Sonify : Making Visual Graphs Accessible

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ABSTRACT

Data visualizations are an essential tool to comprehend large datasets. However, for visually impaired people (VIP), it is nearly impossible to access visually complex data representations. Current accessibility solutions fall short in providing comprehensive access to data visualizations, which may deter VIPs from pursuing STEM, finance, and other data-heavy fields. We designed and evaluated Sonify - a sonification tool to make data visualizations accessible to VIPs through audio and tactile interactions. This paper is a case study of the iterative design cycle followed while developing Sonify, and the qualitative evaluation of interactions with (n=8) users with visual limitations. We outline the unique challenges of designing for accessibility. We describe creating usability studies to evaluate a sound and touch based interface. Finally, through Sonify, we demonstrate how a novel scrubbing interaction technique makes 2-variable linear graphs accessible to a broader range of people, including those with visual limitations.

ACM CLASSIFICATION KEYWORDS

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; K.4.2. Computers and Society: Assistive technologies for persons with disabilities.

AUTHOR KEYWORDS

Accessibility, Assistive Technology, Financial Technology, Iterative Design, Human Centered Design, Sonification, Usability Testing

INTRODUCTION

The ability to collect, interpret, and analyze data has long been integral to professional fields such as science, technology, engineering, mathematics (STEM), finance, and marketing. This has become even more important in recent years due to the increased storage of and ease of access to large datasets through modern computing technology. Professionals dealing with data analysis in fields like teaching, scientific research, financial training, and marketing research, often make use of data visualization tools such as charts and graphs. However, by their very nature, visualisations are often inaccessible for visually impaired people (VIP). [18]. In initial research about accessibility at large[ANONYMIZED], we conducted contextual inquiries with 8 VIPs, and found that a common pain point was the inability to understand visually complex interfaces, including graphs and charts. All 8 people with visual impairments we spoke to told us that they struggle with ‘getting the gist' of the content, visual elements like images and graphs, and/or keeping track of windows on their system [ANONYMOUS].

The population of blind and VIPs have had an increased prevalence since 2012 from 6.6 million to approximately 6.8 million American adults aged 16 - 75+, according to the 2015 American Community Survey [34]. This has led to an increase in the amount of assistive technology that help VIPs to access computers [22]. Despite improvements in accessibility, data visualizations remain relatively inaccessible for people with visual limitations. At present, tools like JAWS[1] [22] or other screen-readers allow people with visual impairments to access content via text-to-speech technology (TTS), but these screen-readers fall short when it comes to reading visual representations of large and complex datasets. Screen-readers might read only the title and axes labels of graphs, or they might skip over the graph altogether. If a person with a visual impairment has access to the dataset itself, they can manually tab through each datapoint in a spreadsheet and listen to the values; this is the main way they can try to mentally capture high-level trends in the data.

With this in mind, our team sought to address accessibility needs in the space of data visualizations, specifically when dealing with two way linear charts as a starting point. While our solution is scalable to all fields that make use of data visualizations, for the purpose of this paper, we chose to focus on VIPs working in the field of finance, which includes traders and analysts. Prior research reports that, of individuals willing to work, 79% of those with severe visual difficulty and 64% of those with extreme visual difficulty were actually working [27]. However, only 2.20% of these professionals fell under the

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category of "Technician or Associate Professional (inspector, finance dealer, etc.)". Hence, having identified finance as an underrepresented area of work for VIPs, and moreover, due to the team's shared interest in financial technology, we decided to focus on financial graphs.

We chose to use line charts since they are widely used in the field of finance, often to visualize a change in stock price values over different time periods. We started our design process by brainstorming 70 ideas, proceeded with scoping down to 11 ideas based on intra-team peer review, low fidelity prototyping and evaluation of these prototypes, further scoping down and evaluation of 3 high fidelity prototypes, and eventually iteratively designing to our final high-fidelity product. This iterative design process extended for a period of 4 months, and resulted in Sonify, a sonification took that makes line graph visualizations of stock price data accessible to VIPs. In this paper, we outline the iterative design cycle we followed while developing Sonify, and the qualitative evaluation of interactions with (n=8) users with visual limitations. We outline the unique challenges of designing for accessibility. We describe creating usability studies to evaluate a sound and touch based interface. Finally, through Sonify, we demonstrate how a novel scrubbing interaction technique makes 2-variable linear graphs accessible to a broader range of people, including those with visual limitations.

