2021 | 0.169 | 0.093 | |
| Anxiety | Overall | 0.110 | <0.001 | p<0.001 |
| Anxiety | 2017 | 0.085 | 0.167 | |
| Anxiety | 2018 | 0.048 | 0.342 | |
| Anxiety | 2019 | 0.049 | 0.627 | |
| Anxiety | 2020 | 0.215 | <0.001 | p<0.001 |
| Anxiety | 2021 | 0.072 | 0.471 | |
| Upper Extremity Limitation | Overall | 0.075 | 0.013 | p<0.05 |
| Upper Extremity Limitation | 2017 | 0.163 | 0.008 | p<0.01 |
| Upper Extremity Limitation | 2018 | 0.070 | 0.172 | |
| Upper Extremity Limitation | 2019 | -0.295 | 0.004 | p<0.01 |
| Upper Extremity Limitation | 2020 | -0.009 | 0.882 | |
| Upper Extremity Limitation | 2021 | 0.194 | 0.053 | |
| Walking Limitation | Overall | 0.046 | 0.130 | |
| Walking Limitation | 2017 | 0.125 | 0.042 | p<0.05 |
| Walking Limitation | 2018 | 0.043 | 0.405 | |
| Walking Limitation | 2019 | -0.340 | <0.001 | p<0.001 |
| Walking Limitation | 2020 | -0.027 | 0.666 | |
| Walking Limitation | 2021 | 0.150 | 0.136 | |
| Fatigue and Limited Stamina | Overall | 0.089 | 0.003 | p<0.01 |
| Fatigue and Limited Stamina | 2017 | 0.086 | 0.164 | |
| Fatigue and Limited Stamina | 2018 | 0.019 | 0.703 | |
| Fatigue and Limited Stamina | 2019 | 0.087 | 0.394 | |
| Fatigue and Limited Stamina | 2020 | 0.125 | 0.047 | p<0.05 |

| Disability Type | Year | Φ | p value | Significance |
|-----------------------------------|----------------|---------------|------------------|-------------------|
| Fatigue and Limited Stamina | 2021 | 0.097 | 0.334 | |
| Blind or Seeing Limitation | Overall | -0.135 | <0.001 | p<0.001 |
| Blind or Seeing Limitation | 2017 | -0.033 | 0.596 | |
| Blind or Seeing Limitation | 2018 | -0.215 | <0.001 | p<0.001 |
| Blind or Seeing Limitation | 2019 | 0.100 | 0.327 | |
| Blind or Seeing Limitation | 2020 | -0.200 | 0.002 | p<0.01 |
| Blind or Seeing Limitation | 2021 | 0.094 | 0.351 | |
| Deaf or Hearing Limitation | Overall | 0.015 | 0.624 | |
| Deaf or Hearing Limitation | 2017 | 0.049 | 0.425 | |
| Deaf or Hearing Limitation | 2018 | 0.054 | 0.286 | |
| Deaf or Hearing Limitation | 2019 | 0.166 | 0.103 | |
| Deaf or Hearing Limitation | 2020 | -0.109 | 0.084 | |
| Deaf or Hearing Limitation | 2021 | -0.110 | 0.273 | |

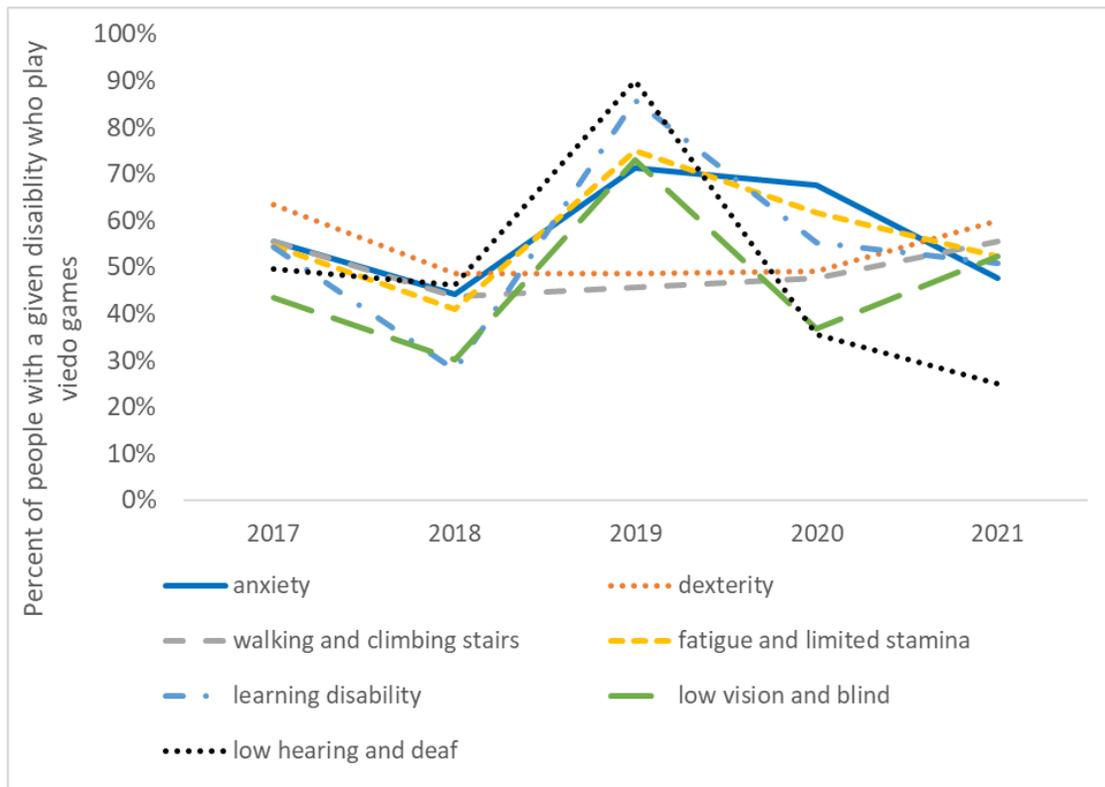


Fig. 2. Percent of Respondents by Disability Group Who Play Video Games by Year.

(Source: AURC 2017-2021)

Table 2 includes analysis of gaming by disability type for both overall and by year. For people with learning disabilities, respondents were not significantly more or less likely to play video games than people with other types of disabilities. Overall, people in three disability groups play video games more than people who do not have that disability type: people with anxiety ($\Phi=0.110$, $p<0.001$), people who have upper extremity limitations ($\Phi=0.075$, $p=0.013$), and people with fatigue and limited stamina ($\Phi=0.089$, $p=0.003$). Conversely, people who have limitations seeing or are blind play video games less than people with other types of disabilities ($\Phi=-0.135$, $p<0.001$). These relationships, however, are not consistently significant and not always consistent in direction across all years, indicating there is a likely influence of year on playing video games by disability type. For example, when examined overall, people with anxiety play video games more than people with other types of disabilities ($\Phi=0.110$, $p<0.001$). That relationship, however, is present in the year-by-year analysis only for 2020 ($\Phi=0.215$, $p<0.001$). People with walking limitations report playing video games more than other disability groups in 2017 ($\Phi=0.125$, $p=0.042$) but fewer than other disability groups in 2020 ($\Phi=-0.340$, $p<0.001$).

Video Game Platforms

Of the respondents who played video games, 62.4% play on a console (e.g., Xbox, Nintendo), 57.9% play on a computer, and 68.4% play on a phone. To better understand the use of gaming platforms by respondents, we examined not only which platforms gamers play on as a dichotomy, we also examined the overlap of platform usage (Figure 4). Respondents who played video games most commonly played on phone, computers, and consoles (31.4%) followed by phone and computer (17.4%), console (14.2%), phone and console (13.8%), phone (10.4%), computer and console (7.2%), and computer (5.7%).

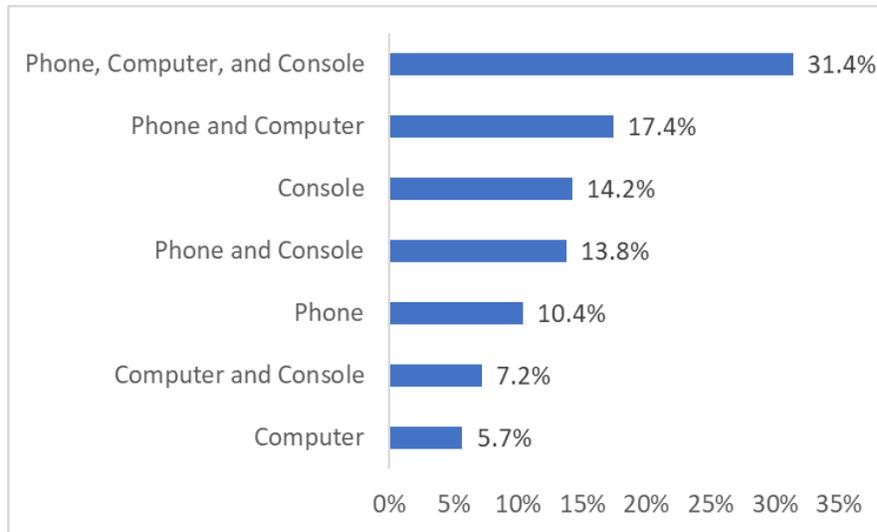


Fig. 3. Gaming Platforms Used by Respondents Who Play Video Games.

(Source: AURC, 2017-2021)

Video Game Playing and Demographic Measures

Males consistently identify as playing video games more than females. Overall, males significantly play games more than females ($\chi^2=11.630$, $p<0.001$). These differences were also significant in the analysis for 2018 ($\chi^2=10.171$, $p=0.001$) and 2019 ($\chi^2=7.397$, $p=0.007$) data, but not for other years. While there is variation in the trends among race and ethnic groups, the differences are only not significant for 2018 ($\chi^2=8.510$, $p=0.037$) and 2021 ($\chi^2=141.28$, $p<0.001$). African Americans report playing video games more often than other race and ethnicity groups for 3 of the 5 years for which data were collected: 56.30% in 2018, 87.50% in 2019, and 86.40% in 2021. For age groups, there were significant differences across all years combined ($c=74.650$, $p<0.001$) as well as in 2017 ($\chi^2=21.179$, $p<0.001$), 2019 ($\chi^2=15.793$, $p=0.003$), and 2020 ($\chi^2=8.510$, $p=0.037$)=30.331, $p<0.001$). Overall, older people report playing video games at a lower percent than younger people.

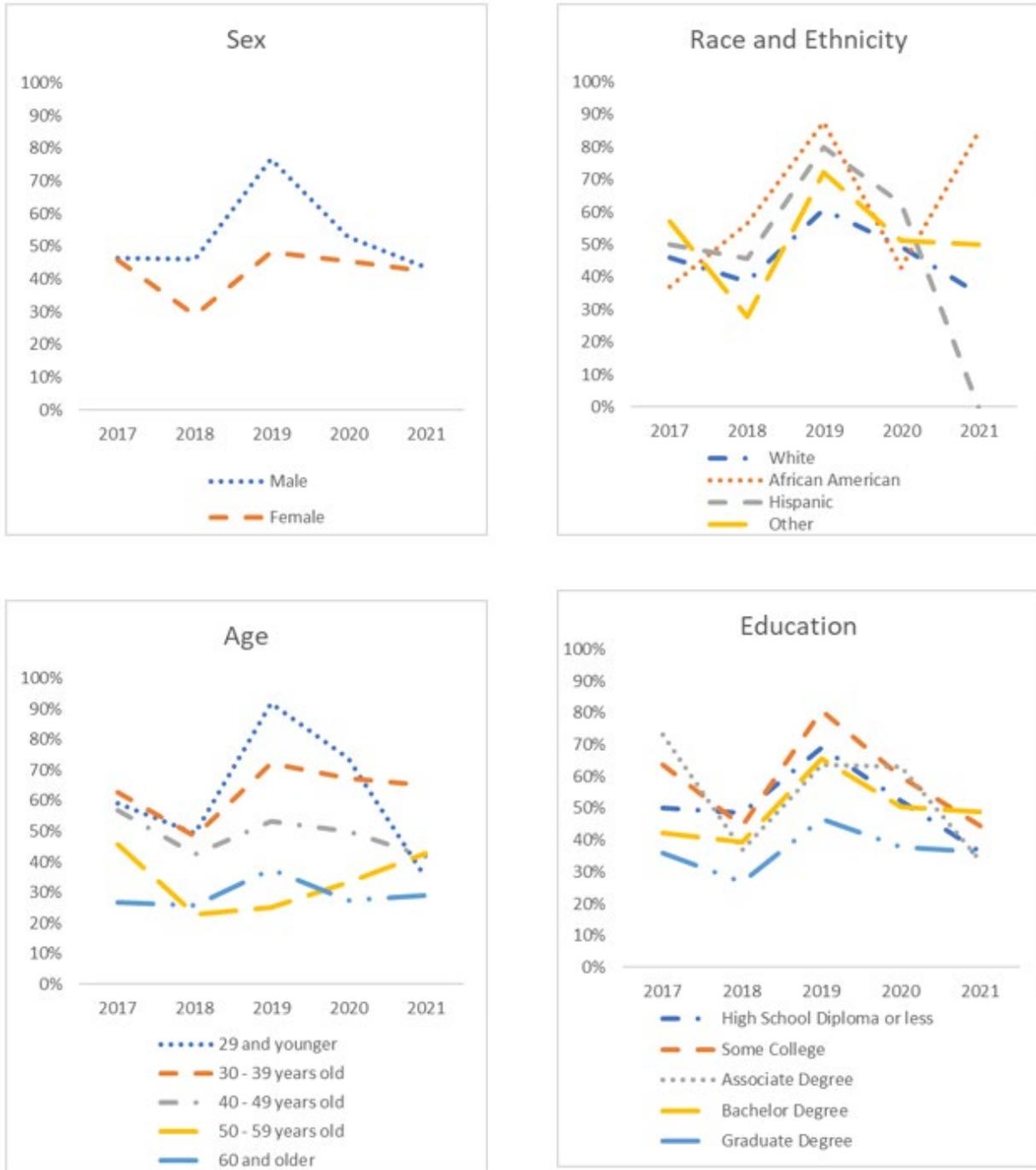


Fig. 4. Percent of People Who Play Video Games by Demographic Groups and Year.

(Source: AURC 2017-2021)

Discussion

This work can aid understanding of e-gaming among adults with disabilities over time. Nearly half (45.9%) of respondents reported playing video games. Males and younger adults with disabilities report playing video games less than females and older adults with disabilities. People with a graduate degree report playing video games less than people with lower levels of education. These demographic patterns reflect patterns of e-gaming participation in the general population. Variation in e-gaming participation by disability type requires additional inquiry to understand motivations, facilitators, and barriers to participation.

There is a notable amount of variability in gaming patterns for adults with disabilities. The percentage of respondents who played video games varied by year, with the highest percentage noted in 2019. Trends within disability and demographic categories were also heterogeneous when analyzed year by year. While variations in sampling probably contributed to some of this variability, the data suggests also that e-gaming activity may not be consistent or linear over time. The social and technological determinants of video-gaming activity over time should be investigated.

People with specific types of disabilities reported higher levels of gaming: anxiety, upper extremity limitations, as well as fatigue and limited stamina. These findings that individuals with upper extremity impairments and/or difficulty with stamina and fatigue have a higher likelihood of engaging in gaming is consistent with previous work (Thompson, et al. 157). They suggest that at least some disability groups are enjoying the social and personal benefits of gaming. The work of Tabacof and colleagues (1) found that the inclusion of individuals with SCI in eSports resulted in greater reported levels of social connectedness and feeling of enablement, which might explain higher levels of gaming for those with limited upper extremity use and stamina.

There is also a body of evidence of higher rates of gaming in those with anxiety. Multiple studies have demonstrated the positive effects of playing commercial video games for people with anxiety, including both prevention and reduction of anxiety symptoms (Kowal et al. 1).

Conversely, people with visual limitations are less likely to play video games. This could possibly be attributed to the relatively limited availability of accessibility features in mainstream video games for players who are blind or have very low vision. Some video games can be played by people with limited vision, including specialized audio games and fighting games like *Mortal Kombat* which rely on memorized input combinations rather than extensive navigation. Still, many popular games lack sufficient audio cues and other options to make them accessible for players who are blind or have low vision.

More gamers with disabilities reported gaming across all three primary categories of platforms (console, PC, mobile) than any other combination of platforms or any single platform. This suggests a need for developers to use a cross platform approach to improve accessibility of their products and increase inclusion of people with disabilities in mainstream gaming.

Year by year results should be interpreted cautiously due to factors that may have influenced the results of the yearly analysis. Convenience sampling was employed as results were obtained by analyzing the entry survey associated with the AURC database. The AURC conducts numerous studies each year, each with varying inclusion criteria. The substantive focus and number of studies completed each year can impact the characteristics – demographic breakdown, technology use (including video game playing), type of disability or functional limitation, etc. – of the full sample of individuals recruited to the database in that year. More in-depth qualitative research is needed to fully understand the patterns and preferences of disabled gamers. No clear predictable trends over time could be established by simple demographic

categories alone. Richer insights may be drawn from collecting additional data detailing the personal experiences of gamers with disabilities and how gaming has changed for users over time. It may be helpful to collect additional data on how changes in gaming software, hardware, peripherals, and the larger gaming industry may change the interaction experience and overall participation in gaming by people with disabilities.

