

COVID-19 Highlights the Issues Facing Blind and Visually Impaired People in Accessing Data on the Web

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ABSTRACT

During the COVID-19 pandemic, dissemination of data on the web has been vital in shaping the public's response. We postulated the increased prominence of data might have exacerbated the accessibility gap for the Blind and Visually Impaired (BVI) community and exposed new inequities. We discuss findings from a survey (n=127) on data accessibility followed by a contextual inquiry (n=12) of BVI people conducted between June and September 2020. 94% of survey respondents had concerns about accessing accurate COVID-19 data in a timely manner. Participants described how they encountered broad inaccessibility at early onset of the pandemic, and how advocacy efforts and complimenting their access with a wide range of sources helped fulfill their needs. By examining how BVI users interact with accessible COVID-19 data dashboards, we observed the effect of data literacy, confidence, and modality preferences on user strategies and takeaways. Our observations during this critical period provide an understanding of the impact access or inaccessibility has on the BVI community in a time of crisis and important implications for improving the technologies and modalities available to disseminate data-driven information accessibly on the web.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in accessibility**; **Visualization application domains**.

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accessibility, data visualization, accessible data visualization, web accessibility, blind, visually impaired, user experience

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1 INTRODUCTION

Since the onset of the COVID-19 pandemic [75], data visualization has played a vital role in promoting awareness, informing the public, guiding policy, and predicting future outcomes [86]. *Flattening the Curve*, for example, was a central public health strategy popular during the early months of the pandemic that used visual graphics to demonstrate the importance of slowing down the spread [83]. During this time, news organizations, numerous independent websites, and every state in the US launched at least one website with updates and data dashboards [57]. These tools provided the general public easy access to up-to-date statistics and trends showcasing the disease's progression. While data visualizations on the web have flourished with the aid of several web tools and libraries [14, 24, 25, 100], these methods have often relied on representations that leverage visual modalities for consumption, which leaves large parts of news and information on the web inaccessible to people who are Blind and Visually Impaired (BVI) [35, 48].

Anecdotal evidence reported in the general media captured some of the barriers faced by the BVI community in obtaining proper access to vital COVID-19 information in their local communities and brought renewed awareness to the accessibility gap [35, 52, 57, 62]. In response, a number of websites were independently launched in efforts to provide more accessible alternative representations to the BVI community [35]. These efforts provided alternative modalities

for data consumption such as alt text, data sonification, and access to tabular data. In this work, we survey BVI people's general experiences with data-driven information during the COVID-19 pandemic and make use of in-the-wild websites as well as public interest in the pandemic as a *site* to better understand the accessibility gap and what needs and challenges continue to impact BVI community.

We present findings from a mixed-methods study conducted between June and September of 2020. While the COVID-19 pandemic reached global impact, we focused our observations on members of the BVI community residing in the US. We collected data through an online survey (n=127) followed by an interview and contextual inquiry (n=12) using three common websites that provided access to different data representations (e.g. descriptions, tables, and sonified graphs). Our paper contributes:

- (1) An understanding of the barriers faced by the BVI community in accessing timely and reliable COVID-19 information during a critical period of time
- (2) Observations and recommendations on what practitioners and the research community could do better to improve and remove such barriers now and in future times of crisis
- (3) Summary findings on strategies used by BVI users to gain insights from data representations on the web and how well accessible representations meet BVI users' needs.

Our findings build upon what other studies in times of crisis have found: that people with disabilities (PWD) are often more impacted at early onset and disproportionately [93, 99], and provide additional context surrounding access barriers to important data-driven information. The majority of survey respondents (117/125, 94%) had concerns about accessing accurate COVID-19 information in a timely manner. Participants described how at the early onset and most critical time of the pandemic, they encountered broad inaccessibility, particularly of spatial graphics, trends, and statistics.

In follow-up interviews, participants discussed measures to overcome accessibility barriers, such as participating in advocacy efforts and relying more on community groups and information provided by blindness organizations to complement inaccessible information from more mainstream sources. For data that is accessible on the web, we observed the effect of data literacy, confidence, and modality preferences on user strategies and takeaways; and discuss broadly their implications on data accessibility both during times of crisis and in more general contexts.