BACKGROUND

Existing technologies in the field of data accessibility utilize tactile and haptic feedback as well as auditory interpretations of chart data. Our initial design ideas focused on tactile solutions given that these have been integrated as standard tools for VIPs, including individuals with complete blindness [26]. However, people with disabilities often have to purchase expensive custom hardware that adds another component to their workspace, especially when the tools are tactile-based. Through early prototype testing, we chose to pursue an auditory and tactile solution, as these are prevalent methods used to represent the visual world [5, 31,40] and audio can be easily built in to the users' current workspace. However, we continued to test tactile solutions that could leverage common technologies.

Through this work, we sought to build on existing research in sonification of visual information, which has been used in tools ranging from text-to-speech programs to blood oxygen monitors [17, 28, 35, 39, 40, 50]. Sonification of data, graphs, and other visual content provides the ability to represent information in multiple ways without being visually-dependent, which allows people with different perceptual ability to understand visually dependant content [17, 39, 50]. Providing sonified data has not only assisted VIPs but has also been beneficial for other demographics such as students [6]. The use of auditory graphs in educational systems has proven positive results for data interpretation and as an alternative to traditional teaching methods for subjects such as mathematics [6, 17, 39, 48]. These auditory graphs have proven to help students with different learning styles to understand graphical data [2], as well as helped both sighted and VIPs access data [28]

The Web Sonification Sandbox from Georgia Tech [28] takes in a static dataset and returns customizable audio output of a single line chart. The Sonification lab at Georgia Tech also has other publications focused on sonifying visual data for various scenarios such as for driving cues [44], mobile application use [26], and even educational purposes [13, 17].

Apart from accessibility applications and educational benefits, sonified data also allows for the creation of graphics that are also compelling to sighted people. Such auditory data has been used to create new artistic experiences, like that of the Data Driven DJ [14], as well as collaborative multimodal datasets, that can help reduce information overload [18, 28, 42].

After identifying several tools and solutions in the field of data sonification, we found there to be a lack of open source, and user friendly technology that help VIPs directly plug in data and access it through alternate modalities. Moreover, none of the solutions we looked at addressed the nuances of financial data, such as stock prices. This finding steered our team to design an open source assistive tool to represent data using alternate modalities of interaction. In the following section we describe the design and evaluation process of the tool in question.

DESIGN

In this iterative design process, we went through 5 phases of designing and evaluating prototypes of increasing fidelity. In order to gain meaningful user insights, we kept several potential users involved through each stage of design [15]. This section outlines our methods for designing and evaluating each phase, the rationale behind the chosen method, and how the usability evaluation at each stage helped the product evolve. Methods include varying combinations of contextual inquiries [9], think aloud sessions [36], and cognitive task analysis [41].

Recruitment

For evaluating our prototypes in different lifecycle stages of the product, we recruited 8 VIPs, who constitute potential users, 14 accessibility experts, and 13 finance experts. We refer to our participants as V[n], A[n] and F[n] respectively, in the following sections of the paper, where 'n' refers to the unique numeric id of the participant . VIPs included 5 VIPs with complete blindness, and 3 VIPs with partial (mild to severe) visual impairments. Participant demographic, and recruitment detail is mentioned in table [1]. All participants signed consent forms for video and audio recording, and for using the data collected for research purposes.

Participants	Number	Code	Source of recruitment	Age range
Visually Impaired People	8	V[n]	[Anonymized], [Anonymized] University, Computer Center for Visually Impaired People at [ANONYMIZED].	23 - 56 (M = 33)
Accessibility Experts	14	A[n]	[Anonymized], [Anonymized] University, New York Public Library	NA
Finance Experts	13	F[n]	[Anonymized]	NA

Table 1 : System for codifying research participants with visual impairments, expertise in accessibility, and expertise in finance.

Design Phase 1

The stock price line graph is commonly used in financial task analysis, so we chose this specific type of data for testing. We conducted think-aloud sessions with 10 finance experts (F[1] - F[10]) in which participants were presented with a static line graph of the NASDAQ [23] stock price graph on a computer, and asked to think aloud as they evaluated the graph in 1 minute. We recorded audio transcripts, and identified key values as seen in Figure 1.