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Learning with ADHD: A Review of Technologies and Strategies

Melissa Kumaresan¹, Lindsay McCardle², Sambhavi Chandrashekar², Ece Karakus², Colin Furness¹

University of Toronto¹, D2L Corporation²

melissa.kumaresan@mail.utoronto.ca, lindsay.mccardle@d2l.com,
sambhavi.chandrashekar@d2l.com, ece.karakus@d2l.com,
colin.furness@utoronto.ca

Abstract

As part of our continuing efforts to improve inclusion in teaching and learning, we examined cognitive needs in online learning, specifically relating to attention deficit hyperactivity disorder (ADHD). Through a narrative literature review and environmental scan, we analyzed current knowledge reported in ADHD research to understand its impact on learning for students diagnosed with ADHD and examined the interventions and strategies that support their executive function and focus needs, specifically in an online learning context. We used the lens of a Technology–Content–Pedagogy (TCP) framework to organize and interpret the strategies for supporting students with ADHD in online learning.

Keywords

Cognitive disability, attention deficit hyperactivity, executive function, behavioural intervention, online learning, adaptive strategy.

Introduction

Article 24 of the United Nation's Convention on the Rights of Persons with Disabilities (UNCRPD) recognizes education as a fundamental right of persons with disabilities. Following the onset of the COVID-19 pandemic, online learning has received increasing focus. For learning to be inclusive, we need to find new ways to accommodate students with disabilities online (Gin et al. 12). Of the different types of disabilities, cognitive disabilities are the least understood outside of medical or specialized environments (Blotnicky-Gallant et al. 16).

Attention deficit hyperactivity disorder (ADHD) is one of the most common cognitive disabilities, estimated to affect 8–10% of children and 5–6% of adults worldwide (Ng *et al.*, 123). Before reaching 18 years, three girls are diagnosed with ADHD for every six boys diagnosed (Dalsgaard et al.). By the age of 25, an estimated 15% of people diagnosed with ADHD as children still have a full range of symptoms, and 65% still have some symptoms that affect their daily lives. ADHD remains undiagnosed in many individuals. ADHD is marked by an ongoing pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, which could impact learning (National Institute of Mental Health).

The accessibility team from [D2L Corporation](#), a global learning platform company based in Ontario, Canada, collaborated with the University of Toronto on a 4-month research project to explore cognitive needs in online learning. Due to the short duration, we focused on ADHD as it is highly prevalent and impacts students' ability to focus during class, engage in learning, complete tasks, and keep up with assessments. We explored the nature and impact of ADHD and the interventions used to manage it. Based on that, we identified a set of teaching and learning strategies for educators focused on technology, content, and pedagogy to support students with ADHD in online learning.

Research Objectives and Questions

Our research objectives were (a) to examine the prevalence and characteristics of ADHD and the resulting challenges in the context of learning, and (b) identify mechanisms for educators to support online students with ADHD. Our study was driven by two research questions:

1. What is the impact of ADHD on the experience of learning?
2. What are the strategies and tools that help manage online learning with ADHD?

Methods

We conducted a narrative literature review (Rumrill Jr and Fitzgerald 166) using the following databases: PsycInfo, PubMed, Scopus, CNAHL, Cochrane Collaboration for systematic reviews, ERIC, and Web of Science. We used combinations of the following search terms: ADHD, ADD, Attention-Deficit Hyperactivity Disorder, online learning, distance learning, blended learning, intervention, LMS, learning management system, executive function, behavioural, technology, assistive technology, strategy, accessibility. We initially identified abstracts of 48 original research papers and meta-analyses published in English between Jan 1, 1990, and June 30, 2021, then selected 30 for in-depth review. Of these, we identified 12 papers (including 4 meta-analyses) as key to our analysis as they contained information that matched key topics connecting ADHD to learning. In addition, we conducted an environmental scan (Choo 29) using Google search with the same terms as for the literature review. We accessed 35 websites and found 17 pages with relevant information that were included in the analysis. We summarized key findings from each study and then identified patterns using qualitative content analysis techniques by tagging and organizing those findings (Berg 304). We used an online learning framework described in the next section to interpret the findings.

TCP Framework for Online Learning

Based on Chandrashekar and Wang's (2019) Platform-Process-Content framework and Koehler and Mishra's (2009) Technological-Pedagogical-Content-Knowledge model, we built the Technology–Content–Pedagogy (TCP) framework (see Figure 1).

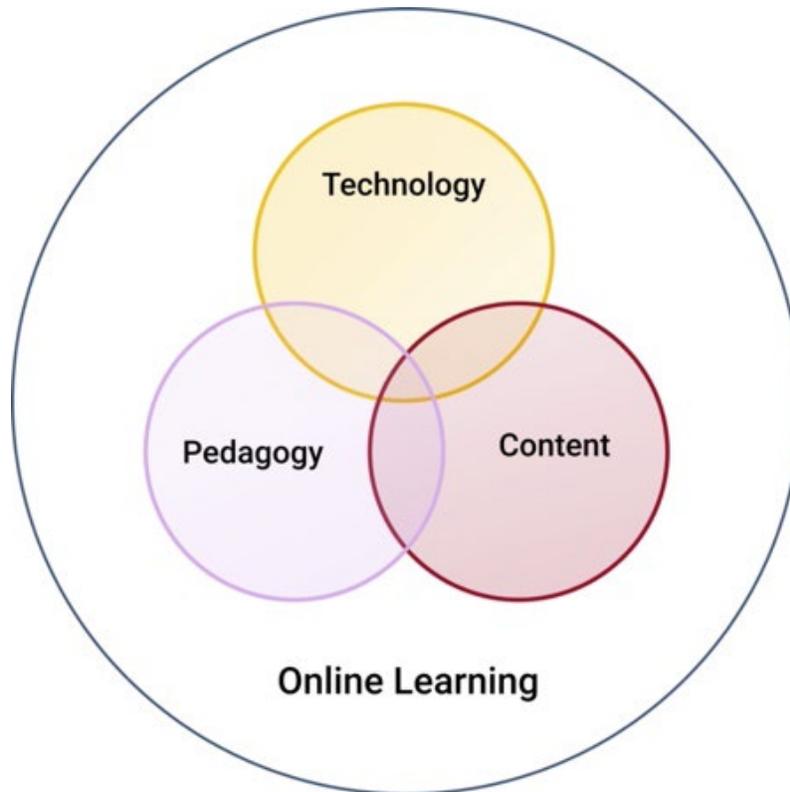


Fig 1: Technology–Content–Pedagogy (TCP) framework

This framework comprises three layers within the online learning space. First, the *technology* layer, relating to accessing and interacting with the online learning platform and all associated tools. Second, the *content* layer, relating to producing and consuming accessible learning and assessment content. Third, the *pedagogy* layer, relating to facilitating inclusive pedagogical practices that support Universal Design for Learning (UDL) principles. UDL is a framework to improve and optimize teaching and learning for everyone (CAST). The three layers form the online learning stack and are meant to be used together; each layer is necessary

but not sufficient for an optimally inclusive online learning experience. Ensuring accessibility in each layer is necessary to ensure ‘full-stack accessibility’ in online learning. We used this TCP framework to organize and interpret our findings.

Findings

About ADHD

ADHD is a neurodevelopmental disorder that typically manifests early in development (Khan et al. 2). Parts of the ADHD brain develop more slowly than a neurotypical brain, resulting in a spectrum of ADHD conditions from mild to severe (Novotney). The Diagnostic and Statistical Manual of Mental Disorders (DSM) classifies ADHD into three types, marked by (1) inattention, (2) hyperactivity/impulsivity, and (3) a combination of both. Combined type is the most common form of ADHD, while hyperactive/impulsive is the least common.

In most cases, ADHD is comorbid with other learning or psychiatric conditions, making it difficult to differentiate ADHD (Rommelse et al. 282). Many students with significant cognitive disabilities might also have co-occurring motor and sensory impairments that impact their ability to learn (Erickson and Geist 87). A diagnosis of ADHD is highly correlated with lower levels of academic success, including lower rates of high school and college completion, and those with ADHD symptoms tend to experience behavioural difficulties and obstacles in their work and personal lives (Hoben & Hesson 40). ADHD is marked by a delay in the normal developmental unfolding of cortical executive function.

Executive function is the ability to perform goal-directed tasks using organizational skills and the ability to plan, sustain attention, and control impulsivity (Rigoni et al. 875). All persons with ADHD, regardless of subtype or severity, are characterized by an impairment of executive function (Brown 38). Students with ADHD perform more poorly on measures of executive

function than those without ADHD (Brown 37). This could impact their school performance, among other things. However, they can excel in academic settings if supported with appropriate interventions (Brown 39; Levy and Hay 43).

Interventions Used with ADHD

There are two primary forms of interventions used to manage ADHD: medical, and behavioural. Traditionally, stimulant medication has been the main intervention for ADHD, and it still plays a major part in managing the condition with or without other forms of intervention. Over two-thirds of children and teens who have been diagnosed with ADHD take medication to manage it (CDC). But medication is found to be minimally effective in increasing academic achievement or improving peer relationships (Chronis, Jones, & Raggi 6), which tend to respond better to behavioural interventions (Clay 45).

Behavioural intervention from parents and teachers is another form of support for ADHD. While most of such interventions require physical co-presence, it is possible to use them in an online context with synchronous meeting tools and pedagogical processes (Andersen and Sorensen). A combination of medical and behavioural interventions is found to be optimally effective (Barbaresi et al. S36; Wolraich et al. 1740).

Strategies for Teaching and Learning

Several strategies have been reported for supporting learning with ADHD, some of them for use by teachers as behavioural interventions and some of them by students as measures for self-monitoring or self-regulation. We examined the strategies through the TCP framework lens. Table 1 lists the strategies under technology, content, or pedagogy based on which layer each of the strategies is predominantly associated. These are each discussed further below.

Table 1: Online learning strategies for ADHD

| Technology | Content | Pedagogy |
|---|---|---|
| Accessible authoring tools with dictation support | Structure & overview templates for creating content | Frequent feedback and positive attention |
| Assistive tools like text-to-speech with highlighting | Assessment artifact creation and submission templates | Multimodal options for task completion |
| Speech-to-text programs to help with writing | Templates for comprehension of content | Motivation through awards and game-based learning |
| Self-monitoring aids | Templates for communication | Peer tutoring |
| Reminder programs and intelligent agents | | Shielding from distractions to improve focus |
| Virtual reality | | Multimodal communication |
| | | Information chunking |
| | | Means for collaboration and knowledge-building |

Technologies used most in special education are computer-based and web-based (Liu, Wu, and Chen 3620). The options to support students with ADHD through technology are ever-increasing. However, finding the right tool to address a student's specific needs could get challenging given the variance in the characteristics of ADHD across different students (Mosher et al., 2020, p. 2). These characteristics may affect the way each of them responds to specific technologies.

Digital technologies offer possibilities for multimodal expression/communication amongst students and teachers. Some technologies focus on aiding students with ADHD for production and dissemination of information such as accessible authoring tools with dictation support or speech-to-text programs, and accessible information consumption with text-to-speech and highlighting tools (Sorensen and Andersen 49). Assistive tools for reading difficulty use various combinations of instructional strategies to grab learners' attention and focus (Thapliyal & Ahuja, 2021, p. 2). Mobile devices such as iPad and iPhone allow students to store learning material including textbooks in apps like the iBooks. This technology allows the use of strategies like highlighting and note-taking for boosting reading comprehension, which are critical for students with low attention.

Some technological tools help students with self-monitoring their progress with learning or task completion (Blotnick-Gallant et al. 5). Reminder systems and intelligent agents help with remembering recurring tasks such as completing assignments for self-regulation (Rigoni et al., 2020, p. 882). Teachers use these strategies in their classrooms, to provide their students with ADHD with optimal interventions to enhance both their learning and behavioural functioning at school (Blotnick-Gallant et al. 16). Virtual reality environments can help foster rapid interaction and real-time feedback, keep students active by performing activities on their own or in collaboration with other students, and allow teachers to have tools to measure student performance and provide feedback (Cardona-Reyes et al. 3787).

Well-designed technology strategies have the potential to provide visibility to what students can do and what they know. When things go well, the self-esteem of the student improves; when they do not, there is an opportunity for teacher insight into what to improve to provide adequate support (Sorensen and Andersen 57).

In terms of content, both consistency and structure are important for students with ADHD (Sorensen 50). Teachers must focus on maintaining consistency in their communication and learning material. An effective strategy for this is to provide templates with appropriate structure to the students for creating content, artifacts and submissions for assessment, note-taking for comprehension, or communicating (Cinquin 165).

It could get difficult for students with ADHD to simultaneously work on content and structure. Templates serve to scaffold their learning process. Writing templates can offer the student a frame for the task at hand. These could be created by teachers using popular software such as MS PowerPoint or MS Word.

From a pedagogy perspective, several strategies are reported to promote consumption and production of information by the learner as well as engagement with the learning process. To make consumption of learning material easier, teachers are encouraged to use multi-modal representation and communication (Sorensen 53). This helps with providing choices to the students to engage through the mode that best suits them. Providing students flexibility for task completion such as allowing multiple modes for task completion (oral as well as written) facilitates submissions. Communication can be facilitated through building in means for collaboration and knowledge-building (Sorensen & Andersen 46).

Engagement with the learning material is enhanced through information chunking, which refers to dividing content or assignments into smaller parts or modifying them to reduce the length of tasks to enable students to complete each piece without losing their attention. Research indicates that frequent feedback, positive attention, and rewards motivate students with ADHD to remain engaged and respond better (Rigoni et al., 2020, p. 882). Awards and game-based

learning may also help with this. However, the environment must be constructed to shield students from distraction (Sorensen 53).

Peer tutoring is another useful pedagogical strategy that draws upon other students. Peer tutors are sometimes enrolled into the same course as the student. They help students interpret the course material and assist them in understanding what is expected of them in that course. How the peer tutor works with the student to help them be successful in the course depends on the level of accommodation that student needs (Blotnicky-Gallant et al. 15).

Some strategies could require additional preparation time, such as providing advanced organizers for content and customizing learning materials for the student. When teachers use these strategies in their classrooms, their students with ADHD are provided with optimal interventions that may enhance both their learning and behavioural functioning at school (Blotnicky-Gallant et al. 16). It is important, therefore, to ensure that teachers have appropriate training and support for the time required to implement such evidence-based strategies.

Discussion

Technology emerged as a strong factor in providing behavioural interventions to students with ADHD in online learning both directly as a modality-interchange tool and indirectly as a vehicle for supporting content creation and consumption using templates. The pedagogical processes that support students with ADHD align with UDL principles (REF), enabling multiple modes of content and communication, and multiple means of action, expression, and engagement. This suggests that the practice of inclusive education based on UDL principles would greatly benefit students with ADHD in the class, both for students who declared their disability and for those who did not.

Regarding the usefulness of the TCP framework for categorizing the strategies, it is evident from Table 1 that some strategies based on mindfulness (Xue et al. 1), humour (Erdoğdu & Çakıroğlu 3), and exercise (Ng et al. 124) that have a positive effect on learning do not fit into it directly. Humour could be applied to some extent to pedagogy, especially to teacher-to-student and student-to-student communication. Erdoğdu and Çakıroğlu (3) posit three dimensions of student engagement: behavioural, emotional, and cognitive. When humour is infused into a learning activity, it creates a positive emotional atmosphere. This can increase motivation and engagement. Thus, using humour brings students and teachers closer (Mayer & Estrella, 14).

The three layers, technology, content, and pedagogy, also intersect with one another (see Fig 1). This affords us to consider if any of the strategies might lie in the cusp of two layers, or at the intersection of all three layers. Considering the case of a text reader that highlights and reads out text loud. While this is a technology, it also improves engagement. It is arguable whether the strategy that engages the student using a text reader to consume learning content would fall under technology, or at the intersection of technology and pedagogy or at the intersection of all three layers in the centre. We would argue that it falls only under technology as the increased engagement is not on account of anything the teacher did or designed into the content but because of the technology. More work needs to be done to examine strategies from this angle.

Further, much more work is needed to examine the effectiveness of strategies and combinations of strategies. Many of the strategies considered in the reviewed literature were suggested based on findings (e.g., Rigoni et al. 881) or reported based on teacher use (Blotnicky-Gallant et al. 9). Other strategies or approaches were explored in research, but effectiveness of the strategies was not measured (e.g., Sorensen & Andersen, 47-48). Given the range of experience for learners with ADHD, it is important evidence for strategy effectiveness includes

studies both with high internal validity and those with high external validity. A combination of between group and within-subject designs is important to provide evidence for strategy effectiveness in the population of learners with ADHD (Fabiano et al. 130).

Conclusions

Through this research, we derived insights about the accessibility needs of students with ADHD and ways to support them in an online learning environment. We drew our data for this research only from secondary research and did not gather empirical data. Conducting primary research with students with a range of cognitive needs is an important future goal. It would also be useful to examine other cognitive conditions such as learning disabilities, autism spectrum, and developmental disabilities. Supporting students with cognitive disabilities who require specialized attention from teachers and specialists during these pandemic times is vital to ensure they are not left behind.