2 RELATED WORK

2.1 COVID-19 and the impact on PWD

In past historical times of crisis and rapid change, people with disabilities (PWD) have often suffered disproportionate impact [93]. A number of recent studies have reported on the early and immediate impact on PWD of sweeping policies and behaviors enacted at the onset of the pandemic (e.g. the move to online education, lockdowns, shelter-in-place orders, etc) [43, 53, 82, 104].

Gleason et al. conducted a Twitter analysis of enacted COVID-19 health measures and found that improper dissemination of public health information was one particular domain that negatively impacted PWD [43]. Of the 55 government agencies' analyzed tweets that contained public health guidance information, only 12 agencies

employed alt text descriptions –resulting in only 56% of images being accessible. Another study conducted in March 2020 investigated the experiences of BVI adults during the start of the COVID-19 pandemic through a large-scale survey [82]. While the study examined a broad range of topics, one of the findings revealed that BVI users more often rely on information channels that summarize information rather than those that provide direct access to the data (e.g. news anchors or sighted relatives). One possibility for resorting to these sources of information are access barriers. Preliminary findings from Holloway et al.'s survey that compared the experiences and needs between sighted and blind users accessing COVID-19 information revealed similar findings [54].

Anecdotal evidence reported in the general media also captured barriers the BVI people faced when seeking proper access to vital COVID-19 information in their communities [35, 52, 57, 62]. Jeffries et. al. used automated tools to analyze the accessibility of each of the 50 US states' websites disseminating COVID-19 data in April 2020 [57] and found that all contained accessibility issues ranging from low contrast text to missing labels. Ensuring accessibility of government agency websites is particularly crucial because PWD may rely on them even more than the general public.

2.2 Web accessibility for screen reader users

Screen readers are the most common assistive technology used by BVI users to access web-based content [61]. Websites need to be designed and programmed thoughtfully to ensure proper access with screen reader technology. The Web Accessibility Initiative (WAI) of the World Wide Web Consortium (W3C) defined the Web Content Accessibility Guidelines (WCAG), which provide a set of guidelines on how to make web content more accessible to all, including screen reader users [2]. Power et al. found that only 49.6% of problems were addressed by the guidelines (WCAG 2.0), revealing that meeting accessibility criteria does not ensure screen reader users have access to the information [79].

The lack of accessibility across the web has been a documented problem [23, 61], from government websites [46, 74], to social media [42, 70], to productivity tools [30, 34, 98]. Various studies highlight the intricate relationship between accessibility and usability and its impact on screen reader users' navigation of the web [20, 63, 94]. Empirical studies have sought to characterize screen reader users' browsing strategies, challenges, and coping mechanisms or workarounds to recommend solutions that improve both web accessibility and usability for BVI users [19, 21, 23, 38, 41, 61, 65, 71, 89, 96]. Understanding the challenges encountered by BVI users on the web in various domains has led to important recommendations and systems that help improve web accessibility. In this spirit, our goal is to make observations and recommendations towards improving BVI users' access to data-driven information.

2.3 Accessible data representations

BVI people most often rely on labels and alternative text (alt text) on web images and charts [22, 68], which provide a textual alternative to graphical content in web pages. WCAG provides general guidelines for the creation of alt text [2], while the National Center for Accessible Media provides more specific guidelines for describing STEM-related images, including data charts [50]. For data-driven

content, guidelines also recommend including the source data in tabular form. Using these guidelines, Morash et al. developed and evaluated a template-based description generator for data charts which lead to more standardized word usage and structure [68].