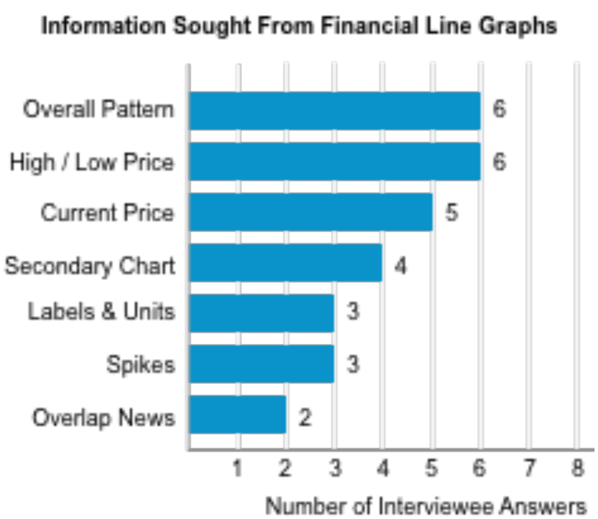

Figure 1 : Financial professionals reported these items as the most important when quickly reading a financial line chart. They look for overall pattern or trend, high / low price of the stock for that day, the current price of the stock, graph labels and units, and any spikes in the price over time. They may compare the chart with another related one or with relevant news events.

After establishing the information that is key for reading a stock price line graph, we began rapid prototyping. We designed 5 prototypes for products that would enable VIPs to review financial charts and graphs in low-fidelity paper and Apple Keynote, shown in figures 2-5.

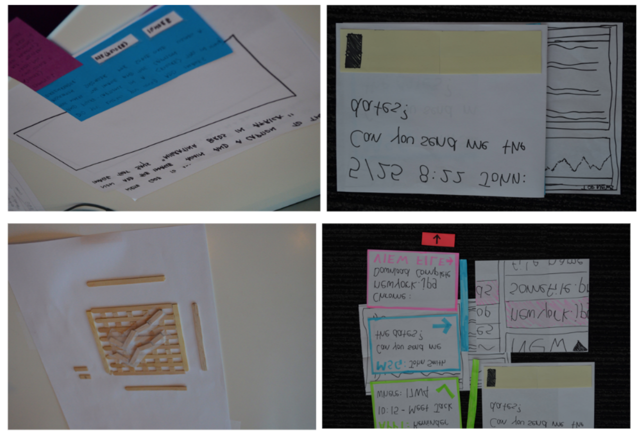

Figure 2 : Audio representation of line graphs through computer generated pitch.
Figure 3 : Using ambient sound to demonstrate changing stock prices in a table. Hearing different elements of the GUI spatially, by associating a different sound with each element to distinguish them.
Figure 4 : Keyboard shortcuts to listen to stock price values, as well as trends of the line graph.
Figure 5 : Tactile line chart that enables users to touch elevated line graphs to feel the trend of the graph.

Recruiting. We recruited 7 accessibility experts A[1 - 7], 2 finance experts F[1,2] who are involved in the development of financial graphs, and participant V[1].

Observations. We observed participants completing tasks using each of the prototypes and asked them to think aloud while doing so. These tasks were geared toward finding key stock price-related information, such as trends, high and low prices, and stock price on a particular date.

- Finance expert F[2] suggested that we needed more data in the prototype 1 (figure 1). F[2] quoted, “So... I don’t have a picture of what this chart is representing.”
- Participants understood sonified charts, though with less comfort than tactile charts. Participant V[1] said, “What I’m getting here are individual items, but I’m not really sure how to fit them into a picture.”
- Accessibility experts A[1-7], as well as participant V[1] were able to quickly describe the trend using prototype 4 (tactile charts) (figure 2).
- Ambient sound was somewhat effective but could not provide enough data on its own. Participant V[1] quoted, “What’s going up and what’s going down? There’s just not enough data!"