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People with Disabilities Online Engagement During COVID-19

Raeda Anderson^{1,2}, George Usmanov^{1,2}, Nicole Thompson¹, John Morris¹
The Shepherd Center¹, Department of Sociology at Georgia State
University²

Raeda.Anderson@shepherd.org, gusmanov1@gsu.edu,
Nicole.Thompson@shepherd.org, John.Morris@shepherd.org,

Abstract

The COVID-19 pandemic led to a rapid increase of online engagement. High levels of online engagement continue across different contexts including ordering food and meals, telehealth, and working remotely in the United States. This study examines these behaviors for adults with disabilities online engagement during the COVID-19 pandemic via analysis of data from a self-administered online survey by adults in the US with disabilities (N=409) on food access, school and work, health, and social activities. Online food access was common as 53.5% ordered groceries and 55.3% ordered meals. Of students, 96.0% attended class online. Of respondents who are currently working, 82.5% attended a meeting online. 26.2% of respondents attended an online fitness class and 60% had a telehealth appointment. The most common online social event was attending a virtual party or social gathering (55.3%), followed by streaming a concert or a play (38.9%), and attending a religious event (36.2%). Online engagement during the COVID-19 pandemic varies for people with different types of disabilities. The most notable differences existing in telehealth appointments. People with learning disabilities, anxiety, difficulty speaking, upper extremity limitations were more likely to have completed more telehealth appointments than people with other types of disabilities.

Keywords

Online engagement, COVID-19 pandemic, disabilities, online engagement during COVID-19

Introduction

The COVID-19 pandemic led to a rapid increase of online engagement. High levels of online engagement continue across different contexts including ordering food and meals, telehealth, and working remotely in the United States (Dou et al. 212; Wosik et al. 957). The shift to virtual forms of communication and access to resources can reduce barriers for certain groups while creating new barriers for others (Annaswamy et al. 2). Negative effects to the shift for online engagement are not equal across all populations, especially when considering how people with different types of disabilities engage online (Anderson et al. 146; Jesus et al. 7). The rapid shift to online engagement has revealed ongoing barriers for people with different types of disabilities. This study examines how people with different types of disabilities engage in different online activities: food access, school, work, health, and social events.

People with different types of disabilities engage with technology in various manners. Recent studies report that people with different types of disabilities engagement in the community is largely limited due to the need for physical distancing (Annaswamy et al. 1; Gin et al. 7). Social interaction is an important buffer for people with disabilities health and is necessary for maintaining mental and physical health (Tough et al. 15; Warner et al. 1423). A recent study shows that community engagement, such as attending church or social gatherings, are the most limited during the COVID-19 pandemic (Koon et al. 3). For people with disabilities communicating with family and friends continues through virtual platforms like Zoom or Skype, however, little is understood how people with different types of disabilities are engaging with their community during COVID-19 (Anderson et al. 150, Landes et al. 3; Thompson et al. 163). The importance of examining how people with different types of disability are engaging with

their communities, including social events, work, and school, will help to develop strategies for limiting social isolation.

Access to healthcare continues to change during the COVID-19 pandemic for people with different types of disabilities. Healthcare, including communicating with medical staff and therapeutic appointments, is an important factor in reducing adverse health events for people with disabilities (Okoro et al. 882). Telehealth, or telemedicine, has become the primary method to communicate health problems and performing health assessments (Okoro et al. 883). People with different types of disabilities have various needs, and thus, telemedicine is not equally suited for all. For example, dexterity assessment for people with upper extremity limitations or cognitive assessments for people with traumatic brain injuries would be challenging, if not impossible, to do effectively over telehealth. Understanding the access to healthcare across people with different types of disabilities is important for maintaining the diversity of care necessary for all.

Accessing food and groceries has rapidly changed during the COVID-19 pandemic. Online ordering services for meals and/or groceries has become important for people with disabilities accessing food. Studies consistently show that food access is important to maintaining health, especially during the COVID-19 pandemic (Annaswamy et al. 2; Kinsey et al. 334; Niles et al. 5). There is a necessity to explore if patterns exist across people with different types of disabilities' access to food via virtual formats to address previously unknown disparities. The goal of this study is to examine the online activities including food access, school, work, health, and social events that people with different types of disabilities engage in.

Methods

Data are from the *Technology, the Pandemic, and Social Interaction* survey using a convenience sample of the Consumer Advisory Network (CAN) and Accessibility User Research Collective (AURC). Participants completed the self-administered online questionnaire during April and May of 2021. All current members of the CAN and AURC (1,106) were sent the survey and 36.98% participated in the survey (N=409). The AURC and CAN are both managed by researchers at Rehabilitation Engineering Research Center for Community Living, Health and Function (LiveWell RERC) at Shepherd Center, a rehabilitation hospital in Atlanta, Georgia. CAN and AURC members are U.S.-based national networks of people with disabilities that are 18 years or older and report having a disability or functional limitation.

Disability is measured via a series of dichotomous indicators of ‘yes’ and ‘no’. Learning disability, anxiety, and difficulty speaking disability measures were based on responses to the question “*Do you have any difficulty with the following challenges or limitations? (check all that apply)*” and response options of “*Difficulty learning or a learning disability*” for learning disability, “*Frequent worrying, nervousness, or anxiety*” for anxiety, and “*Difficulty speaking so people can understand you*” for difficulty speaking. Dichotomous indicators for blind and deaf were generated based on responses to “*Do you have any of the following vision or hearing limitations? (check all that apply)*” with “*Blind (without usable vision or completely blind)*” and “*Deaf (unable to hear)*”. Walking as well as fatigue and limited stamina measures were generated from responses to “*Do you have any of the following physical challenges or limitations? (check all that apply)*” with “*Difficulty walking or climbing stairs*” for walking and “*Difficulty with fatigue/limited stamina*” for fatigue and limited stamina. Upper extremity limitations is measured by combining responses to “*Do you have any of the following physical*

challenges or limitations? (check all that apply)” for “*Difficulty using your arms*” and “*Difficulty using your hands and fingers*”. If respondents selected either or both, they were coded as having an upper extremity limitation.

Demographic measures include gender, student status, employment status, race, college graduate, and age. All demographic measures except age are measured as dichotomous indicators. Gender was measured by an indicator “*What is your gender?*” which were recoded from “*Male*”, “*Female*”, and “*Other (please specify)*” to “*Female*” and “*Male*” where “*Other (please specify)*” were dropped due to very small numbers of respondents who responded “*Other (please specify)*”. Student was measured by a dichotomous indicator generated from “*Student (full-time)*” and/or “*Student (part-time)*” to the question “*What is your occupation? (check all that apply)*”. Similarly, employed was measured by a dichotomous indicator via “*Employed (full-time)*” and/or “*Employed (part-time)*” to the question “*What is your occupation? (check all that apply)*”. White is measured by “*What is your race/ethnicity? (check all that apply)*” and respondents who selected “*White or Caucasian*”. College graduate is generated by collapsing “*Associate’s degree*”, “*Bachelor’s degree*”, “*Master’s degree*”, and “*Doctoral degree*” to “*What is the highest level of education you have completed?*”. Age is generated by subtracting responses from “*What year were you born?*” from 2021 to calculate age.

Online engagement is measured via dichotomous indicators generated from a check all that apply question “*Have you done any of the following due to COVID-19? (Check all that apply)*”. Each response option aligns with an area of online engagement: food access, school, work, health, and social. For food access, dichotomous indicators were generated for ordered groceries based on the response to “*ordered groceries online or through an app*” and ordered meals based on the response to “*ordered food online or through an app*”. School and work

measures were generated based on the responses to “*attended a class for school online*” for school and “*attended a meeting for work online*” or work. Health measures were generated based on responses to “*had a telehealth appointment*” for telehealth appointment and “*participated in an online fitness class and/or did an online workout video at home*” for online fitness class. Lastly, social measures were generated from “*had a virtual party of social gathering online*” for virtual party or social gathering, “*watched a concert or play that was live streamed*” for streamed a concert or play, and “*attended a religious event online*” for attended a religious event.

Analysis includes descriptive statistics and Φ (phi) to test the relationship between pairs of dichotomous indicators (Fleiss et al. 237). Statistical significance is denoted as a p value less than 0.05 (Frankfort-Nachmias and Leon-Guerrero 358). Pairwise deletion was used for case-by-case analysis (Weaver and Maxell 150).

Analysis

Table 1. Disability and Demographic Summary Statistics (N=409). Data: Technology, the Pandemic, and Social Interaction.

| Disability or Demographic | Percent | n |
|---|----------------|----------|
| Disability: Learning disability | 21.3% | 87 |
| Disability: Anxiety | 23.5% | 96 |
| Disability: Difficulty speaking | 9.0% | 37 |
| Disability: Upper extremity limitations | 18.6% | 76 |
| Disability: Walking | 24.4% | 100 |
| Disability: Fatigue and limited stamina | 19.6% | 80 |
| Disability: Blind | 34.2% | 180 |
| Disability: Deaf | 3.4% | 14 |
| Demographics: Female | 53.6% | 188 |
| Demographics: Student | 6.8% | 28 |
| Demographics: Employed | 47.4% | 194 |

| Disability or Demographic | Percent | n |
|----------------------------------|----------------|----------|
| Demographics: White | 75.0% | 270 |
| Demographics: College Graduate | 69.9% | 248 |

| Demographic | Mean | SD |
|----------------------------------|-------------|-----------|
| Demographics: Age (range: 20-85) | 47.2 | 14.3 |

Table 1 includes the descriptive statistics for demographic variables. The most common disability experienced by respondents is blindness (34.2%), followed by walking limitations (24.4%), anxiety (23.5%), learning disability (21.3%), fatigue and limited stamina (19.6%), upper extremity limitations (18.6%), difficulty speaking (9.0%), and deafness (3.4%). Most respondents are female (53.6%), white (75.0%), and college graduates (69.9%) with less than half employed (47.4%) and some students (6.8%).

Table 2. Online Engagement.

Data: Technology, the Pandemic, and Social Interaction.

| Online Engagement | % | n |
|---|----------|----------|
| Food Access: Ordered groceries | 53.5% | 219 |
| Food Access: Ordered meals | 55.3% | 226 |
| School: Attended a class | 96.4% | 27 |
| Work: Attended a meeting | 82.5% | 160 |
| Health: Online fitness class | 26.2% | 107 |
| Health: Telehealth appointment | 60.4% | 247 |
| Social: Virtual party or social gathering | 55.3% | 226 |
| Social: Streamed a concert or a play | 38.9% | 159 |
| Social: Attended a religious event | 36.2% | 148 |

Table 2 contains the descriptive statistics for online engagement. When accessing food online, 53.5% ordered groceries and 55.3% ordered meals. Of students, 96.4% attended class

online. Of those currently working, 82.5% attended a meeting online. 26.2% of respondents attended an online fitness class and 60.4% had a telehealth appointment. The most common online social event was attending a virtual party or social gathering (55.3%), followed by streaming a concert or a play (38.9%), and attending a religious event (36.2%).

Table 3. Analysis of Food Access by Disability Type.

Data: Technology, the Pandemic, and Social Interaction.

| Activity | Disability Group | Φ | p-value | Significance |
|-------------------|-----------------------------|--------|---------|--------------|
| Ordered Groceries | Learning disability | 0.530 | 0.285 | |
| Ordered Groceries | Anxiety | 0.530 | 0.282 | |
| Ordered Groceries | Difficulty speaking | -0.014 | 0.009 | p<0.01 |
| Ordered Groceries | Upper extremity limitations | 0.130 | 0.085 | |
| Ordered Groceries | Walking limitations | 0.085 | 0.085 | |
| Ordered Groceries | Fatigue and limited stamina | 0.064 | 0.197 | |
| Ordered Groceries | Blind | 0.217 | <0.001 | p<0.001 |
| Ordered Groceries | Deaf | -0.040 | 0.415 | |
| Ordered Meals | Learning disability | 0.047 | 0.340 | |
| Ordered Meals | Anxiety | 0.069 | 0.162 | |
| Ordered Meals | Difficulty speaking | -0.025 | 0.616 | |
| Ordered Meals | Upper extremity limitations | -0.063 | 0.201 | |
| Ordered Meals | Walking limitations | 0.054 | 0.272 | |
| Ordered Meals | Fatigue and limited stamina | 0.022 | 0.653 | |
| Ordered Meals | Blind | 0.204 | <0.001 | p<0.001 |
| Ordered Meals | Deaf | 0.088 | 0.074 | |

More respondents with difficulty speaking had ordered groceries online compared to respondents with other disabilities ($\Phi=0.014$, p<0.01). More blind respondents had ordered groceries ($\Phi=0.217$, p<.001) and meals ($\Phi=0.204$, p<.001) online compared to respondents who are not blind.

Table 4. Analysis of School and Work by Disability Type.

Attended a class: only students in analysis. No deaf respondents were students; Attended a meeting: only employed respondents in analysis; Data: Technology, the Pandemic, and Social

Interaction

| Activity | Disability Group | Φ | p-value | Significance |
|--------------------|-----------------------------|--------|---------|--------------|
| Attended a class | Learning disability | -0.179 | 0.343 | |
| Attended a class | Anxiety | -0.222 | 0.240 | |
| Attended a class | Difficulty speaking | -0.413 | 0.029 | p<0.05 |
| Attended a class | Upper extremity limitations | -0.304 | 0.107 | |
| Attended a class | Walking limitations | -0.304 | 0.107 | |
| Attended a class | Fatigue and limited stamina | -0.333 | 0.078 | |
| Attended a class | Blind | 0.143 | 0.448 | |
| Attended a class | Deaf | - | - | |
| Attended a meeting | Learning disability | -0.002 | 0.979 | |
| Attended a meeting | Anxiety | 0.157 | 0.029 | p<0.05 |
| Attended a meeting | Difficulty speaking | -0.058 | 0.423 | |
| Attended a meeting | Upper extremity limitations | 0.005 | 0.948 | |
| Attended a meeting | Walking limitations | 0.086 | 0.232 | |
| Attended a meeting | Fatigue and limited stamina | 0.125 | 0.082 | |
| Attended a meeting | Blind | 0.011 | 0.875 | |
| Attended a meeting | Deaf | -0.092 | 0.201 | |

Table 4 presents results for disability status and online school and work. Fewer respondents with difficulty speaking who are also students reported attending class online ($\Phi=-0.413, p<0.05$). Respondents who are working and have anxiety were more likely to have attend a meeting online ($\Phi=0.157, p<0.05$).

Table 5. Online Social Activities by Disability Type.

Data: Technology, the Pandemic, and Social Interaction

| Activity | Disability Group | Φ | p-value | Significance |
|------------------------|-----------------------------|--------|---------|--------------|
| Online fitness class | Learning disability | 0.139 | 0.005 | p<0.01 |
| Online fitness class | Anxiety | 0.143 | 0.004 | p<0.01 |
| Online fitness class | Difficulty speaking | 0.103 | 0.037 | p<0.05 |
| Online fitness class | Upper extremity limitations | 0.016 | 0.747 | |
| Online fitness class | Walking limitations | 0.024 | 0.630 | |
| Online fitness class | Fatigue and limited stamina | 0.057 | 0.248 | |
| Online fitness class | Blind | 0.016 | 0.745 | |
| Online fitness class | Deaf | -0.020 | 0.682 | |
| Telehealth appointment | Learning disability | 0.201 | <0.001 | p<0.001 |
| Telehealth appointment | Anxiety | 0.260 | <0.001 | p<0.001 |
| Telehealth appointment | Difficulty speaking | 0.099 | 0.046 | p<0.05 |
| Telehealth appointment | Upper extremity limitations | 0.258 | <0.001 | p<0.001 |
| Telehealth appointment | Walking limitations | 0.275 | <0.001 | p<0.001 |
| Telehealth appointment | Fatigue and limited stamina | -0.027 | <0.001 | p<0.001 |
| Telehealth appointment | Blind | -0.027 | 0.587 | |
| Telehealth appointment | Deaf | -0.067 | 0.172 | |

Table 5 presents the findings between the relationship of disability type and health activities. Respondents with a learning disability ($\Phi=0.139$, $p<0.01$), anxiety ($\Phi=0.143$, $p<0.01$), or difficulty speaking ($\Phi=0.103$, $p<0.05$) were more likely to have attended an online fitness class. Respondents with a learning disability ($\Phi=0.201$, $p<0.001$), anxiety ($\Phi=0.260$, $p<0.001$), difficulty speaking ($\Phi=0.099$, $p<0.05$), upper extremity limitations ($\Phi=0.258$, $p<0.001$), walking limitations ($\Phi=0.275$, $p<0.001$), and fatigue and limited stamina ($\Phi=0.299$, $p<0.001$) were more likely to have had a telehealth appointment.

Table 6. Analysis of Online Social Activities by Disability Type.

Data: Technology, the Pandemic, and Social Interaction.

| Activity | Disability Group | Φ | p-value | Significance |
|-----------------------------------|-----------------------------|--------|---------|--------------|
| Virtual party or social gathering | Learning disability | 0.047 | 0.340 | |
| Virtual party or social gathering | Anxiety | -0.001 | 0.991 | |
| Virtual party or social gathering | Difficulty speaking | 0.027 | 0.590 | |
| Virtual party or social gathering | Upper extremity limitations | 0.063 | 0.201 | |
| Virtual party or social gathering | Walking limitations | -0.003 | 0.953 | |
| Virtual party or social gathering | Fatigue and limited stamina | -0.052 | 0.292 | |
| Virtual party or social gathering | Blind | 0.152 | 0.002 | p<0.01 |
| Virtual party or social gathering | Deaf | 0.034 | 0.489 | |
| Streamed a concert or a play | Learning disability | 0.002 | 0.965 | |
| Streamed a concert or a play | Anxiety | 0.008 | 0.871 | |
| Streamed a concert or a play | Difficulty speaking | -0.024 | 0.625 | |
| Streamed a concert or a play | Upper extremity limitations | -0.070 | 0.155 | |
| Streamed a concert or a play | Walking limitations | 0.013 | 0.791 | |
| Streamed a concert or a play | Fatigue and limited stamina | 0.011 | 0.818 | |
| Streamed a concert or a play | Blind | 0.165 | 0.001 | p<0.01 |
| Streamed a concert or a play | Deaf | -0.095 | 0.055 | |
| Attended a religious event | Learning disability | -0.043 | 0.381 | |
| Attended a religious event | Anxiety | -0.021 | 0.673 | |
| Attended a religious event | Difficulty speaking | -0.007 | 0.889 | |
| Attended a religious event | Upper extremity limitations | 0.137 | 0.005 | p<0.01 |
| Attended a religious event | Walking limitations | 0.081 | 0.103 | |
| Attended a religious event | Fatigue and limited stamina | 0.065 | 0.190 | |
| Attended a religious event | Blind | 0.079 | 0.111 | |
| Attended a religious event | Deaf | -0.002 | 0.970 | |

Table 5 contains the results on the relationship between disability types and online social activities. Blind respondents were more likely to have attended a virtual party or social gathering ($\Phi=0.152$, $p<0.01$) and streamed a concert or a play ($\Phi=0.165$, $p<0.01$). Respondents with upper

extremity limitations were more likely to have attended online religious events ($\Phi=0.137$, $p<0.01$).