Text-based and numerical descriptions of graphics are less precise, more error prone in their interpretation, and require more cognitive load than a perceptual interface that directly renders the same information through touch, sound, or vision [47, 88, 95]. Sonification is another method that exploits sound to make data graphics more accessible by transforming data relations into perceived relations in an acoustic signal [97]. Zhao described a set of Auditory Information Seeking Actions (AISA) and design considerations to support such actions for users interacting with data through sound [105]. Various plugins, such as the SAS Graphics Accelerator for Google Chrome [12] and for Excel [80], allow users to import data tables and explore data sonifications. Additionally, various systems have investigated the use of multimodal interfaces to enable users to understand different data charts [45, 67, 102, 106]. For example, the iSonic system allowed blind users to find facts and discover trends in georeferenced data by supporting map sonifications with tightly coordinated access to the tabular data [106].

An alternative or complementary approach to audio, are tactile graphics. While touch is best suited for conveying spatial information [28, 47, 60], technology in tactile displays that would enable dynamic access to tactile images over the web is still immature and not widely available [76]. In this work, we focus on data representations that are currently available through the web and the strategies users can employ to understand the data with them.

2.4 Visualization literacy & data insights

Data and visualization literacy refers to one's ability to translate questions into task queries and gain insights from data representations [26]. As information becomes more quantitative and as society relies increasingly on computing devices, data and visualization literacy have become an essential set of skills [31].

When interacting with data, users often perform several elemental tasks with the goal of answering questions and gaining insights from the data [66, 73, 107]. Studies have looked at how people construct mappings between the data and visual representations [55], how these representations support spatial reasoning tasks [51, 91], and strategies used by sighted users to draw insights from data visualizations [32, 49, 87, 101]. Yi et al. identified different processes through which users gain insights (Provide Overview, Adjust, Detect Pattern, and Match Mental Model) and recommended their use in designing and evaluating visualization systems [101].

This work aims to understand BVI users' preferences when accessing data representations on the web and how existing tools support their exploration.

3 METHODS OVERVIEW

We conducted a mixed methods study to understand BVI users' experiences with data on the web during the COVID-19 pandemic between June and September 2020, a time when the US was facing a second wave of new infections.

In the first part of the study, we launched an online survey to understand BVI users' current experiences, preferences, and needs for

accessing data-driven media during COVID-19. In the second part of the study, we leveraged in-the-wild accessible-branded COVID-19 websites as a *site* to conduct a contextual inquiry. Our goal was to observe firsthand how accessible data representations on the web are used by BVI users to gain insights and make decisions, and to elucidate on whether there are remaining practical considerations that could improve BVI users' experiences with data on the web. Detailed study protocol and questions are contained in the supplementary materials.

4 SURVEY OF DATA ACCESSIBILITY NEEDS, PREFERENCES, AND EXPERIENCES

An online survey was launched on Qualtrics and open for one month between June–July 2020. Questions included both Likert questionnaire items (unipolar and bipolar scales) and free form responses when applicable. Non-probability based sampling was used to recruit survey respondents. We circulated an IRB-approved announcement through mailing lists managed by local and nationwide blindness organizations in the US. The eligibility criteria included: being at least 18 years of age, identifying as blind or visually impaired, and being a fluent speaker of English. All questions were optional and participants could opt-in to a raffle for a chance to win one of twenty gift cards with a 15 USD value—survey completion was not necessary to enter the raffle.

4.1 Data analysis

The overall number of registered responses (171) was filtered down to 127 total responses to remove responses that were empty or did not meet the eligibility criteria. For Likert scale and categorical questions with short responses, we used descriptive statistics to summarise frequency distributions of those responses.

4.2 Participants

Participant ages ranged from 18 to 84 years old, with a median age of 40, and a mean of 42. 68.3% (86/127) identified as female, 30.2% (38/127) as male, and 2.4% (3/127) preferred not to disclose information about gender. When describing their level of vision, 42.5% (54/127) described themselves as totally blind, 31.5% (40/127) as legally blind, 19.7% (25/127) as having some shape or light perception, and 6.3% (8/127) described having very low vision. All users (127/127, 100.0%) relied on a screen reader as their primary assistive technology for accessing information on the web. Additionally 18.9% (24/127), used their screen reader in combination with screen-magnifying technologies.