Results. Although participants had an affinity for tactile charts of static data, we found that designing a dynamic tactile interface was not feasible given our time constraints, so we focused on data sonification of line graphs. For testing purposes, we selected one subset of data that is often represented on a line graph: stock prices over time. These charts are ubiquitous in financial analysis, which is one of the fields we identified as relatively inaccessible for people with visual impairments. We chose to test pitch variation in the following phase based on well-documented research on pitch perception indicating that people are able to connect changes in information with changes in pitch [4, 16, 29, 33, 45, 51]. Additionally, we sought to convey information about large financial datasets, and there is a wider range of variation in pitch than other dimensions of sound, such as loudness [37].

Design Phase 2

While we realized that a dynamic tactile interface was out of scope, we recognized that the interactive component of tactile interfaces was compelling and effective. Rather than having the user press a button to play the audio version of a graph, we sought to combine tactile and auditory interfaces, to test whether the combination would effectively allow users to interact with financial data. We developed and tested 3 prototypes:

- **Trackpad Scrubbing:** A desktop application that allowed users to interact with an audio graph via touch on a computer trackpad. Similar to how you can scrub through audio or video clips in editing software or videos, our prototype enabled users to drag a finger left and right along a trackpad at any pace to play a sonified line of stock prices over time. The horizontal movement across the trackpad traversed X-values (dates). The rising and falling pitch of audio tones corresponded to Y-values (stock prices). Users could also press the spacebar at any point to have a screen reader read out the price and date at that point.
- **Keyboard Audio Navigation:** An application that allowed people to use keyboard shortcuts to play the trend of a line and reveal important summary information such as highest, lowest, and current price.
- **Sound Preference:** A system to test sound preferences using an open-source tool built by the Sonification Lab at Georgia Tech [28] to experiment with different sounds for line graphs. We could sonify lines using different instruments (e.g. a saxophone) and tweak the volume, speed, and other qualities of the sound.

We tested the 3 prototypes and and sought to answer these specific questions:

1. **TrackPad Scrubbing:**
   - Are participants able to understand and perform the scrubbing interaction on a trackpad?
   - Are participants able to gather the gist of a line graph by using the trackpad scrubbing interaction?
   - Are participants able to gather the specific values at points and identify points of drastic change?
2. **Keyboard Audio Navigation:**
   - Are participants able to gather the gist of a line graph by using the keyboard shortcuts?
   - Does the ability to navigate through specific values on the graph help participants better comprehend the graph?
   - Are participants able to retain important information from the graph?
   - Do participants prefer a keyboard navigation system to the trackpad interaction?
3. **Sound Preference:**
   - What sound specifications do participants prefer?
   - How accurately are participants able to comprehend the audio graph?

Figure 6 : A user with severe visual impairment uses the phase 2 prototype to explore the test stock price graph

Figure 7 : Setup for users to test (1) trackpad scrubbing to play sonification of a line using a computer trackpad and (2) keyboard shortcuts to play the trend from beginning to end and read out key information like high and low prices or prices for specific months.

Recruiting. Because we had limited access to participants with complete blindness, for the sake of time, we tested with 6 finance experts F [2,4,6,7,9,11] and 1 VIP, V[2] with partial visual impairment as proxy participants. We asked them to interact with the prototypes (which lacked any any visual interface) and answer questions based solely on what they heard.

Testing.

We first ran a pilot test with our accessibility experts and user experience experts, after which we finalized our prototypes and protocol, including the post-test questionnaire and the order of tasks.

In each session, we conducted a pre-test questionnaire and went through tasks for each of the 3 prototypes in a 30 minute session in a usability testing laboratory. We asked participants to reproduce the audio they heard as a drawing on paper to find out how well the prototypes were accurately conveying information. In each session, we had a moderator and four other researchers observing through a one-way mirror and taking notes.

Observations.

- Participants who used the scrubbing prototype were more successful at quickly drawing the "gist" of the graph. While participants who used the keyboard prototype took longer but drew more detailed and refined graphs.
- Participants wanted information beyond the trend line; they wanted to know exact values that went along with the scrubbing interaction, as well as summary information about axes, date ranges, highs, and lows.
- Participants preferred a more joyful sound such as the steel drum option, for listening to the sonified graph.
- Mixing trackpad and keyboard interactions was not effective; participants using the trackpad often forgot to press the associated space bar; some participants reported having forgotten about the interaction.
- Participants found the trackpad's relative spatial positioning confusing. If they touched the top right corner of the trackpad, they expected to be on the top right corner of the graph. Instead, their position moved slightly northeast of their previous position, often to a place far away from the top right corner of the graph.