Conclusions

People with disabilities have a high level of online engagement. For food access, over half have ordered groceries online (53.5%) and ordered meals online (55.3%). For those who are students, nearly all (96.4%) have attended a class online due to COVID-19. Similarly, most who work have attended a meeting online related to their employment (82.5%). In relation to health, about a quarter of adults with disabilities completed an online fitness class (26.2%) and over half have had a telehealth appointment (60.4%). Social events are also commonly occurring online including virtual parties and social gatherings (55.3%), streaming live concerts and/or plays (38.9%) and attending religious events (36.2%).

These trends are not homogenous across disability groups. Online engagement during the COVID-19 pandemic varies for people with different types of disabilities. All overarching categories have significant results with the most notable differences existing in telehealth appointments. People with learning disabilities, anxiety, difficulty speaking, or upper extremity limitations have completed more telehealth appointments than people with fatigue and limited stamina.

To that end, people with disabilities are not uniform in how they engage in online activities and future research must consider the various challenges that people with disability encounter with online engagement. It is crucial to understand the patterns of online engagement among people with disabilities to develop strategies for access to communication resources. These finding should be deeply considered when developing online platforms for food access, school, work, social events, as well as healthcare.

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Secure Color Combinations of Stairs for Senior Citizens

Hiroyuki Nakamura
Shibaura Institute of Technology
nkmr@shibaura-it.ac.jp

Abstract

This study aims to promote safety in using stairs in public places among an aging population. In this study, the author focuses on how tread and nosing (an edge of a tread) of each step on a staircase can be painted in colors of greater visibility for older adults who experience cataracts or age-related yellowing of the lens of their eyes. The author investigated the effects of ambient light on the color combination of stairs in public spaces where color guidelines strongly recommend color choices. Furthermore, the focus of this study is not on detecting the presence of stairs but instead perceiving where the stair steps are so that a person approaching the stairs does not take a wrong step. This study suggests that the color combination of Munsell Values 5YR6/2 for tread and 10R4/6 for nosing is the most visible color scheme for older adults in the stairs at Tamachi Station in any ambient light. The color scheme of Munsell Values 10YR2/2 for tread and 5Y9.5/10 for nosing is also a safe color combination, particularly in evening light on a cloudy day.

Keywords

Older adults, aging, color combination of a staircase, ambient light, visibility, wayfinding

Introduction

Aging weakens our physical and cognitive functions. Color changes with age (Shinomori, 2003), and yellowing of the lens affects our daily lives (Ishihara, 1998). Due to aging, reduced visual function, cataracts, and lens yellowing can cause older adults to stumble and fall in the evening and at night (Cabinet Office, 2010). Stairs, in particular, are places where older adults face danger. When older adults see a step from the top of a staircase, it is difficult for them to recognize the edge of the step in the evening or at night.

The global community is aging. It is especially critical in Japan. The number of people aged 65 and over accounts for 29.0% of the population and is still increasing (Statistic Bureau, 2021). This phenomenon causes various issues, such as the confinement of older adults and the lonely death of living alone (Cabinet Office, 2019). Physical, psychological, and social environmental factors make older adults confined. Many of them feel insecure about their connection to the community. They should have specific roles in society, community, and family and participate in society (Cabinet Office, 2019). Transportation and urban environments need to be friendlier for older adults who go out into the community searching for income or development of opportunity. In particular, public facilities should become more critical. This background let the Japanese government enact the so-called “New Barrier-Free Law” in 2007 to ensure accessibility of transportation systems and buildings. Since this law came into effect, efforts have been made to increase the visibility of stairs in stations by painting the edges of the treads in different colors.

On the other hand, the central government of Japan enacted the “Landscape Law” in 2004. This law strongly encourages local governments to create their landscape plans, including the color guidelines of building facades, especially in public places. Since Japan is a centralized

country, about one-third of the local governments (1,718 municipalities) have followed this directive and then made their plans. However, the recommended colors for urban areas tend to be low in saturation (Kametani et al., 2000, Kobayashi 2013) and difficult to distinguish for older adults.

We can find several studies in architecture, urban planning, and ergonomics. Some studies examined the relationship between the colors of urban landscapes and the color vision characteristics of older adults (Tonosaki, 2012, Ohgai, 2004), and others examined the effectiveness of safety colors defined by the Japanese Industrial Standards (JIS) for older adults (Ochiai et al., 2021). We can find some studies on color combinations of stairs (color schemes for tread and nosing) that match the visual characteristics of older adults (Ministry of Land, 2003, Mijy, 2009). However, these studies do not consider the effects of ambient light. Since Mijy uses a method of presenting color chips on a PC screen to simulate easy-to-see colors, it remains difficult for subjects to evaluate actual spaces and stairs.

Therefore, in this study, the authors investigated the effects of ambient light on the color combination of stairs in public spaces where color guidelines strongly recommend color choices. Furthermore, the focus of this study is not on detecting the presence of stairs but instead perceiving where the stair steps (and the boundaries between tread and nosing) are so that a person approaching the stairs does not take a wrong step.

Methods

In order to select the color scheme for stairs that is easily visible to older adults, it is best to experiment with painting actual stairs. As it is not impossible, but it is certainly unsafe for participants in a study. Therefore, it is common to use photographs for the simulation. However, the space is compressed into a single plane in an ordinary two-dimensional photograph, so it is

impossible to recognize depth. Therefore, when looking down from the top of a staircase, it is not easy to distinguish each staircase step.

In this research, we simulated using stereo images. We selected the stairs of Tamachi Station in Tokyo, where an accident involving older adults occurred. We define the horizontal part (step) of each staircase as “tread” and the edge of a tread as “nosing” (Fig. 1). The authors experimented in two stages: preliminary and main experiments.

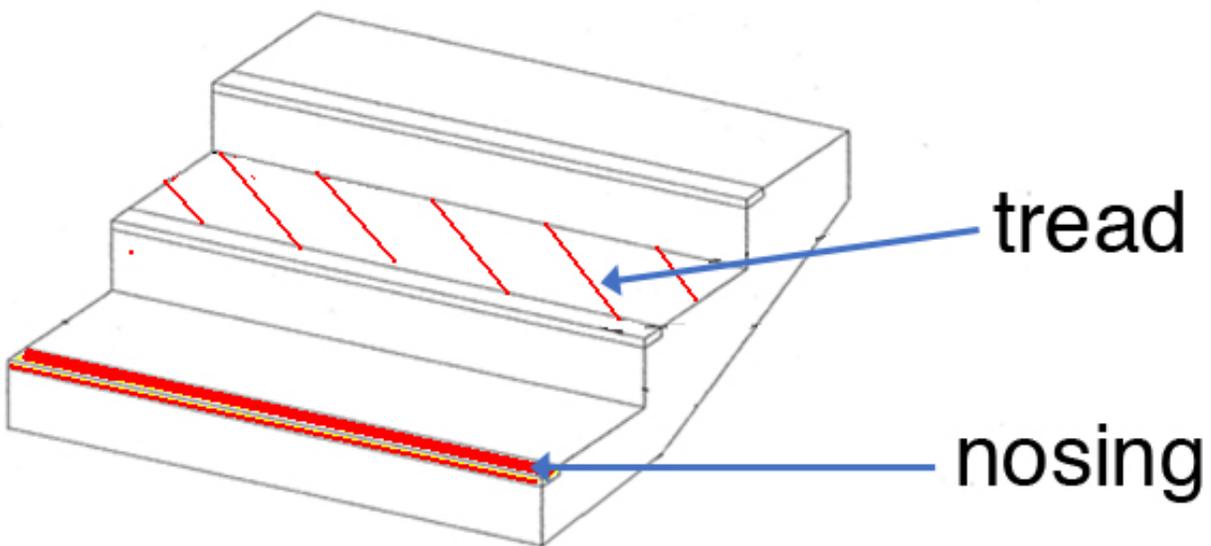


Fig. 1. Structure of a Stair: Tread and Nosing.

Preliminary Experiment

The subjects were 40 students. The age range is 21-22. We used simulation software (“aDesigner” from the ECLIPS Foundation) to simulate the vision of people in their 70s approximately. The subjects viewed the images projected on the screen from the 3D projector with polarized glasses and evaluated them.

It is natural to wonder about the color space reproducibility of the projector and the color change when viewed through polarized glasses. We used a color calibrator (x-rite's i1) to make

proper corrections, and we confirmed in a previous study that almost no significant color shift occurs (Nakamura 2005).

Main Experiment

The subjects were 51 people aged 65 years or older. The age range is 65-84. The average was 73.7. 17 with cataracts. The subjects wore a VR viewer (GOOICE VR-PARK) to view and evaluate the images. The images were presented using a smartphone (SONY XZs SO-03J). The color calibrator corrected the color reproduction.

Table 1. Color Combination of Tread and Nosing in Munsell Values.

Note: Color scheme B is Brick Color and D is Yellow Color.

| Color Scheme | Munsell Value of Tread | Munsell Value of Nosing |
|---------------------|-------------------------------|--------------------------------|
| A | 2.5Y8/1 | 2.5Y5/3 |
| B (brick color) | 5YR6/2 | 10R4/6 |
| C | N5.5 | N0.5 |
| D (yellow color) | 10TR2/2 | 5Y9.5/10 |

In this research, the following four ambient lights were selected. They are “daytime sunny” (5500K), “evening sunny” (3500K), “daytime cloudy” (6500K), and “evening cloudy” (7000K). The four combinations of colors were selected based on previous studies (Ministry of Land, 2003, and Mijy 2009.) The color guideline of Minatku, where Tamachi Station locates, includes these colors (Table 1.) Each image was modified in color according to the white balance to simulate each ambient light by Adobe Photoshop (Fig. 2.).



Fig. 2. The Camera Used in the Main Experiment.

The camera used to photograph pictures in the main experiment is tilted downward slightly to emulate human sight to look down at the stairs.

For the stereo images, the simulation tool developed by the authors (Nakamura et al., 2005 and 2010) was used in the preliminary experiments, and the tool using a VR viewer was used in the main experiment instead.

Two compact digital cameras (SONY P-200) were placed in parallel in the preliminary experiment for photography. One digital camera (CANON 6D) was moved to the left and right in the main experiment. In both cases, the distance between the optical axes of the left and the right lenses was 65mm. 65mm is the average distance of human eyes. The color temperature of the ambient light was measured with a color thermometer (SEKONIC C-500) and used for calibration. The lens's focal length is approximately 45mm in 35mm format equivalent. This focal length makes about 50 degrees of view angle, close to the effective field of view when

gazing. The camera was set at 150 cm from the ground, assuming the average height of Japanese people to be 160 cm. The camera was tilted downward from the top of the stairs (Fig. 3.)

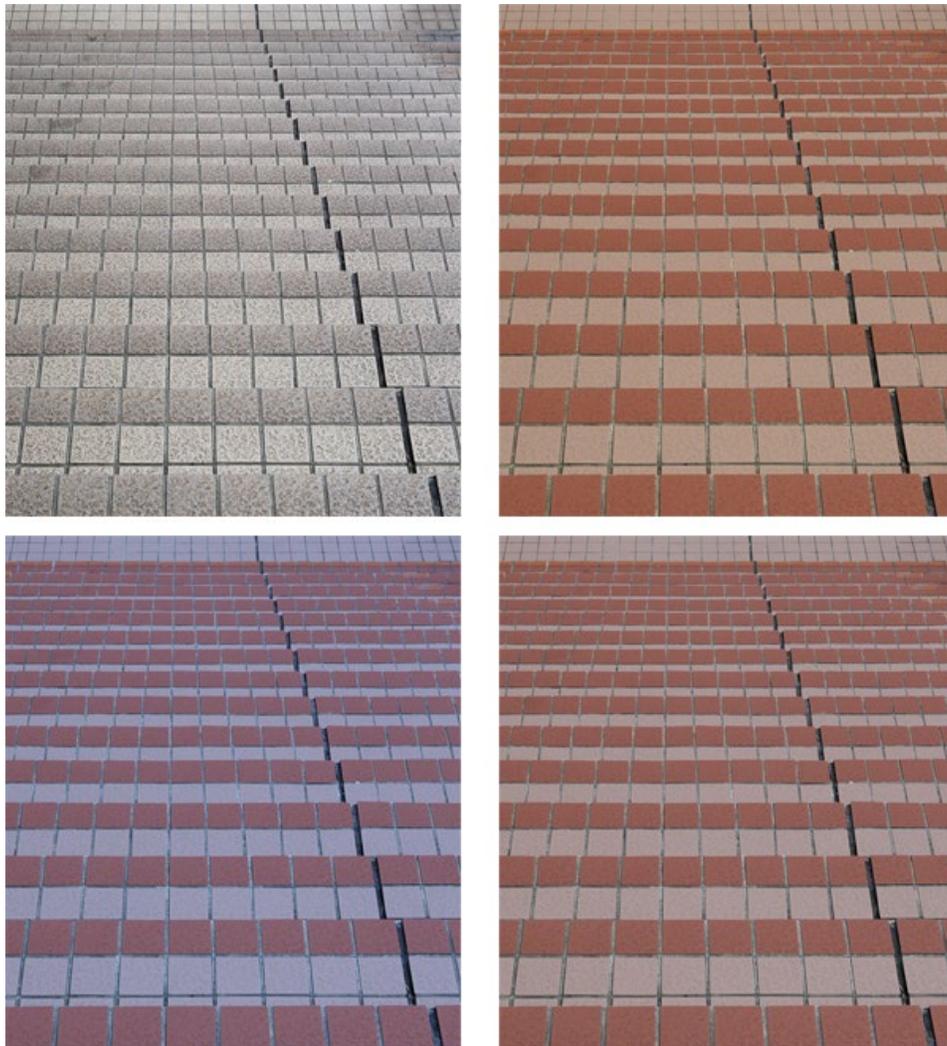


Fig. 3. Color Combination of Stairs in Three Ambient Lights (Munsell value is 5YR6/2 for tread and 10R4/6 for nosing). Pictures are only in standard 2D format and only a half of stereo images (the right half of the stereo images) because it is impossible to view them without viewers.

Top Left: Reference image (current combination) in 5500K. Top Right: Simulated image in ambient light 3500K (Munsell value is 5YR6/2 for tread and 10R4/6 for nosing). Bottom Left: Simulated image in 7000K (same Munsell value). Bottom Right: Simulated image in 5500K

(same Munsell value).

In the preliminary experiment, the images were projected on the 140inch screen from a distance of 4m. This screen size and the distance provide a nearly equal angle to the effective field of view. In the main experiment, the images are viewed with a VR viewer. The distance is similar to the typical distance from a person's eyes to a staircase when they are about to step on them. The virtual distance when viewing a VR viewer in the main experiment is also this distance. The subjects tilted slightly downward to simulate standing at the top of the stairs.

In both the experiments, two items are evaluated: “whether nosing is easy to recognize” and “which images look relatively dangerous.” Subjects evaluated in nine grades (-4,-3,-2,-1,0,1,2,3,4) in the preliminary experiment and seven grades (-3,-2,-1,0,1,2,3) in the main experiment. When the visibility of the simulation image is equal to the reference image, a grade is zero. Positive grades are given when the simulation image is superior to the reference image.

After a brief explanation, the subject puts on the polarized glasses in the preliminary experiment. While standing, they viewed the images in the following order: stereo adjustment image, reference image, color neutralization image, and simulation image. Here, the adjustment image is an image to confirm the stereoscopic view. The reference image is an image of the current nosing and tread. The color adjustment image is a neutral gray image to reset the color adaptation. The simulation image is with different color combinations. The procedure for the main experiment is similar, but instead of polarized glasses, a VR viewer is worn.

Results

Table 2. T-Test Results on the Scores of Color Combinations in the Preliminary Experiment.