4.3 Findings

4.3.1 Importance of Access to Data. Figure 1a shows that 63% of respondents answered positively that having access to data-driven news articles is very important (26/126, 20.6%) to extremely important (54/126, 42.9%). Similarly, 65% of respondents reported encountering data-driven media regularly on a weekly (51/127, 40.2%) to daily basis (31/127, 24.4%), and no participant reported not having encountered data-driven media (Figure 1b). In contrast to both of these reports, 73% of respondents did not agree that data-driven

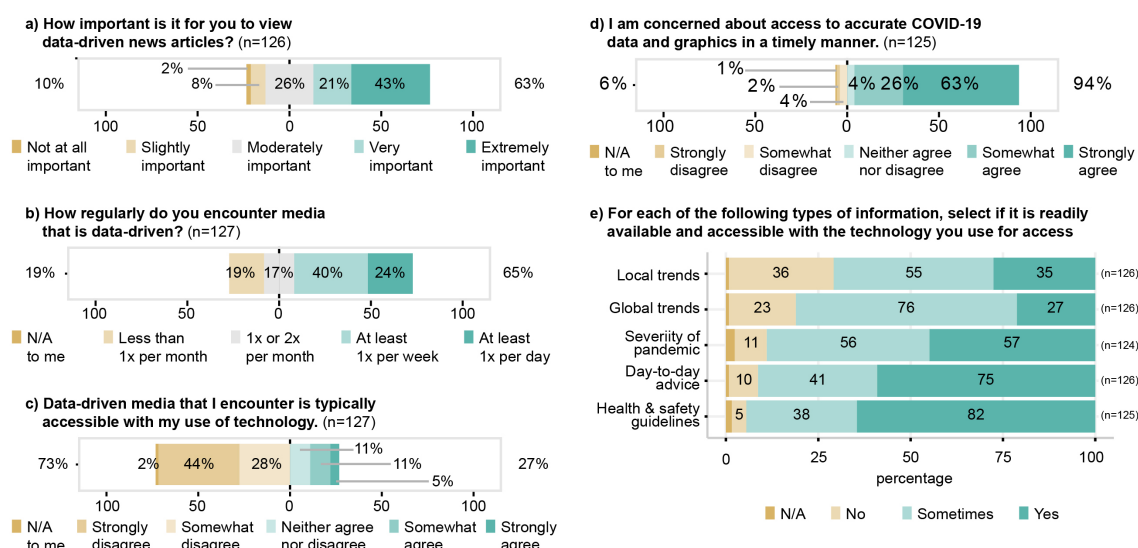


Figure 1: The majority of survey respondents reported a) access to data-driven new articles is very or extremely important, b) they encounter data-driven media regularly or all the time, c) they encounter data-driven media that is typically not accessible with their use of technology, and d) they have concerns about accessing local COVID-19 data and graphics in a timely manner. e) Respondents reported local trends and global trends as most commonly inaccessible types of COVID-19 information.

media encountered was typically accessible with their use of assistive technology, with 44% (56/127) of responses in the strongly disagree category (Figure 1c).

Most issues reported around incompatibility with users' choice of screen reader have been documented by prior literature throughout the past two decades [23, 61, 71, 74], or addressed by accessibility guidelines that are available to content creators (e.g. WCAG [2], NCAM [50], Section 508 [1]). Respondents described that alt text and tabular data were often missing despite being considered best practice, in addition to insufficient image descriptions and table formatting issues.

4.3.2 Concerns on Access to Timely COVID-19 Information. In regards to consumption of COVID-19 information, 94% (117/125) agreed they have concerns about accessing accurate information in a timely manner, with 63% (79/125) of responses in the Strongly Agree category (Figure 1d). 98 of 125 respondents provided commentary on the types of information to which access could be improved. The majority of responses related to improving access to data-driven graphs and statistics (77/98, 78.6%). For example respondents commented on the lack of access to pandemic progression trends particularly in their local community, comprehensive descriptions of infographics and informative videos, and location and testing hotspots typically available as visual maps. Other respondents commented on providing "better access to everything" (6/98, 6.1%), more clear guidelines and advice (6/98, 6.1%), "not sure" (8/98, 8.2%), and none (1/98, 1.0%). When asked to rank the accessibility of types of information, respondents ranked *global trends* and *local trends* as most commonly inaccessible, followed by information on the *severity of the pandemic*, *day-to-day advice*, and *health and safety guidelines* (Figure 1e).