Results. We decided to combine the positive elements from the two interactive prototypes: (1) interactive “scrubbing” control for line audio and (2) key data values from the keyboard shortcuts. We asked the users if they were able to gather a trend of the graph using the scrubbing and keyboard shortcuts, 4 out of the 6 participants agreed that they were able to gather the trend. During this testing we were able to validate our intended interaction between the trackpad and keyboard to provide a trend of the graph as well as details, as a participants stated, “I would periodically press the spacebar as I moved through to have a more exact understanding.”

Figure 8 : Results of a session to map key pieces of information to custom gestures in a mobile application

To address the problem of trackpad disorientation, we chose to switch from using a desktop trackpad to using a touchscreen. The absolute spatial mapping of smartphone and tablet devices would allow users to drag their finger across with the graph without losing their place. We specifically chose iOS over Android because iOS is widely used by VIPs [30].

Design Phase 3

In phase 3, we analyzed our problem space research to prioritize features for this tool:

- Move through sonified line graph
- Play an "overview" of the graph audio
- Read out value at finger's point on graph
- Indicate edges of the graph
- Read out current price
- Read out start price
- Read out high/low price
- Read out Title
- Read out X and Y axis

We assigned a set of gestures to provide these relevant pieces of information. We built our prototype using the Swift programming language as an iOS application. A double-tap at the top and bottom of the screen read high and low values, respectively; a double-tap to the left of the screen read the starting value, and to the right of the screen read the current value. A single tap anywhere on the screen read out the price and date of that point on the graph. For sonification of the line, we mapped values to pitches between the data points [3, 7, 35, 51], based on past study results and our user feedback.

Recruiting. We tested our prototype with 1 participant with a severe visual (V[3]), impairment and 3 participants who are blind (V[4,5,6]).

Testing. We asked participants to think-aloud as they explored the graph, completed tasks, and used the custom gestures. We gave tasks on both an iPad and an iPhone to compare how different device screen size might impact the granularity of the user’s understanding.

Results. Overall during this phase of our prototype testing we found that participants were able to correctly describe the general moves of the line graph and identify spikes in the data. All the participants we tested with were able to identify "oh right around here" the graph data goes down. We walked them through the custom gestures available on the device and they successfully tapped on the screen to access individual data points.

When participants were first given the prototype there was some confusion on what gestures they were able to use. For example, our team had to explain what double tapping at the top and bottom of the screen meant multiple times before participants became comfortable. One participant specifically mentioned that it was challenging to learn new gestures that were different than those already used in VoiceOver, Apple's built-in screen reader technology [1]. One of the main insights we gathered from this phase was that our hypothesis that using a larger device would aid the user in interacting with the granular level data. The size of the iPad actually inhibited the participants from understanding the full size of the graph. Participants preferred the smaller iPhone screen to the larger iPad screen because they could constantly feel the edges of the phone and understand where their finger was relative to the edges of the graph.

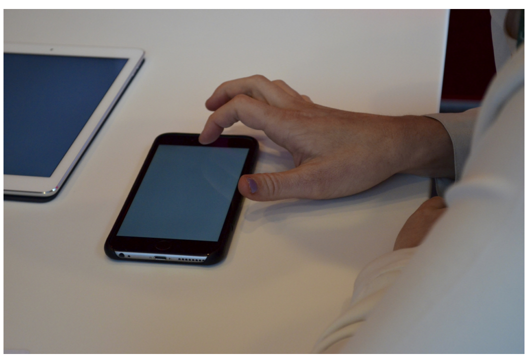

Figure 9 : A user scrubs through the sonification of a graph of stock price over time on a mobile phone with the Phase 3 prototype. The user braces their thumb on the edge of the mobile device to keep track of their finger position on the screen.

Design Phase 4

VoiceOver Integration. Based on the test results from our custom gestures, we redesigned the interactions to match VoiceOver (iOS built-in screen reader) for improved discoverability and fluidity. To do so, we divided the screen so that the top ½ would recognize VoiceOver gestures to provide supplementary info and controls for the graph while the bottom ½ would support scrubbing through the graph and individual taps to read out values for that specific points.