Note: Color Scheme B is Brick Color and D is Yellow Color.

| Ambient Light | Color Scheme | Average Score | t-value | p-value | Significance |
|---------------|--------------|---------------|---------|-----------------------|--------------|
| Daytime Sunny | B | 7.7 | 17.68 | 1.35×10^{-8} | 1% |
| Daytime Sunny | C | 7.0 | 2.93 | 8.41×10^{-3} | 1% |

| Ambient Light | Color Scheme | Average Score | t-value | p-value | Significance |
|----------------|--------------|---------------|---------|-----------------------|--------------|
| Evening Sunny | B | 8.0 | 11.12 | 2.97×10^{-7} | 1% |
| Evening Sunny | C | 7.6 | 6.80 | 2.38×10^{-5} | 1% |
| Evening Sunny | A | 7.3 | 5.30 | 1.72×10^{-4} | 1% |
| Daytime Cloudy | B | 7.2 | 11.00 | 8.05×10^{-7} | 1% |
| Daytime Cloudy | C | 6.6 | 2.85 | 9.51×10^{-3} | 1% |
| Evening Cloudy | B | 7.9 | 8.22 | 1.79×10^{-5} | 1% |
| Evening Cloudy | C | 7.2 | 5.55 | 2.71×10^{-4} | 1% |
| Evening Cloudy | D | 7.6 | 6.78 | 7.02×10^{-5} | 1% |

Table 3. T-Test Results on the Scores of Dangers in the Preliminary Experiment.

Note: Color Scheme B is Brick Color and D is Yellow Color.

| Ambient Light | Color Scheme | Average Score | t-value | p-value | Significance |
|----------------|--------------|---------------|---------|-----------------------|--------------|
| Daytime Sunny | B | 4.1 | 11.00 | 8.05×10^{-7} | 1% |
| Evening Sunny | A | 3.0 | 2.89 | 8.10×10^{-3} | 1% |
| Evening Sunny | B | 4.1 | 3.18 | 4.87×10^{-3} | 1% |
| Daytime Cloudy | A | 3.7 | 2.33 | 2.22×10^{-2} | 5% |
| Daytime Cloudy | B | 3.0 | 3.18 | 4.87×10^{-3} | 1% |
| Evening Cloudy | C | 3.0 | 2.51 | 1.53×10^{-2} | 5% |
| Evening Cloudy | D | 3.0 | -2.51 | 1.53×10^{-2} | 5% |

We used four different color schemes of stairs considered excellent visibility characteristics for older adults and four ambient lights in the preliminary experiment. Of these 16 combinations, t-tests were conducted on the results of nosing's visibility evaluation. The results of the t-test were compared with the reference image (the current color scheme) at a significance level of 5% (indicated *) or 1% (indicated **) (Table 2). A t-test was also conducted to evaluate the danger (Table 3.) The following were clarified:

- 1) The color combination of Munsell values (tread 5YR6/2, nosing 10R4/6) is legible under any ambient light compared to the current scheme.

- 2) The Munsell values (tread 5YR6/2, nosing 10R4/6) are near-safe colors that do not present any danger under any ambient light.
- 3) The combination of Munsell values (tread 10YR2/2, nosing 5Y9.5/10) is a more legible and safer color for recognizing nosing in the evening light of a cloudy day.

Table 4: The t-test result on the scores of color combination in the main experiment

Note: Color Scheme B is “brick color” and D is “yellow color” in the main experience.

| Ambient Light | Color scheme | Average Score | t-value | p-value | Significance |
|----------------|--------------|---------------|---------|-----------------------|--------------|
| Daytime Sunny | B | 1.1 | 1.74 | 5.26×10^{-2} | 10% |
| Daytime Sunny | D | 1.1 | 1.80 | 4.80×10^{-2} | 5% |
| Evening Sunny | B | 1.9 | 4.60 | 2.51×10^{-4} | 1% |
| Evening Cloudy | B | 0.9 | 1.72 | 5.44×10^{-2} | 5% |
| Evening Cloudy | D | 1.3 | 2.65 | 1.00×10^{-2} | 5% |

In the main experiment, we used the two combinations of colors to consider the subject's burden and three ambient lights such as “daytime sunny” (5500K), “evening sunny” (3500K), and “evening cloudy” (7000K). The results of the t-test are shown in Table 4. The differences from the current color scheme were found at a significance level of 5% (indicated *) or 1% (indicated **). Figure 4 shows the average scores of each color combination in each ambient light.

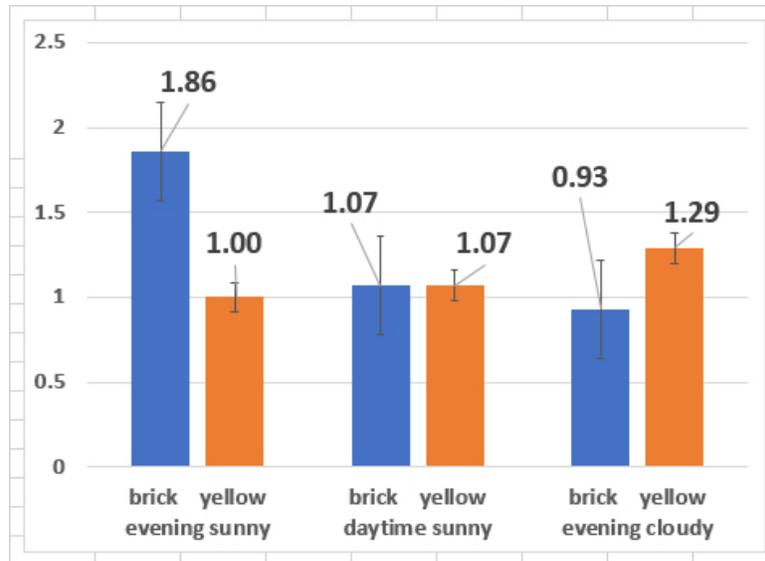


Fig. 4. Average Score of Each Combination of Colors and Ambient Lights.

The results were divided into two age groups: 28 people (65-74) and 23 people (75 older). In the color scheme (tread 5YR6/2, nosing 10R4/6), there was 1% significance in younger seniors on the “evening sunny.” In the color scheme (tread 10YR2/2, nosing 5Y9.5/10), there was 1% significance on “evening cloudy.” From the above, the following were clarified.

- 1) The color scheme with a Munsell value (tread 5YR6/2, nosing 10R4/6) is safe on “daytime sunny,” “evening sunny,” and “evening cloudy.”
- 2) This color scheme is less dangerous among the three types of ambient light.
- 3) After the experiment, the subjects were asked to write freely. About 70% of the subjects pointed out that yellow, widely understood as characteristic and reassuring, is “too conspicuous” and “tires the eyes.”

Discussion

The main experiment results showed a positive difference in the visibility of nosing for brick color (tread 5YR6/2, nosing 10R4/6) at the 1% significance on “evening sunny.” The

yellow color (tread 10YR2/2, nosing 5Y9.5/10) showed a positive difference at the 5% significance on “evening cloudy.” This result is the same as that of the preliminary experiment.

In each ambient light, the brick color tended to show the edges of the stairs more clearly than the yellow color on the “evening sunny” condition. The yellow color tended to show the nosing more clearly than the brick color on the “evening cloudy.” The brick color was relatively noticeable on the “evening cloudy” because of the ambient light conditions. However, on the “evening sunny,” the brick color tended to be more noticeable than the yellow color because of the orange tint of the surroundings. In the same way, the yellow color was not noticeable on the “evening sunny” because of the ambient light conditions. However, on the “evening cloudy,” the yellow color was more noticeable and straightforward to recognize because of the dim surroundings.

When the visibility of nosing was compared between men and women, no significant difference was found. In comparison with the reference image, on “evening sunny,” there was a positive difference at the 5% significance for women and a positive difference at the 1% significance for men in the brick color stairs. Therefore, we believe that the visibility of stairs tends not to change much between men and women.

There was no significant difference in the visibility of nosing between the two age groups at “evening sunny” and “daytime sunny.” on “evening cloudy,” there was a 5% significance between the age groups to recognize nosing. In the case of “evening cloudy,” there was a 5% significance between age groups in the visibility of the yellow color stairs.

In comparison with the reference image, in the case of “evening sunny,” there was a positive difference at the 1% of significance for the relatively younger seniors in the brick color stairs. In the case of “daytime sunny,” there was a positive difference at the 1% significance for

the relatively older seniors on the brick color stairs. In the case of “evening cloudy,” the yellow color stairs showed a positive difference at the 1% significance for the older adults.

Although the visibility of nosing changes depending on the ambient light and the viewer's attributes, it is suggested that both brick and yellow color schemes are apparent on the stairs of Tamachi Station.

However, in terms of “which image felt more dangerous,” the results were opposite for brick color and yellow color. For the brick color, the reference image (the current color scheme) tended to be perceived as more dangerous in all ambient light conditions. On the other hand, for yellow, the comparison image tended to be perceived as more dangerous.

In addition, many of the free descriptions of the brick color were positive, such as “calming color” and “reassuring color.” However, many yellow descriptions were negative, such as “the yellow color distracts people from paying attention to the surroundings” and “yellow is an easy color to see, but it stands out more than other colors.”

Incidentally, although there was no statistically significant difference in which image was dangerous, women tended to find the stairs in the reference image (the current color scheme) more dangerous in the cloudy evening light. In contrast, men tended to find the yellow color stairs slightly more dangerous. We speculate that this may be partly due to differences in the way men and women see colors. In a color test, “Men need slightly longer wavelengths than women to perceive the same hue across almost the entire visible spectrum (Israel Abramov, 2012.) As a specific example, the fruit orange may appear slightly redder to men than to women. Similarly, green grass may almost always appear greener to women and slightly yellow to men. This research suggests that differences in color distinction may have led to differences in the perception of danger.

When comparing the two groups of older adults, there was no significant difference in the visibility of nosing in either “evening sunny” or “daytime sunny.” However, relatively young subjects perceived the brick color stairs on “daytime sunny” as dangerous. In contrast, relatively old subjects tended to perceive the stairs in the reference image (the current color scheme) as dangerous. In the yellow color staircase, the younger seniors perceived the staircase in the current color scheme as more dangerous than the older seniors.

These results suggest that brick color stairs are a less dangerous color scheme than yellow color stairs in Tamachi Station. However, the visibility of nosing changes depending on the ambient light and the viewer's attributes. In addition, it was confirmed that yellow, which is considered a JIS safety color, is a noticeable color. Nevertheless, the main experiment suggested that yellow should not be used for the entire edge of the stairs.

Conclusion

From this research, the authors conclude the following:

- 1) The brick color (tread 5YR6/2, nosing 10R4/6) stairs and yellow color (tread 10YR2/2, nosing 5Y9.5/10) stairs are considered to be color schemes with high visibility for nosing in any of the three types of ambient light: “evening sunny,” “daytime sunny,” and “evening cloudy.”
- 2) In the three types of ambient light, brick color stairs are less dangerous than yellow ones.
- 3) Yellow, considered a JIS safety color, should not be used for a wide range of nosing.
- 4) There is no difference in the visibility of brick color stairs depending on the gender or age of older adults, and there is a tendency to perceive the brick color scheme as less dangerous.

From the above, we can suggest that the brick color (tread 5YR6/2, nosing 10R4/6) scheme is the most visible color scheme for older adults in the stairs at Tamachi Station in any ambient light.

This study also suggests the following:

- 1) The colors listed by the color guidelines are prevalent in many cities in Japan, North America, and modern parts of Europe. Therefore, the results are adaptable to Japan and many cities and public spaces worldwide.
- 2) In the cataract simulation used in this study, a similar color combination is noticed in the younger and older age groups. This result suggests that the cataract simulation software such as aDesigner can be used to a certain extent to evaluate the color combination of stairs. However, since the viewing conditions we utilized in the preliminary and the main experiments in this research are different, further verification is needed.

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AR-Based Haptic Whiteboard User Interface for Blind People

Reinhard Koutny, Klaus Miesenberger
Intistut Integriert Studieren, Johannes Kepler University Linz,
Altenbergerstraße 69, 4040 Linz
reinhard.koutny@jku.at, klaus.miesenberger@jku.at

Abstract

In a professional as well as an educational context, visual two-dimensional information spaces, like whiteboards, are frequently used to explain complex relations of the topic at hand, highlight important thoughts during discussion or structure ideas. During meetings facilitating this kind of aids, blind people can participate in the actual verbal discussion, and, if the tool used is digital and accessible, can access the textual information via screen readers. However, the spatial arrangement of pieces of information, which is usually crucial information as well, is not accessible. This work presents an AR-based user interface approach and prototype, which allows blind people to haptically access spatial information on two-dimensional information spaces, like whiteboards.

Keywords

Blind/Low Vision, Mobile Technology, Augmented Reality (AR), Employment & Workplace, Education

Introduction

Two-dimensional shared information spaces, like whiteboards and similar means are commonly used in numerous contexts. Business meetings often use whiteboards to gather thoughts and structure complex relationships. In education, blackboards are widely used for similar purposes. These tools offer crucial benefits to sighted people during lecture, discussions and meetings, while blind people miss out on this source of information in multiple ways. Firstly, textual information on traditional paper-based whiteboards is not accessible to this group of people. However, text alone is only one part of the information usually stored. Most of the time the position and spatial arrangement of chunks of information is valuable knowledge as well. Pieces of information placed next to each other are often related. Pieces of information above one another can act as headings. Additionally, not only the consumption of information is sufficient, but also the manipulation and creation are normally necessary for inclusion. Taking whiteboards with notes on them in brainstorming meeting as example: While sighted people can write notes and stick them to the whiteboard at the position they like, blind people cannot do that on traditional whiteboards. Furthermore, during discussions in these kinds of meetings, whiteboards get included in the conversation. People point at them to emphasize on an argument, which again is not possible for blind people.

In summary, whiteboards and similar tools are commonly used in many contexts, but they are not accessible to blind people for several reasons. This work proposes a cost-effective and flexible user interface approach that aims at overcoming these issues and allowing blind people to access spatial as well as other information and participate as equals in these kinds of scenarios.

State of the Art

Making spatial information accessible to blind people is a research field that has been investigated for many years and in numerous contexts. Navigation and world exploration are two

popular research topics, which manifested in countless different user interface approaches (Brock and Kristensson; Geronazzo et al.; Guo et al.; Willis and Helal). One important issue to highlight in this context is that it is of utmost importance to avoid overloading the auditory channel of a blind person. This is safety critical for outdoor navigation, but also crucial for other scenarios. In a meeting or lecture setting, a user interface that heavily relies on the auditory channel forces the user to decide to either operate the user interface or pay attention and contribute to conversations happening simultaneously. Braille displays are an established approach within the community, but are best suited for linear text. There are variations to this, like the HyperBraille pad offering a two-dimensional array that can be used to display 2D information (Stephan Pölzer and K. Miesenberger). However, it comes with several disadvantages like a high price, a relatively low resolution, limited market penetration and relatively large enclosure, which makes it less than ideal for transportation.

Alternatively, augmented reality has shown that user interfaces involving spatial concepts can be used to successfully assist people in work environments (Lahlou; Büttner et al.). This technology opens up the possibility for flexible and cost-effective user interface concepts (Wacker et al.), also tailored to blind people (Verma Aashish, Miesenberger Klaus, Pertl Gregor, Reithmayr Kerstin). This work presents a user interface approach based on Google's ARcore Framework (Google Developers) utilizing off-the-shelf smartphones to allow blind people to haptically access and understand a 2D information space.

Conceptual Solution

Our user interface approach aims to provide an alternative to traditional paper-based whiteboards, which allows blind people to not only retrieve textual information, but also access and understand the spatial arrangement of pieces of information (notes) on a whiteboard, which implicitly holds crucial information about cohesion and hierarchy. Moreover, users are not only

front of him or her. If the smartphone and the user's hand approach a note, the phone starts vibrating, getting stronger the closer the device is. If the phone touches a note, it starts to vibrate continuously. Text-to-speech (TTS) announces the title of the note. This lets the user explore the whiteboard haptically and understand the spatial arrangement of notes.

- Retrieve detailed information of note: If the user virtually touches a note, the user can click the volume up button to retrieve additional information, including the body text and the name of the person who created the note.
- Move and rotate note: The user can not only retrieve spatial information of the whiteboard but can also manipulate the position and rotation of the note. When the user touches a note, he or she has to press and hold the volume up button and move the phone in the desired position and orientation. The position and the rotation of the note on the whiteboard changes in real time, also visually in the digital whiteboard application.
- Highlight note: Additionally, the user can highlight parts on the whiteboard in two different ways. Firstly, the user can, when touching a note, visually highlight a note to sighted people by clicking the volume down button.
- Show cursor: Secondly, the user can activate a visual cursor on the whiteboard to draw attention to a whole region on the whiteboard by just pressing and holding the volume down button.

System Feedback for User Actions

User involvement showed that for every action, which the user performs and the system recognizes, some form of system feedback is highly desirable. Even though physical buttons are used for all actions, which already provide tactile feedback when being clicked, a confirmation

via either vibration, sound or even voice proved to be highly beneficial to make users feel more secure when navigating the application.

In particular, the following feedback mechanisms were implemented:

- Every successfully initiated action activates a chime as confirmation. This applies to: moving and rotating a note, showing the cursor, highlighting a note. Retrieving additional information already triggers text to speech. Therefore, no additional feedback is required in this case.
- Every unsuccessful initiation of an action triggers a warning/fail sound. This can happen if the user tries to trigger an action that requires a note, but the user's hand and the smartphone are not in range of a note. This applies to: moving and rotating a note, highlighting a note and retrieving additional feedback of notes.
- If the user decides to rotate a note, the current angle of the note is communicated via vibration. The closer the angle is to 0 degrees, the stronger the vibration gets. At 180 degrees, meaning the note is upside-down, the vibration is at its lowest level.

Technical Implementation/Prototype

A fully functional prototype (see figure 2) of the Android app as well as the digital whiteboard application has been implemented. From a technical perspective, it relies on a server infrastructure, which holds all information on the whiteboard. A web interface allows a traditional visual view on this information during meetings or lectures (see figure 1). This web interface, and any other user interfaces, communicate with the server with a standardized interface, namely a REST-Service for data exchange supporting all CRUD operations and a web socket services for real-time events (e.g. when notes get changed and other views need to be updated). The AR-based smartphone app also uses the same interface to retrieve and modify data.