To address access barriers encountered through mainstream channels, respondents commented on a number of approaches they took, such as:

- (1) looking for accessibility branded COVID-19 data dashboards [4, 64] and news websites (e.g. NFB Newslane) created to meet the needs of the BVI community where "the data has been returned to its numeric form" and "text format" (15/52, 28.8%);
- (2) learning to interpret data using sonification techniques and tools [12] to "access graphics and chart[s]" (13/52, 25.0%);
- (3) listening more to podcasts and news videos where overall trends are "better described" (11/52, 21.2%);
- (4) relying more on live visual interpretation services (e.g. AIRA) or help from relatives to "describe the data to me" (8/52, 15.4%);
- (5) looking for download access to raw tabular data (5/52, 9.6%).

4.3.3 Takeaways. Survey findings revealed that while BVI users place high importance on the consumption of data-driven media, several barriers prevent proper access. 93% of survey respondents agreed they have concerns about accessing accurate COVID-19 data and related graphics in a timely manner. Despite guidelines to provide comprehensive alt text and proper access to tables, this gap remains in practice. In particular, we observed a lack of access to up-to-date trends and geospatial data illustrating the progression of disease in local communities or locations for access to testing. Unlike visual data graphics which can be programmatically updated, comprehensive image descriptions typically require human authoring to keep up to date. Respondents reported on several sources of information that provide more accessible means to information; we investigate how well these sources fulfill BVI peoples' needs in the next part of the study.

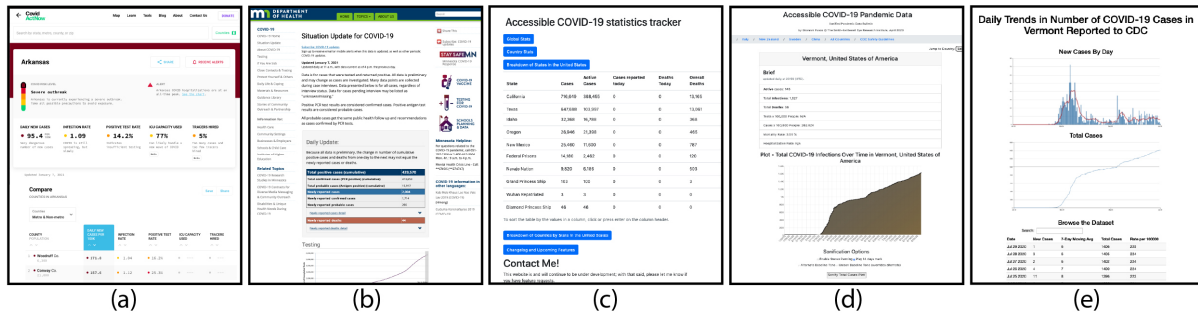


Figure 2: A selection of COVID-19 websites and data dashboards visited by participants. a and b were examples of sites that individual participants used frequently (COVID Tracking Project, MN Department of Health Situation Update). c, d and e were branded as accessible and explored by all participants for the contextual inquiry (CVStats, covid.ski, AccessibleData).

5 CONTEXTUAL INQUIRY

Based on the survey findings, we wanted to better understand how BVI users access data-related information about COVID-19 on the web, observing both the strategies they use and challenges they encounter. The pandemic also created a unique situation where numerous websites were created to meet the needs of BVI users by providing alternative representations to information that was otherwise more challenging to access through mainstream data trackers [35]. These website all provided access to similar datasets tracking the progression of disease but leveraged different representations and modalities. We made use of these in-the-wild accessible COVID-19 websites as well as public interest in the pandemic as a *site* to observe whether there are remaining challenges that limit BVI users' engagement with data even with websites branded as accessible, and if so, understand how they could be improved.