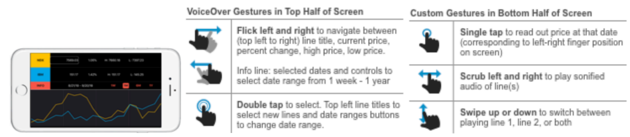

Figure 10 : Description of gestures used in Sonify

Dual-Line Functionality. When we interviewed finance professionals about how they read financial charts, they reported that they typically analyze the patterns and intersections of two lines on a stock chart to make decisions on whether they should buy or sell a stock. For example, they often look at one line for a single stock's price and compare it with an index like the S&P 500 Index. Given financial people use these two lines to analyze their stock data, we added a second line to the graph at this stage to allow for VIPs to have access to similar data points. While other research has identified what types of sounds are the most pleasant to the listener, including instrumental sounds like a violin or saxophone [10, 35], we hypothesized that less complex sounds would be easier to distinguish while listening simultaneously. We chose to use sounds generated using simple sine and square waves. A simple sine wave can be described as sounding pure while a simple square wave can be described as sounding shrill or rougher than a sine wave. We designed the application to play one line into the left ear with a sine wave sound while playing the second line into the right ear as a square wave sound. The user can swipe up and down in the VoiceOver section of the screen to switch between playing Line 1, Line 2, or both Lines 1 and 2. If both lines are selected, Sonify plays both pitches for the date corresponding to the user's finger position as they scrub; if they tap, it plays out the current value for each line. We wanted to test users' ability to distinguish between the two lines and identify points where they cross and/or diverge, which is an important use case in analyzing financial stock price charts.

Recruiting. We tested this prototype with 1 user with a severe visual impairment (V[2]) and 2 users with complete blindness (V[7], V[8]).

Observations.

- Users completed several tasks with the new Voice-Over-based and picked them up well.
- Users were able to identify when the 2 lines, played in opposite ears, crossed, or when one of the lines spiked.
- Users were able to build an understanding of the dataset quickly; one user said, "Just remember that I haven't seen graphs in 20 years. The only thing that I have used in the last 20 years are Excel sheets. By using this app... my ears and my brain make this feel much easier."

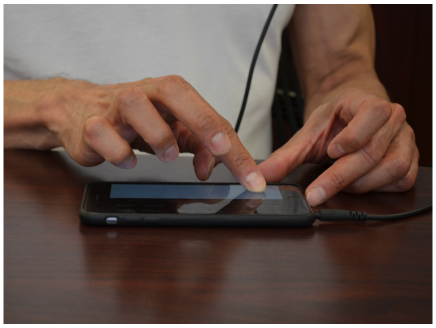

Figure 11 : A user scrubs through the sonification of a dual-line graph using the Phase 4 prototype. They wear headphones in order to listen to one line in each ear.

Results. We found that using a combination of a tactile and sonified successfully communicates the gist of line graph. Playing audio of differing sound quality in 2 different ears allowed participants to describe 2 lines and identify movement. We realized that integration with existing accessibility features is very important since users are familiar with those interactions.

Graphical User Interface Development. Finally, we built a barebones visual user interface (UI) for the application because our earlier research revealed how important it is for people with visual impairments to be able to collaborate with sighted peers [2]. We tested this UI to ensure accessibility for people with color blindness and/or low vision.

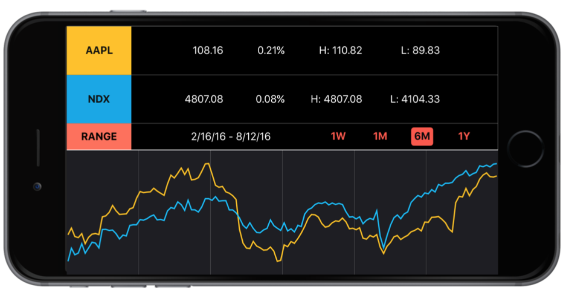

Figure 12 : The final interface design of Sonify, with visual elements incorporated to display the two stock entities with the current, high and low stock prices. The interface also includes the current date range of the data and options to switch between date ranges. Finally it includes the two linear graphs.