It furthermore relies on Google ARcore Framework (Google Developers). This framework uses

the smartphones camera and inertial sensors to provide positioning data of the device. Unity (Technologies), usually a game engine, is used to create virtual objects in space in front of the user, each object corresponding to a note on the whiteboard. The positions and the distances between these objects correspond to the positions and distances of the notes on the whiteboard. Colliders attached to these objects trigger haptic events. If the smartphone is close to a note it starts vibrating; the closer the smartphone gets to the object, the stronger the vibration gets. If the smartphone touches the object, the vibration becomes continuous. The volume buttons are used to activate different modes, either by clicking, or pressing and holding the button (see chapter Conceptual Solution).

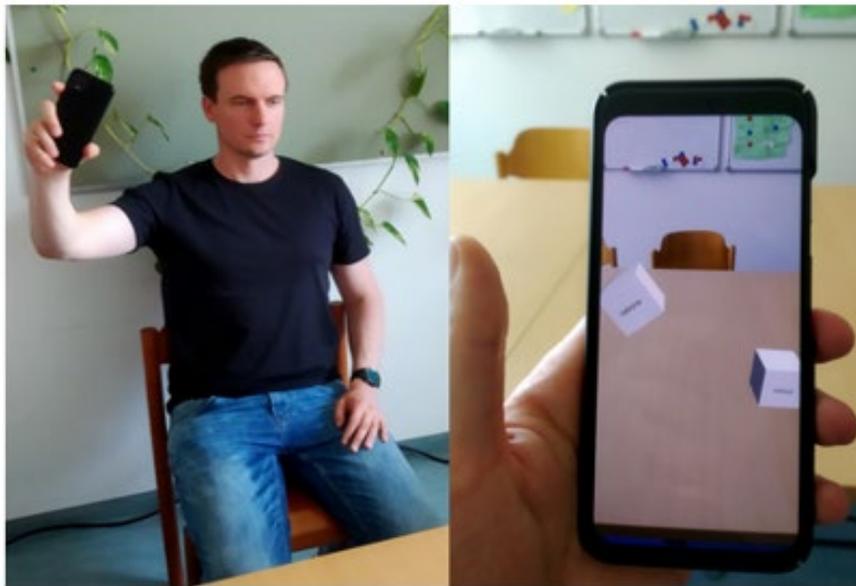


Fig. 2. Left Image: Person Using the Smartphone to Explore the Virtual Whiteboard Haptically.

Right Image: Note Surrogates Displayed in AR Smartphone App.

User Feedback and Requirements for the Next Iteration of the Prototype:

Recent user feedback has highlighted following user requirements and features based upon them, which will be added in a next iteration of prototype:

- **Configure Motion Range:** Depending on the user, his or her preferences, the setting and the surrounding environment, the dimensions of the virtual surface erected in front of the user and therefore the range of motion needs to be made user-adjustable. In some instances, users want to use less space and narrower motions to explore the whiteboard. In other instances, especially with more spare physical space and a larger number of notes, a larger range of motion might be preferable. This feature will be implemented by allowing the user to configure the range of motion during an initialization phase at the first run of the application or manually triggered during subsequent runs.
- **Search function:** Users expressed the need for a search function to locate single notes on the whiteboard. This user interface feature will be implemented using a combination of the web interface and the smartphone app. Blind users can choose a note, which they want to search on the whiteboard. Afterwards the mobile app switches into a different mode, which shows only the desired note on the virtual plane and increases the range from where the vibration feedback starts. This will allow the user to comfortably locate single notes on the whiteboard.
- **Sequential guided walkthrough:** Users expressed the desire for a guided walkthrough for sequential traversal of all notes on the whiteboards. Normally, users, who open an unknown whiteboard for the first time, pick a random position on the whiteboard and start exploring the rest of the whiteboard from there. Usually, the starting position is around the center, which leads to a free but relatively unstructured exploration process. While some people prefer this method, other users stated that they are worried that they might miss a note and they additionally want a guided walkthrough, which guarantees that they traverse all notes from start to finish.

Conclusion and Further Work

In this paper, we presented a user interface approach and fully working prototype, which aims at making 2D information spaces, like whiteboards, accessible to blind people. It uses affordable off-the-shelf hardware to make this spatial information haptically understandable. TTS and sound cues assist the user and grant access to additional information. Current user testing shows promising results. Users describe the exploration of the whiteboard using vibrations as intuitive and valid alternative to sound. While blind people were involved from the beginning and throughout the development, it has not been tested at a broader scale. Therefore, the next major step are evaluations to study the benefit for blind people as well as highlight areas where the concept or the prototype can be improved.

Future Applications

User feedback has shown that there is interest in bringing this kind of haptic user interface to other scenarios. Especially the educational context seems to offer promising scenarios where this approach might be able to support blind and severely visually impaired students in understanding spatial information. Examples where this approach could be applied are geographic maps, mathematic and chemical formulas but also content like the solar system or the structure of molecules.

Geographic maps are an obvious scenario. However, mathematic and chemical formulas might not necessarily be, since they can be serialized and displayed on braille displays. While this is certainly true, a spatial presentation accessible to blind students could still offer benefits, especially in mixed classroom settings, where the teacher and other students are sighted. During conversations, sighted students might refer to spatial aspects of a formula, which excludes blind people. E.g. “I don’t understand the top-right part of the equation. Could you please explain it

again?” If blind students are able to understand the spatial layout of the subject of discussion, they might be able to participate and contribute regardless.

In contrast to geographic maps and whiteboards, which hold two-dimensional spatial information, the user interface concept might even be extendible to three-dimensional information spaces like the structure of molecules, geometric figures, maps of multi-storey buildings etc. These use cases will offer additional challenges, probably in terms of orientation to ensure that the blind user does not get lost. In addition, more physical space around the user is required. For 2D information spaces a virtual “wall” erected in front of the user is sufficient. However, to display the third-dimension actual physical space around the user is necessary.

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Inclusive Framework for Indoor Accessibility in Low Resource Settings for Persons with Visual Disability

Vikas Upadhyay and M. Balakrishnan
Amarnath and Shashi Khosla School of Information Technology,
Indian Institute of Technology Delhi, New Delhi, India
vikas.upadhyay@cse.iitd.ac.in, mbala@cse.iitd.ac.in

Abstract

The rising adoption of mobile technology in low resource countries like India has contributed significantly towards independent outdoor accessibility for all including persons with visual impairment (PVI) through applications such as Google Maps, Lazarillo, Blind-Square, and Soundscape, etc. In contrast to this, indoor accessibility is challenging for PVIs, mainly due to the uneven landscape of indoor maps with accessibility information, as well as accessible mediums to communicate them. This makes them continue to feel more dependent, less confident, and more insecure. The major contribution of this paper is to address the problem of indoor wayfinding and accessibility for PVIs to a certain extent. This work involved an eighteen-month-long system-level development including need assessment, design, implementation, and testing. The proposed system includes a custom web-based indoor mapping tool to create digital indoor maps and, an indoor accessibility application for the PVIs. We investigated the requirements and feasibility of indoor wayfinding and accessibility information in the context of low-resource countries. We deployed this system into three distinct venues including a hospital covering a total mapped indoor area of about 40000 square meters. Initial user feedback has clearly shown that the indoor maps and accessibility information have the potential for a significant improvement in indoor navigation and accessibility of these spaces with a low-cost intervention. Based on these understandings, we propose a step-by-step procedure to set up a digital map and localization infrastructure for indoor spaces and build accessibility applications around that. Our iterative implementation has proven to be an easy-to-scale mechanism in similar indoor spaces.

Keywords

Indoor Mapping, Accessibility, Navigation, Wayfinding, Location-Based Services,
Visually Impaired

Introduction

Out of a total of 285 million populations, approximately 91 million people with vision impairment are living in South-East Asia (Furtado et al., 2020). Most of these populations (Approximately 90%) are dependent on sighted assistance for any activities that require indoor mobility. Independent indoor mobility poses considerable challenges for PVI and limits their opportunities in life to access education, job, entertainment, and social engagement which make them feel isolated (Chanana, 2020). Globally, the landscape of accessible indoor maps and mediums to communicate wayfinding and accessibility information are extremely poor. This is mainly because indoor navigation and accessibility are still not a commodity and typically require customization at considerable costs and the existing solutions are highly customized for a specific environment whereas there is no widely accepted solution exists. In a low-resource setting, standard solutions like “clear” signage that can at least support the PVI with sighted assistance, are either missing altogether or not effective with very few exceptions of airports and modern metro stations (Ahmed, 2015). Further, as they do not get easily updated when major structural changes happen, they can also be very expensive to maintain. Accessibility of signage and other wayfinding cues for PVI is still a challenge, globally. The revolution of outdoor navigation over the last decade has shown, that low-resource countries have bypassed the use of physical maps in outdoor navigation tasks and are extensively using digital maps. To appreciate this difference, we should understand that two key technologies that have revolutionized outdoor navigation - satellite signals to support GPS on mobile phones as well as satellite (or other forms of aerial) imaging for mapping public spaces are not available for indoor spaces at scale. This has also been hindered by the non-emergence of global standards for indoor navigation and accessibility. Thus by and large solutions that have been developed for PVI are generally

customized, do not scale well, and are completely unaffordable for public spaces in low-resource countries (Simões et al., 2020). This work is primarily meant to address this gap. To understand the challenges related to indoor wayfinding and accessibility, we investigated a range of public indoor spaces that included a tertiary hospital, an academic institution, and a national center for visual disability. We found that wayfinding and accessibility are challenging in most of these spaces primarily due to the limited wayfinding and accessibility information as well as the medium to communicate them. We also identified other concerns emanating from limited access to physical, functional, and accessibility information in a public facility. We firmly believe that any successful solution that has the potential to scale in a low resource setting has to address the following four key broad issues.

- It should require only inexpensive infrastructure enhancement
- Creating information to support wayfinding and accessibility must be possible with low skill set employees without requiring access to original drawings of the building
- The solution should support public functions provided by the building
- Support the vast diversity of users including local language support

In this paper, we presented a novel indoor mapping framework to create and update information and map data APIs to build applications around this. To make the solution relevant to low-resource settings, we explore systems requiring low capital costs and even lower service and maintenance costs. *“Major contributions of this paper include, (i) An assessment of indoor wayfinding and accessibility needs for PVIs. (ii) IncluMap: A framework to create, and update accessible digital maps with wayfinding and accessibility information, (iii) IncluNav: An inclusive interface to access map information for indoor navigation and accessibility, (iv) Navigation system deployment at three distinct places to evaluate implementation requirements*

and feasibility in a low-resource setting (v) An open standard operating procedure to create indoor maps and accessibility information to share over IncluNav or build custom applications.”

Earlier Work and Limitations

Earlier studies have suggested solutions to support wayfinding including – sequential mapping (Guerreiro et al., 2017), localization (Ahmetovic et al., 2017), path planning (Kalia et al., 2010), strategic inclusion of signage (Greenroyd et al., 2018), modeling of indoor facilities. Furthermore, there are insights available on open spaces journey planning and engagement for PVI (Bandukda et al., 2020). In the context to low resource setting, many PVI mention that taking help from sighted assistance is also challenging many of the public buildings don't have clear wayfinding signage also reported in earlier studies (Ahmed, 2015). Apart from the cost of retrofitting all existing buildings, maintaining consistency due to incremental design changes is also a challenge (Upadhyay et al., 2019). Even the available signage is inaccessible due to a variety of reasons - illiteracy or low education levels, low vision, and unfamiliar language (Gupta, 2008). The problem related to inclusive and accessible mapping has been highlighted (Froehlich et al., 2019) but there is very limited research available that understand and address the indoor accessibility issues in low resource setting (Barbareschi et al., 2021). For example, in a low-resource setting, there may be multiple uses of the same space for different functions at different times, this transient information creates confusion hence to improve accessibility this also needs to be captured and delivered to all including PVI (Upadhyay and Balakrishnan, 2021a).

Besides creating indoor maps and accessibility information, indoor positioning is another important requirement to deliver the required information. Earlier studies explored indoor positioning problems in the context of PVI using Infrared (Jain, 2014), Bluetooth beacons (Statler et al., 2016; Cheraghi et al., 2017), inertial sensors (Harle, 2013; Kang and Han, 2014)

and fusion models (Wu et al., 2007; Guo et al., 2019). Many indoor positioning systems consider uniform accuracy requirement whereas in practice accuracy requirement varies. Indoor spaces very often may not require high and uniform localization accuracy across the whole navigable space. In addition, handling transitions across buildings, and floors inside a building is challenging using smartphone sensors (Muralidharan et al., 2014). Based on aforesaid methods, many solutions are being developed and tested to enable PVI to navigate independently in unfamiliar indoor spaces like shopping malls (Giudice et al., 2019), hospitals (Rousek and Hallbeck, 2011), railways (Kim et al., 2016), museums (Asakawa et al., 2018), and airports (Guerreiro et al., 2019). Besides this, many specific applications i.e. BeMyEys, Nearby explorer, Lazarillo, Clue, Blind Square are already being used by PVI to get navigation assistance, and route guidance (Swobodzinski and Parker, 2019). There have also been a number of examples of digital systems to aid people in navigating some specific indoor environments My Way is a mobile app to access Boston children's hospital maps and images through GPS over smartphones. Wright used a touch screen monitor to enable users to find 16 pre-selected destinations based on the frequency of use and reported 86 % success in finding the selected destination (Wright et al., 2010). Guerreiro, presented an interactive virtual navigation app in which PVI can learn unfamiliar routes before physically visiting (Guerreiro et al., 2017). Jaime presented an audio-based virtual environment simulator for orientation and mobility training (Sánchez et al., 2010). Sato presented an enhancement to their indoor navigation work as NavCog3 - a specially designed application for PVI (Sato et al., 2019). B.S. Tjan presented a digital sign system based on retro-reflective tags printed with specially designed patterns and identified them by a handheld camera and computer vision (Tjan et al., 2005). However, nearly all exist in high resource settings.

Despite having the largest PVI population, very little indoor navigation research and intervention have been demonstrated in low-resource countries (Upadhyay and Balakrishnan, 2021a). In low-resource settings, there is a specific challenge like understanding the context and the diversity of the population. Except for a few working drafts (Director-General for Policy Planning, 2017; Greenroyd et al., 2018), globally there is not much prior work available that can clearly identify the challenges and comprehend what are all accessibility information is required to support indoor wayfinding and accessibility, except a few open information standards came into existence (Giannoumis et al., 2018) until recently. Global coverage of indoor maps is poor, how the digital map will be easily generated with the detailed information at scale is remain challenging and what interface modality can be suitable for a diverse population with visual impairment. This work touches upon the aforementioned question in the context of low resources. To the best of our knowledge, there is no systematic development research exists for indoor navigation and accessibility for PVI, especially in low-resource settings.

Need Assessment

Some valuable need assessment study for PVI has been presented in the recent past but is limited to indoor wayfinding in a more structured setting (Ponchillia et al., 2020) whereas assessment of indoor wayfinding and accessibility highly depends on users, environment, regional context, and wayfinding objective (Devlin, 2014). To improve indoor accessibility, another critical aspect is the nature of the information that is provided to a BVI user (Gallagher et al., 2014).

Table 1. The List of Focus Group Participants

(B: Blind; LV: Low Vision; E: Expert; P: Professional; K: Knowledgeable)

| Participants | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 |
|--------------|----|----|----|----|----|----|----|----|----|
| Age | 50 | 42 | 34 | 36 | 38 | 45 | 28 | 58 | 40 |
| Disability | B | LV | B | LV | B | B | LV | B | B |
| Experience | P | E | P | E | E | P | K | E | P |

Clearly, there is a gap for user-centered design attitude concerning the actual problem – one which incorporates universal and inclusive design principles recognizes the uniqueness of the PVI and understands the challenges associated with the environment of use. To understand this, we conducted a survey followed by a semi-structured interview with professionals with visual impairment to realize their experiences and challenges.

The objective of the focus group study of PVIs was to gain an insight into their indoor accessibility experience, behaviors, and practices followed by them. This was not restricted to a health care facility alone. This study was carried out with a total of 9 PVIs - 3 low vision and 6 legally blind, ages ranging from 28 to 58 (mean=42, std.=10, 7 Male, 1 Female - P3 in Table 1) including coming from very diverse professional backgrounds. Based on our focus group inclusion criterion, it was difficult to get an expert female PVI with focused expertise. Informed consent was taken from each participant along with their permission to record the conversation. The survey includes a set of past navigation experiences and challenges, limitations, and expected solutions.

Survey Outcome

Based on the initial survey, we found that *hospitals* are the most difficult places for independent wayfinding and *getting the right information, knowing the position, and heading direction* were the major challenges for PVIs during their journey. The *airport* appears to be the

least challenging for participants due to limited experience since almost all airlines assist PVIIs once they reach the airport. We also found workplaces and metros were most frequently vesting places by the participants. Locate myself and wayfinding could be the most useful application feature as suggested by the participants.

Semi-structured Interviews and Outcome

After the survey, a semi-structured interview was conducted on a similar topic and the session was audio recorded. The average time taken for this study was around 100 minutes for each participant - 30 minutes for the survey, and 60 minutes for an interview with a 10-minute break. All interviews were transcribed, identifying details were omitted and actual names were changed to ensure anonymity. The data was analyzed thematically using an inductive approach to draw themes for wayfinding from an experiential orientation, based only on practical experiences (Thomas, 2003). From the interview data, we were able to code key needs and challenges.