5.1 Procedure

The study was conducted remotely over Zoom and scheduled for 90 minutes. Throughout the contextual inquiry, we used a Synchronized Concurrent Think-Aloud Protocol [90] to understand participants' thought processes and actions. Participants shared their screen and audio and used Google Chrome.

First, participants completed a walkthrough of websites they had previously visited to access information about the pandemic. If participants reported any website(s), we asked them to access the website, reflect on the last time they had accessed it, and show us what information they looked for. Appendix Table 2 summarizes accessibility features present in all the websites visited.

To have a common ground across observations, we also asked participants to visit a set of three predetermined accessible COVID-19 tracking websites. We provided an open-ended prompt following North et al. [73], which encouraged participants to interact with different aspects of the data in the way they chose and reflect on the insights they received. Constructed to be simple to understand and applicable across all three websites, the prompt asked participants to use each website to consider the severity of the COVID-19 pandemic in two predetermined states and make a decision on which one they would choose to relocate to. The prompt was repeated for each of the three websites but with different states to consider.

Participants explored each website to collect and reflect on information until they made a decision. After reaching a decision, we asked participants open-ended questions about their experience and strategies used to understand the information available.

5.2 Accessible COVID-19 websites selection

To make observations on BVI users' access to data on the web, we predetermined a set of three websites that were branded as accessible and provided a variety of alternative representations related to the tracking of COVID-19 data (Figure 2). In particular, we focused on representations mentioned most frequently by survey respondents as important: tabular data, chart descriptions, and sonification of graphs. In selection of these websites, we reviewed survey responses for websites frequently indicated by respondents for accessing information about COVID-19. Websites were coded by their accessibility features and representations (Appendix Table 2). Websites provided either summary statistics and/or timeseries data showing the progression of key statistics over time (e.g. daily new cases, total deaths). Timeseries charts covered similar dates but differed in trends across different states.

The two websites most often mentioned by survey respondents were *CVStats.net* [64] and *COVID.SKI* [4], which presented data using tables and sonification respectively. These websites matched two methods respondents recommended for interacting with data on the web. Our website coding revealed that none of the websites provided comprehensive descriptions as suggested by guidelines for data graphics [50] and indicated as important by respondents. Thus, in addition to observing how users navigated through *CVStats.net* and *COVID.SKI*, we created a third website *Accessible COVID-19 Data* [3] that presented data with alt text and tables following guidelines for data-related graphics [50]. To ensure a standardized word usage and structure in the descriptions, we used a template-based description generator for data charts [68].

5.3 Data analysis

We employed a reflexive thematic analysis [27] to analyze the collected data consisting of notes and verbatim transcriptions. Data extracts were separated into single observations and coded using both semantic and latent approaches. Initial codes were framed as

processes that lead to data insights (overview, adjust, detect pattern, match mental model) [101]. Additional codes were iteratively added, which relate to usability observations, accessibility observations, and participant values. Next, codes were grouped by their shared meaning to generate sub-themes followed by overarching themes. To ensure credibility and exploration of various aspects of the data, repeated discussions and debriefings were conducted among members of the research team. To report on the themes, we use supporting extracts both illustratively and analytically and note participants from whom the extracts were collected from.

5.4 Participants

Participants were recruited from the pool of survey respondents who indicated interest in being contacted for a follow-up interview. From 103 participants who indicated interest, 36 were randomly selected and contacted. 16 participants followed up and 12 participated in the interviews. Participants received a 30 USD Amazon gift card as compensation for their time.

Participant ages ranged from 18 to 74 years, with a median age of 39.5, and a mean age of 42.4. Seven (58.3%) participants self-identified as female, and five (41.7%) identified as male. The majority of participants used JAWS (9/12, 75%) as their primary screen reader, followed by NVDA (2/12, 16.7%), and VoiceOver (1/12, 8.3%). Five (41.7%) participants also used a Braille display. Participants' self-reported expertise in tactile graphics ranged from Advanced Beginner to Expert. Participants' self-reported expertise in audio graphics ranged from No Experience to Expert. Appendix Table 1 contains a breakdown of demographics by participant.