DISCUSSION

Through the case study of Sonify, we demonstrate the importance of iterative design and evaluation cycles while designing for accessibility. Iterative design is critical when building for specialized/unique user populations, such as communities with visual impairments, as each phase of testing reveals new insight that might not have surfaced when designing at once for that population. We also introduce a novel interaction technique that allows people with visual impairments to quickly build an understanding of data represented on a line graph, which was previously difficult if possible at all. We highlight the importance of integrating new interactions with standard accessibility tools like TTS software. Additionally, we show that playing pitches of different sound quality in opposite ears allows VIPs to track the progress of 2 distinct lines on a graph. Finally, we make Sonify an open-source tool for continued work in making datasets accessible to people with visual impairments.

While iterative design is beneficial to improving the usability of any product, it is even more so when designing for a unique user group such VIPs. Designers tend to miss key needs and goals for users with disabilities, and choose to conform to predefined generic usability norms. While norms are important, they may not be accessible to all users and therefore may not apply in the design of assistive technology. For instance, testing early prototypes led us to understand that designing on a mobile phone screen size was more efficient than using a larger tablet device [1], because VIPs are able to maintain a better tactile estimation of the edges of the graph by feeling the edges of the phone. This finding was of key importance to us, since the interactions designed relied on the absolute position of the finger. Similarly, we realized we could harness the power of complex sound interactions [4] after one round of usability evaluations in which the users reporting understanding sound patterns that were not very discernible to the team. We understood that, because our users often have better than average hearing abilities, they could benefit from multiple simultaneous sound patterns. We infer that when designing for a unique user group, involving the potential users in early stages of design and keeping them involved throughout prototyping stages leads to unexpected insights that help shape key product interactions and features.

Through the design of Sonify, we demonstrate how a combination of tactile- and sound-based interactions can be effectively used to convey data patterns over time. Sonify's scrubbing interaction combined with standard VoiceOver interactions allows VIPs to quickly gather the "gist" of a line graph, describe its movement, and access key values about the graph. These interactions set the groundwork for interactive data sonification and lay guidelines for designers wanting to expand to other types of graphs or datasets. We show that native mobile features such as text-to-speech, can and should be utilized when designing new products for accessibility, especially within the context of line graphs and sonified data. We exhibit that playing two pitches of different sound quality simultaneously in either ear, when combined with tactile scrubbing, enables people with visual impairments to describe movement and crossing points of two different lines on a graph.

We make Sonify an open-source mobile tool to be able to democratize this technology, in the larger spirit of accessibility. Further, we open up the field of comprehending complex data outside of data visualization, and make graphs accessible to users who could not access graphs in the past. The implications of these sonification interactions are far reaching. The framework developed can be used within and beyond the financial workplace enabling those with with visual impairments to get the information they need. The technology can also be used by sighted individuals who seek an alternative way to consume data. As one sighted participant in our study said, it would be beneficial to be able to listen to stock chart data while driving [8]. Beyond that, efforts in this space would positively benefit the potentially 39 million people worldwide who have visual impairments. The technology would empower such individuals to pursue careers in finance and other STEM fields that they might not ordinarily pursue.

LIMITATIONS & FUTURE WORK

In this paper we outline how we used user-centric iterative design methods to design Sonify to make visual graphs accessible to people with visual impairments. However, we consider this work as a beginning initiative and far from complete. While we were able to do multiple levels of usability evaluations with potential users, we still experienced some stages of design in which we could not work with people with visual impairments. As very few individuals with visual disabilities work in finance, we were not able to recruit individuals who meet both criteria. Hence, we referred to finance experts to identify key information about financial charts. However, this information might not be equally key to someone who has different sensory abilities. Another future step to strengthen our findings is to evaluate Sonify with a large variety of data APIs and with a large number of people with visual disabilities both internal and external to the field of finance.

While the tool we made is accessible, testing it with users gave us further insight into how we can make it better. In order to make the Sonify framework more generalizable to contexts outside of finance, we must allow users to upload their own datasets, instead of making a query from a predefined dataset. We must enable users to tab through data points more efficiently. Sonify can currently convey information of upto 2 graphs at once, but in order to be as potent as visual graphs, we must enable ways to convey more than two graphs. Furthermore, in addition to sonification, we must also make use of haptic feedback to convey deeper information about key points such as spikes, changes, and crosses. Finally, with further testing, Sonify can allow greater dimensions of data to be conveyed by using more complex sound interactions such as loudness, pitch, and frequency, as opposed to the current version which only uses pitch.

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