Familiarity of the Built Environment: Information requirement during the indoor journey depends on one's familiarity with the building as well as the critical and transient nature of the "learned" information about the building. While discussing this, P2 suggested, "I have three categories of buildings, one is familiar buildings where I visit two-three times in a month or more, second could be a somewhat familiar building where I know the building but do not visit frequently, maybe once in two to three months and the last could be an unfamiliar building where I visit once in six months or more." Most of the participants suggested a similar three-level classification.

Cues and Landmarks for Building Orientation: In the discussion we found, that to gain the natural orientation inside a building there should be a tactile or a sound landmark that PVIIs can

identify and learn over a period of time. P1 shared, “The whole orientation is based on landmarks, we always rely on tactile, sound, or smell because they are more reliable landmarks for orientation. To locate a door of a room, foot-mat outside it would help because one can guess where the door can be.” P3 added one interesting experience, if I am guiding a visually impaired person, one interesting landmark is the level change or a speed breaker that I generally mention.” In outdoor settings, people refer to “travel straight and as soon as the speed breaker comes you take a left or count three-speed breakers and then turn right as these are very useful tactile landmarks.” P5 added, “In the case of indoors, sound landmarks like an escalator or a lift opening and closing or humming of a fan at a certain location are useful. Further, if there is any fountain or water flowing landmark that is also useful.” Route knowledge and orientation happen with the help of these landmarks over time but clearly, it also depends on the visit frequency. Some of these cognitive landmarks can be captured over the map and delivered to PVIIs for reassurance and orientation.

Prerequisites and Route Preview: Overall journey experience depends on the ease of access to the service offered with timeliness. Prerequisites are the prior information or arrangement required to fulfill the navigation objective. Participants experienced critical miss of doctor’s appointments because of the inaccessibility of printed timings on the appointment card. Another painful experience shared was missing the boarding the train due to the lack of information about platform numbers. Route preview is also a prerequisite and important for navigation planning even among sighted users. It was interesting to understand that route preview can be useful for simple and smaller routes but complex routes require real-time navigation. Route preview can have different levels, ranging from beginner to expert, where landmarks along routes can be appropriately made available to be useful for orientation without the cognitive overload. Many

times, it is difficult to get help from other people easily and it's also not safe in this pandemic situation. Here, the route preview can be useful to gain enough route knowledge to feel more confident during way-finding.

Accessibility of Mobile Navigation System: P1 shared “While walking with a cane in one hand whether it's indoors or outdoors, simultaneously holding a smartphone is challenging.” Often to use a smartphone, one may need to touch the phone using both hands and, in this process, the cane may lift from the ground which leads to disorientation. P4 shared “my all focus sticks to navigation, I can't afford to do anything else, often in stairs if one hand is holding the cane, the other hand is used to hold the railings or some other support.” Though single-hand use of smartphones with talk-back is possible its reliability in general and noisy environments, in particular, is an issue. The implication is that preferably the smartphone-based navigation supports the hands-free operation.

Open Spaces: One participant shared his travel experience, “airports have different challenges altogether because airports have so much open space (he was referring to large halls) there is no corridor anywhere and such open spaces are always a challenge for me”. Similar challenges can be seen in campus-like spaces which may have multiple buildings and may require traveling across large open spaces - covered as well as uncovered. Tactile paths are effective in such open spaces to get a path to move but are constrained in the information sense as it is not clear where it is leading to? In places where you can't trail with something like a wall or a corridor, a PVI can quickly lose direction. One possible way could be to break the open spaces using tactile markings and create landmarks that are annotated on the map to support navigation as well as orientation.

A semi-structured interview with participants suggests that the preference for using a wayfinding application depends on its ease of access and utility to the overall navigation objective. For example, P9 mentioned, “I use Lazarillo and it offers seamless integration of outdoor maps and transport applications. I usually book my Uber from Lazarillo itself.” The amount of information provided in turn-by-turn navigation should vary based on users’ familiarity with the building. Points of interest and information priority along a route encountered in a hospital can be completely different from a shopping mall or a museum. Participants’ journey experience indicates that an outdoor-indoor transition remains unaddressed. All of the participants mentioned that finding the right orientation and accessing information along the route are challenging even in popular applications like Google Maps. A route guiding suggestion like “head southwest, and walk around 10 meters” has little significance for PVIs. In a multi-lingual country like India, applications not supporting regional languages are an additional serious issue. Detailed analysis of these studies helped us to generate a set of specifications and help the development of solutions that can substantially improve the indoor journey experience of PVIs. We identified, that functionally a successful indoor wayfinding and accessibility system should provide two essential information with bounded tolerance: the first is the current location and heading direction, and the second is the route to the destination incorporating intermediate points of interest (PoI), decision points. To follow a navigation route, PVIs need to have real-time access to information about the distance and direction to PoI and upcoming turns until the destination is reached. Apart from wayfinding to enhance usability, people also need access to the services associated with a navigable landmark. Such a comprehensive framework to deliver semantic information can also have a universal acceptance

since this is useful to mainstream users. These form the basis of requirement specification as well as implemented case studies in the rest of this paper.

Derived Specification

While performing navigation, PVI's pay considerable attention to their other senses to understand their environment better and to identify landmarks and clues hence any solutions should not interfere with these senses. A suitable interface is critical for inbuilt accessibility; the solution would be effective only when it can be easily configured to the level of information required by the specific user in a building. Journey well-being is measured by the overall experience that is close to a sighted assistance throughout the journey (Cupples et al., 2012). Based on these discussions, a set of specifications have been evolved. We categorized them into wayfinding, accessibility, and functional requirements.

Wayfinding Requirement

- Turn by turn navigation is the most acceptable approach in indoor navigation, where access to location and heading direction should be readily available to PVI's.
- To locate an exact door or a counter, a user-triggered Bluetooth audio beacon placed at the door or a counter can be the most interactive and effective mechanism for PVI's [40].
- Route guidance must offer a safer route rather than the shortest or fastest route, both to lower the potential danger of collision as well as loss of orientation. e.g. in corridors, a lane free from protrusions, and door and window openings are safer for PVI's.
- Use both clock and direction references for orientation e.g. compared to the "move slightly at 3 o'clock", "turn back and then turn slight left" is preferred by many PVI's.
- Predicting the expected journey time is useful information in navigation planning.

Accessibility Requirement

- It should provide crisp and clear audio without being verbose and always respond to queries in all possible states.
- It should allow PVIs to configure their level of vision, choice of language, and choice of interface - visual or auditory and haptic.
- In certain alerts, vibrations can supplement audio e.g. case of protrusions or an impending level change. Similarly augmenting approaching turns with beeps and a confirmation once the turn is taken can be useful.
- To provide alerts at certain situations or changes e.g. for certain PVIs bright sunlight may be a greater problem than dark corridors.
- For mobile apps, the control interface must be optimized for hands-free operation through speech, or control gestures must be optimized for one-hand operation. This has a practical advantage for PVI who also uses a cane for navigation support.

Functional Requirement

- As an integral part of route preview, it should know, and predict (including waiting time) to make the journey planning more effective. e.g. in a hospital consultation, it should include, “Please carry your patient ID number and consultation may take 45 minutes.”
- Whenever possible, it should ensure that PVIs know who is going to attend to them in their journey and what their roles are. For example, in a hospital journey, they may be Junior residents, doctors, or nurses with their roles. The solution must explain the expected journey/waiting time in different stages in real-time.

- It should offer the help for associated services, for example, to be guided to another lab for (eye) dilation, or to book a follow-up appointment after the consultation is over.
- Offer to read any written materials and recognize objects at the facility via AI techniques using a mobile camera.

Implementation Methodology

The framework proposed in this paper is for making an existing indoor space digitally accessible to all, with a particular focus on PVIs based on the above-mentioned specification. To achieve this, we have built two software modules (refer to Figure 1); module one is a custom map annotation tool to capture points of interest and cues from the indoor environment and create digital maps with additional semantic information (including symbolic, functional and operational information). This information is then provided to users of the indoor space through another custom-built inclusive wayfinding application. Wayfinding application is integrated with the indoor space using Bluetooth low energy beacons for localizing users inside a building. The beacons are placed strategically so that the user application can pick up the signals from the beacons and update the current location of the user to an accuracy of 2 to 3 meters (Upadhyay and Balakrishnan, 2021b). Wayfinding applications use smartphones' electronic compass sensors to help the users orient themselves in the right heading direction. Using accurate location, orientation, and step count this application provides turn-by-turn navigation guidance to PVIs.

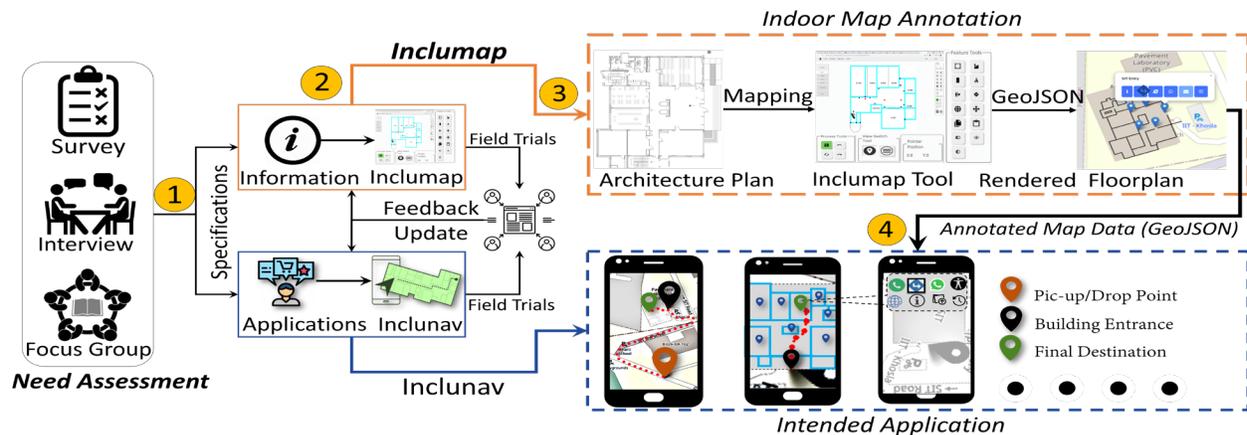


Fig.1. End-to-End Implementation of the Indoor Accessibility System.

Map Annotation Tool

Creating an accurate digital map for indoors with inbuilt accessibility is challenging due to the diversity in spaces and their users (Froehlich et al., 2019). In our survey, we found that organizations managing the spaces typically have architectural floor plans for reference. Besides the building geometry, these floor plans do not contain accurate information and sufficient cues and are often obsolete as it doesn't reflect changes to the building structures that have occurred over time. These floorplans are often in non-editable format (IFC, DWG or PDFs), and thus the organizations cannot incorporate the changes. Considering the need for an accessible digital map with rich information cues, the annotation tool has been developed over a web app², which starts with an existing floor plan in a standard file format (i.e. '.pdf', '.jpg' or '.png'). The building information is categorized by venue (a campus or set of buildings within the same area), and further divided into individual buildings, and their floors. The annotation tool can be used to mark the identified non-walkable areas, key landmarks (including functional and operational info.), accessibility services, and connections between floors (staircases, elevators), buildings (pickup, drop-off points) and local-global reference points. The annotating process has been divided into two stages, pre-processing and map annotation using the IncluMap application.

Annotation Tool Design Strategy

The proposed annotation tool is a progressive web application. Tools front end has been designed in Html-CSS-JS whereas the back-end is in NodeJS. The annotated map data is stored in a graph database (neo4j) and can be accessed by the wayfinding application using cypher queries from building data APIs. Functional requirement of navigation application such as localization, path planning, and route captioning is also supported by annotated map data. Other supporting requirements such as map data security, privacy, and access have been implemented separately. Building/facility authority can provide public access (all users) or controlled access (registered users) to their annotated maps. Flow in terms of landmarks for all the user functions supported by the facility can be added as a layer on top of the map data and can be changed when required without any changes to the underlying map structure.

Data Type: All the annotated map data is stored in a map data server in a graph DB(neo4j) in GeoJson format. Annotated map data is useful for integrating into other custom applications beyond navigation. Multi Floor Annotation: The annotation framework can handle the interconnection between floors. In a building, floors are connected using floor connector points i.e. stairs, lifts and ramps. There is a direct connection between the same-named connector points. For example, a “Lift-1” on level 0 is connected to all the “Lift-1” on all the other levels. Using the building’s pickup and drop point and floor’s connector points, a graph is generated whenever the user searches a path in the wayfinding application. Figure 2 shows an example of how a graph is created when a user searches a path from a location on the Ground floor(“a”) to a destination location on the Third floor (“b”) of building one.

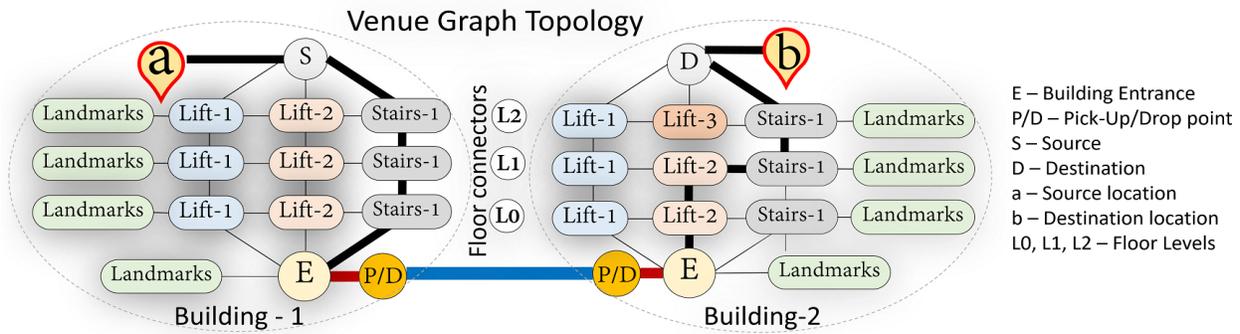


Fig.2. Venue Map Graph where Floors are Connected Through Stairs and Lifts and Buildings are Connected Through Pickup and Drop-Off Points (P/D).

Black lines indicate edges between the nodes whose weights are also calculated while building this graph. In this case, building one is having a connector point (“Stairs-1”) across all floors. When there are multiple connector points in the source floor, the user is shown multiple path options and their distance, each passing through different connector points in the source floor. The user can choose any one path among them for navigation. User-based customization can be used to reduce these options - some may be non-applicable (e.g. stairs option for wheelchair users).

Pickup and Drop-off Points (PDPs): Wayfinding accessibility requires seamless integration of outdoor-indoor transition. This can also be helpful for a campus where mobility among buildings may be required. An annotation tool provides an option to mark the PDPs of a building along with a route to the actual entry door as shown in Figure 3(c) to assist with the outdoor-indoor transition. Within the wayfinding application, PDPs localization has been performed through GPS and the actual entrance of the building is identified by installed Bluetooth beacons at the entry door.

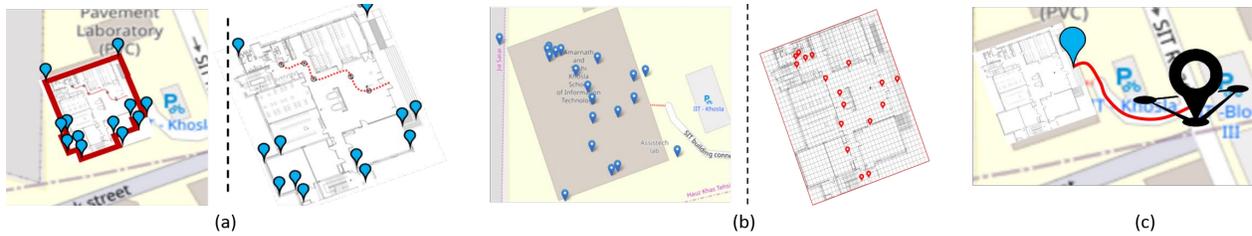


Fig3. (a) Reference Points Selection. (b) A Local Grid to Global Map Conversion. (c) Annotated Pickup/Drop Point and Route to the Building Entrance.

Local Grid to Global Map: In the proposed annotation tool, map annotation is performed in a local grid map at the resolution of 30 cm X 30cm. To make the annotated grid map compatible with the world map, conversion from the local grid map to global latitude-longitude is performed using local-global reference points of the building. These reference points are captured during annotation as shown in Figure 3(a) and conversion of local to global point of interest is shown in Figure 4.

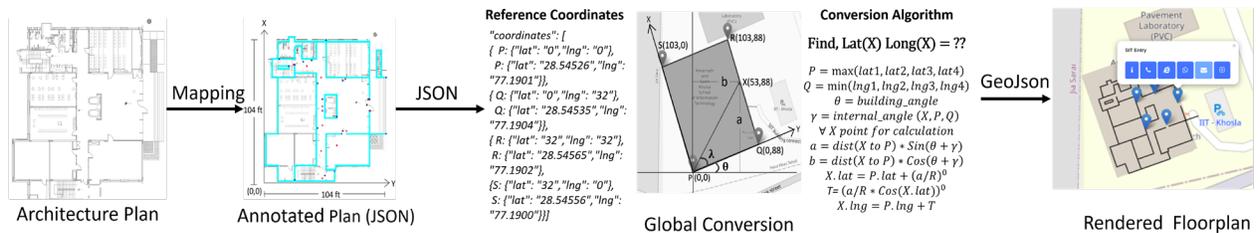


Fig.4. Local to Global Conversion Takes Buildings Data and References Coordinates as Input. This also helps in generating a global to local conversion of PDPs and outdoor points of interest to support navigation during outdoor to indoor transition.