5.5 Findings

We organize our findings to first discuss observations specific to the impact of COVID-19 information inaccessibility and participants' strategies to overcome any access barriers. We then discuss general themes based on participants' experiences and preferences towards accessing and gaining insights from data representations online. The identified themes are grouped as follows:

- *Efforts to access COVID-19 data*: how users access timely information and address inaccessibility
- *Impact of data literacy on understanding*: how prior knowledge and experiences impact users' interactions with data
- *Sources of tension between accessible vs. useful data representations*: how useful accessible representations of data are on the web and factors that impact usefulness
- *Factors that affect confidence*: how participants gain confidence in the insights they draw from data
- *Diversity of preferences for consumption*: what users' preferences towards data are and how these preferences affect individual interactions and takeaways

5.6 Efforts to access COVID-19 data

More than half of the study participants (P1, P7-P12) had specific websites they recurrently accessed to gain up-to-date information about the pandemic. The websites ranged from local government to independent volunteer-based and nonprofit services (Table 2). At onset of the pandemic in the United States (March-April), most

participants checked for daily data updates (P7-P12). At the time this study was conducted (September), some had reduced their frequency to a weekly to monthly basis (P1, P8, P9, P12).

Given this relatively long period of recurrent use, all participants commented on noticing how the accessibility of websites had improved over time and how they had gained more confidence in understanding the data and insights (P7-P12). Participants described that access had initially been more difficult and similar to findings in the survey, most commonly described challenges in navigation. Several participants described how they had experienced a large range of websites that provided COVID-19 data *"in some way, shape or form"* in search of the more accessible and useful ones (P7, P8-P12). Participants also discussed their advocacy efforts to ensure the available tools were made fully accessible. One participant described how initially her state's local website *"didn't have any numbers that JAWS could read"* (P8). She described how most changes to improve the website's accessibility had been enacted as a result of her group's advocacy. Another participant described how she had reached out to the website creators to compliment their efforts but also advocated for more thorough accessibility changes (P7).

Despite applauding the improvements made to the websites' accessibility, all participants also discussed several remaining barriers. One participant commented that while now they had access to the daily case count in their local community, they recognized that they are *"not really getting the full picture"* because they still do not have *"any kind of representation or any way to look [at the data] day to day"* or more holistically (P1). Supporting findings from the survey, participants reaffirmed that spatial information (e.g. trends and map hotspots), are most difficult to find and thus have low expectations for their accessibility. One participant described that *"there are probably ways to look for the trend but I never look because I expect it to be inaccessible"* (P8). During times of emergency where access to data-driven information is important, people not believing the information might be accessible to them is a real concern.

Other participants described having to actively seek out and complement multiple sources of information to get a fuller picture since *"there's no perfect website"* (P7-P10, P12). For example one strategy participants described was *"gleaning on any accessible details from one COVID-19 website"* and using that in complement with the accessible details in another website or dashboard to interpret and understand what the data is saying. Another strategy described was complementing inaccessible graphics in news articles with data representations available through blindness organizations or accessible-branded websites, highlighting how accessible data dashboards provide a way for users to verify and follow along statistics or graphs referred to in mainstream news articles that often don't maintain proper accessibility standards.

5.6.1 Takeaways. Our observations contribute to what other studies in times of crisis have found: that PWD are often impacted early and disproportionately [93, 99], including with regards to access to vital data-driven information. Participants described broad inaccessibility particularly early on in the pandemic when most were keen on accessing daily information. As a result, participants discussed their ongoing participation in advocacy efforts that only then led to change. Other participants described their low expectations for accessing spatial information, how they resorted to piecing together

information from different sources, and relied more on community and advocacy groups as observed also by Holloway et al. [53].