Wayfinding Application

Once the digital map has been created, the next steps involve the strategic installation of Bluetooth beacons and integration with the digital maps. The purpose of the wayfinding application is to create a suitable user interface to localize the users inside the building to deliver location-based information relevant to navigation and accessibility.

Location of Beacons and Other Tags: Small floor plans can be analyzed manually to identify the points requiring high localization accuracy (points for installing the beacons) but this may not be feasible for larger floor plans. Once the digital maps have been created, the annotation tool uses the beacon profile, operating environment, and accuracy requirement to suggest the locations for beacon placement. The placed beacon location can be marked on the floor plan with their MAC addresses, using the annotation tool. The annotated building and beacon data are provided to wayfinding applications through a building data API. Apart from the beacons, we also deployed April tags (Similar to QR codes), to easily recognize the doors through mobile cameras. The April tags can be accessed by scanning and are typically useful for low vision and sighted users and augment certain visual/audio information for a particular location or a service. We found additional braille sticker/tactile markers on the TAG with a “standardized” installation protocol that can make them accessible for persons with blindness.

Localization: All navigation systems require initialization as well as access to relevant data - the venue, building and the floor of interest to the user. It is important to initialize the mobile device with some accurate estimate when the user is stationary, we refer to this as instantaneous localization. Once the initial location is known, the destination searches for the shortest feasible route based on the given map data and provides an initial location and heading direction on the map. After the user takes the first few steps, the motion (using a smartphone inertial sensor) measurement predicts, and range measurement corrects the location estimate using the Bayesian model until the motion estimation is reliable. Infield implementation, after getting a valid beacon list (common list from scanned and building beacon list), system-level localization is performed through a context-aware fusion. This has been implemented through a fusion of histograms and an extended Kalman filter (Sakai et al., 2018; Chanana, 2020). Considering the localization

accuracy requirement inside a venue, the proposed system uses a histogram filter for instantaneous position estimate (using only beacons and map) and an extended Kalman filter (EKF) for an in-route position (using both motion and beacons). Instantaneous localization provides an accurate pose estimate in case of stationary position or unreliable motion measurement (i.e. in case of turn/junction/decision points) whereas in-route localization using EKF provides better pose estimation during movement.

Orientation: Orientation is critical to identifying heading direction. The initial orientation is calculated with respect to the true north in the local grid from the current location to the next intended turn. While navigating, orientation loss may occur due to veering from the original path due to crowds or errors in sensor measurement. Empirically we found that turns/junctions are more prone to orientation errors. Our proposed mechanism checks the location and performs the reorientation step at every turn/junction to ensure the correct orientation.

Path Planning: Most path planning algorithms use some variant of the shortest pathfinding algorithm i.e. Dijkstra or A-star to support indoor navigation for PVIs (Wu et al., 2007). Shortest path planning adds unnecessary smaller turn/curves due to shortest path selection. This increases navigation complexity and more prone to collision due to veering, and errors in location estimation. In comparison to rectilinear, slight turn(left/right)/curve adds to path complexity but does not add many benefits in reducing the path length. To fit the navigational needs of PVIs, we implemented a path refinement strategy where turn with small path length was converted to their rectilinear equivalent. Studies have shown, that PVIs had a tendency to linearize curved paths (Ungar, 2018), hence rectilinear path refinement provides a better correlation in comparison to curved paths and reduces the risk of collision at turns in narrow corridors as shown in Figure 5. In the case of PVIs navigation, stride length varies with the height of the users, and crowd

density in the navigation space. Our application supports users to specify their height in the profile setting.

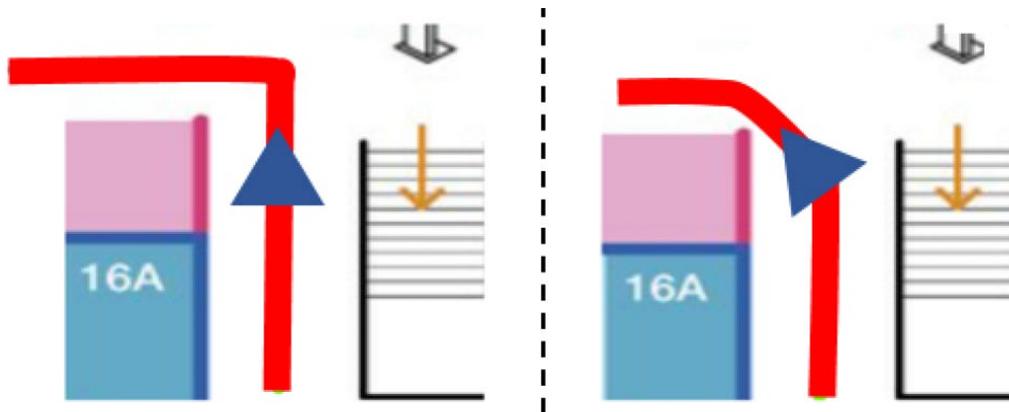


Fig.5. Path Improvement (Left) Due to Rectilinear Path Planning.

Route Captioning and Information Delivery: Route captioning returns the sequence of instructions along the selected route (refer to Figure 6). The level of details along a route depends on the familiarity of the route, the nature of landmarks, and its accessibility. The major information category includes positioning information, orientation information, navigation information, landmark information (this includes in-route landmark and point of interest), and accessibility information (includes obstacle, micro-orientation, surface/light intensity changes, functional information i.e. timings, contact, etc.). To fit the real-time navigation need it was important to keep the instructions short and crisp to avoid information overload and synchronization lag. We found blind users prefer path length in steps whereas low vision prefers meters. All the route and landmark information were provided in audio whereas the combination of beep and vibration was the more effective medium for turns and alert.

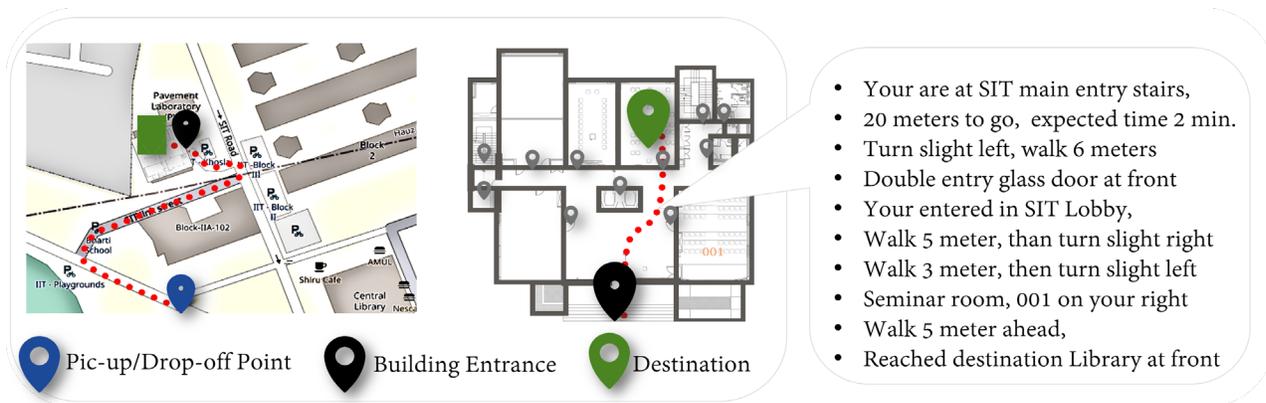


Fig.6. Turn by Turn Route Instruction for a Selected Route.

Integration of Map Data with Localization Infrastructure: Once the indoor localization infrastructure has been installed and integrated with the digital map, the information is available for users to access through the wayfinding application. This application can identify the initial location of users and the user can choose a destination and the application will generate the route requiring the least effort to navigate. During the navigation process, the application provides information cues related to upcoming turns, nearby landmarks, points of interest, accessibility cues such as floor-level changes, and other directional information required on the route. Users can choose to receive detailed information for new locations, and brief information for previously visited locations. The application has been designed to suit the requirement of a large spectrum of visual ability persons. High contrast interfaces make legibility easy for people with low vision or color blindness. The application also factors the security and privacy requirements of an organization managing their indoor spaces by using two-factor authentication systems and capturing the minimum data required. To make it acceptable to a large number of users, the wayfinding application interface has been designed to meet the W3C Accessibility Guidelines for user interfaces and provides turn-by-turn navigation through both visual and audio feeds. This version of the application is an upgrade over the previous and includes the inputs received

from the focus group along with the feedback from earlier work (Upadhyay and Balakrishnan, 2021a).

System Evaluation and Discussion

Objective and Method

The objective of this study was to evaluate the utility of the proposed framework for the ease of indoor navigation and accessibility for PVI. A brief orientation about the study and uses of the IncluNav wayfinding application was conducted with participants. After orientation, an application utility experience study was conducted with participants to evaluate the accessibility of application functionality. Informed consent was taken from all the participants along with their permission to record the trials. An evaluation was made based on task success rate, completion time, difficulties encountered in a task along with their qualitative experiences.

Study Environment and Task Configuration

Due to the ongoing COVID situation, all the safety measures were taken during the trials. A total of 5 PVI participants (2 Low vision, 3 Blind, mean age: 30, std. deviation: 8.4) have been selected for this study. Four participants were college students while one was a working professional. This trial was conducted in one of our campus buildings and consisted of two sets of studies - one is functional experience testing and the other is a goal-directed navigation objective using the IncluNav application. Objective 1 included a *journey from the buildings Pickup/drop-off point to the actual entrance* (Total length: 26meters, Number of turns: 4, Point of interest:2, Nature of the route: Outdoor-Indoor). Objective 2 included a *journey from the building entrance to the faculty lounge, Second Floor* (Total length: 28 meters, Number of turns: 6, Point of interest: 4, Floor transition: one, None, Nature of the route: Indoor)

Result and Discussion

Study 1: Functional Accessibility Experience Task: After initial orientation about the study and application, participants were asked to perform the six functional tasks on the application. The six tasks were – (i) Sign up/login, (ii) Find my location, (iii) Select a destination, (iv) Find heading direction/orientation, (v) Find nearby landmark, and (vi) Profile setting. After completion of each task, the time required to complete the task, and task success rate were recorded and a qualitative rating was taken from the participants on perceived difficulty. Due to space constraints, detailed results of this study are not included. In study 1 above, we calculated the averages of task success rate (TSR), perceived difficulty (PD), and overall scores for each task based on participants' performance. Although the number of the participants was few the results show that finding a location, selecting a destination, and profile setting was easy for the participants whereas finding heading direction and nearby landmarks was difficult in their first attempt. Finding a heading direction was difficult due to the rapid angular motion of participants and the lack of continuous feedback from the application. We observed participants learned this quickly when they repeated the exercise. Sign-up was a little prolonged due to OTP verification, password selection, and profile details (height, vision and route information choice). An overall score (Task success score + difficulty score) for individual tasks except finding heading direction and sign up was above 7 (avg. score = 7.85) in the first attempt, which can further improve with usage. The sign-up and heading direction were found to be difficult (avg. score = 5.9) and would need some redesign.

Study 2: Goal-Directed Navigation Tasks: Participants were asked to complete the goal-directed navigation tasks using the application. Total travel distance, error due to veering, and time is taken to complete the journey were recorded and are presented below.

Outdoor Indoor Transition Task: The first navigation task was to reach the building entrance from one of the PDPs. In our field trial, we found that mobile GPS was able to successfully log the PDP location with around 5.2 meters of error in the local grid map. Orientation is challenging in all existing apps e.g. google map suggests turning southwest which makes no sense for PVI. This was calculated using a mobile compass and expected heading direction with an average error of fewer than +/-10 degrees and was provided to participants in local direction reference (i.e. turn slightly left and walk 20 meters.) Tactile landmark (glass doors and stairs) along with beacons was intuitive to identify the actual entry door. Most of the participants were relying on tactile information for reassurance if it exists (stairs at the entry point and push/pull glass entry door in this case). Table 2a shows the outcome of the navigation task from pickup and drop to the actual entrance of the building with travel distance time and error.

Table 2a. Outdoor-Indoor Transition Task.

(OE: Orientation error, PDPL: Pickup-drop point localization, MEL: Main entry localization, S: Success, F: Fail)

| Participants | OE (in +/- degree) | PDPL error in meter | Drift in meter | Distance in meter | MEL error in meter | Time in second | Task Status |
|--------------|--------------------|---------------------|----------------|-------------------|--------------------|----------------|-------------|
| P1 | 8 | 3.8 | 5.5 | 37 | 1.8 | 96 | S |
| P2 | 14 | 4.2 | 7.8 | 33 | 2.2 | 93 | S |
| P3 | 10 | 5.4 | 7.5 | 31 | 1.7 | 95 | S |
| P4 | 18 | 6.1 | 9.4 | 44 | 5.6 | 108 | F |
| P5 | 10 | 4.2 | 5.2 | 33 | 1.9 | 93 | S |

Outdoor indoor transition is not supported by any of the existing navigation applications. Our effort to support this transition for PVI was found effective in this preliminary study with 4 out of 5 participants being successful in reaching the actual entrance of the building. Our application was able to correct the orientation with an avg. the error of +/- 12 degree which was sufficient

for direction guidance. Drift due to veering is one common problem in navigation tasks but is less encountered indoors. Avg. drift (Sum of drift along the path) was around 7 meters for an actual path length of 26 meters with 3 turns. Our proposed system corrects the drift at every turn. The participants (except P4) were able to reach the actual building entrance with an average localization accuracy of close to 1.9 meters without an additional localization medium. We found the description of the entry door (i.e. Near SIT entry, “stairs having 8 steps”, and at SIT Entry, “a push-pull, glass door”) was quite helpful for participants to navigate to the actual entrance.

Indoor Navigation Task: After reaching the entrance, participants were localized by the beacons, and a notification was played about route preview (“Faculty lounge, 28 meters away, on the second floor”). The second navigation task was to perform indoor navigation from the main entrance to the faculty lounge (Second floor). A set of observations has been recorded and presented in Table 2b. Indoor navigation observations show that the average drift (sum of drift along the path) was 2.64 meters for a total journey distance of 28 meters with 6 turns. This compares well with outdoors because of constrained walking spaces and frequent turns. Time taken to complete the journey was largely due to the increased number of turns. P3 and P5 were reoriented by the application due to motion in the wrong direction which added additional turns but ensured route correction. Waiting time at the lift was excluded in journey time computation.

Table 2b. Indoor Navigation Task. (S: Success)

| Participants | Total Turns (minimum turn: 6) | Drift in meter | Distance in meter | Time in second | Task Status |
|--------------|----------------------------------|-------------------|----------------------|-------------------|----------------|
| P1 | 6 | 2.1 | 31 | 122 | S |
| P2 | 6 | 2.5 | 30 | 128 | S |
| P3 | 8 | 2.9 | 31 | 132 | S |
| P4 | 6 | 2.6 | 30 | 125 | S |
| P5 | 9 | 3.1 | 32 | 141 | S |

Semi-structured discussion with participants was analyzed to understand the effectiveness of the proposed framework to support indoor navigation and accessibility. We found the tactile landmarks (push-pull glass door, doormat, fingerprint access near door) are more prominent and easier to recall for PVIs just like visual cues for sighted hence contributing to the cognitive map. Sound (i.e. lift or a fan) and smell (cafeteria or a lab) are cognitive landmarks but not abundant indoors. This outcome reinforces the fact we discussed the earlier representation of information in such a way that can make a space more interactive and accessible for PVIs. In the task execution, we tried to analyze the utility of route preview and found it to be highly biased with memory and was not a preferable choice for PVIs especially for the blind if real-time navigation is available. However, low vision participants were able to follow the route preview to reach their destination for simpler routes having < 4 turns. One interesting finding was to create a mental map and route knowledge. A detailed and perceivable feature description is important. The discussion reveals that the feature correlation was easy for the participants with significant independent navigation experience, due to better special motor skills. These trials were conducted in a controlled environment due to COVID restrictions. From our trial, we found that crowded, noisy, and open spaces were more prone to error for PVIs. In the wayfinding app, a course correction was made with bearing measurement at every incoming turn, and orientation was found to be accurate even on a long trail. To support error recovery if a user went in the wrong direction, applications re-route the users from the current location to their destination. Route information from building prior have been used to estimate the grid likelihood to recover smaller errors during navigation task.

Conclusion

In the context of a low resource setting, we have demonstrated how the proposed tools based on an inclusive framework can be used to create a system-level deployment to support indoor wayfinding and accessibility. The proposed solution can be scaled and evolve as a standard framework for providing not only navigation assistance but also provide access to relevant information and services to large-scale indoor facilities. This can lead to a universal acceptance of the proposed solution since increasing indoor functionality and services add to the information load hence its accessibility. The annotation tool developed in the project has been designed to accommodate a variety of information cues relevant for accessibility, wayfinding, and functional access keeping PVI as prime users in a context low resource setting. Users of the annotation tool may also come from a variety of backgrounds, with varied digital literacy and spatial understanding of indoor spaces, thus appropriate interfaces and automation features can simplify the process. Although the proposed mapping application has multiple manual involvements to create accessible digital maps and has a scope for improvement, we believe this can be a useful contribution to creating more indoor maps and accessibility data at scale. At this moment we are engaged with organizations owning public spaces like universities and hospitals to create a standard operating procedure for setting up a digital map of buildings to communicate, wayfinding, accessibility, and functional information to their user over an accessible medium i.e. smartphones.

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