5.7 Impact of data literacy on understanding

We report on how participant's data literacy and experience impact the takeaways gained from data representations.

Using domain-specific knowledge to broaden insights. Prior work show that readers with higher level of graphical understanding use particular language and make more aggregate observations [37, 59]. Similarly, we observed how participants leveraged these characteristics to accomplish data tasks in several ways. Participants devoted attention to domain-specific “*words that would indicate sharp rises*” like “*exponential*” (P5), grouped spatial features into data-visualization concepts such as local and global extrema (P11), and connected spatial features to prior “*experience of touching tactile graphics*” (P5). By applying their prior data literacy knowledge and experience, participants focused on key areas of the representations, abstracted information pertinent to the task, and constructed spatial models to navigate and understand the data.

Knowledge gaps lead to gaps in insights. Gaps in knowledge caused participants to misinterpret the data or limited their ability to gain insights altogether. One example is with the case of sonified plots. Participants without prior knowledge of sonification drew false comparisons by directly comparing pitch values across different plots. Other participants did not know how to interpret sound features altogether. P2 remarked “*This is interesting. The daily one is not a steady tone. So those wavy sounds probably mean something*”. While users may identify sound characteristics such as trend, frequency, interval, from the sonification, how accurately they map those characteristics to data graphics insights depended heavily on domain-specific knowledge and websites providing sufficient context to easily make those associations.

5.7.1 Takeaways. Participants leveraged their prior data literacy knowledge and experience to effectively navigate and understand data representations. However, gaps in knowledge and unfamiliar domain-specific terminology caused participants to misinterpret or limit their understanding of the data. Public service websites, especially during times of crisis, should provide content that is accessible to general audiences without assuming domain expertise. Participants often found summaries of key metrics and main takeaways to be the most accessible and digestible (P2, P5-P7), which we recommend public service websites to prioritize at the top of pages populated with data content. Additionally, participants uncertain about terms and features often explored their immediate surroundings to seek clarification of those features (P4, P5-P7, P10, P11). We recommend all domain specific phrases be accompanied with references or simple definitions next to the phrase rather than in dedicated sections, as screen-reader's navigation features may lead users to easily skip past those sections.

5.8 Sources of tension between accessible vs. useful data representations

While participants were able to access the data and information in different ways across all the websites visited, accessible data representations often did not provide all the utility participants were looking for.

No one representation is best for all tasks. Unlike visual and tactile graphs, where broad patterns can be readily retrieved and contextualized, gaining the same information is more difficult through audio-based representations [105]. With tactile graphics, participants described being able to quickly explore both detailed and overall trends, and explore different data series in parallel. However, for web audio-based methods, participants described how the amount of information presented made comparisons difficult (P1-P4, P6, P8-P12). Choi et al. found that long and complicated descriptions impose a greater cognitive load to the reader [33]. We observed how the mental load of comparing sonifications sequentially can also be difficult. Furthermore, while participants described how tables made retrieval of values easier, tables did not facilitate understanding of the broader picture, echoing observations made from prior works [29, 92]. The usefulness of each representation was much more dependent on the task, emphasizing that just having access to a data representation does not mean users will find the specific representations useful for their intended tasks.

Supporting screen reader interactions. While a data representation may offer the utility that users need, usability issues in screen reader navigation can make search and retrieval difficult. For example, screen reader users often use heading levels or link lists to skim through web content. However, tables and alt text are not designed to provide similar functionality and users have to resort to sequential navigation, which becomes increasingly cumbersome when wanting to focus on specific regions of the data or make comparisons. Participants adopted coping strategies or workarounds [65] by using link lists to jump between table values tagged as links or opening multiple tabs and leaving their screen reader focus at different parts of the same dataset such that they could easily resume exploration (P3, P9, P12).

5.8.1 Takeaways. Overall, we observed that not all access is equal access [20, 63, 94]. Websites often default to the provision of alt text and tables which are considered best practice. Our observations show that even following best-practice guidelines, these representations can lack the necessary affordances for data-oriented tasks; suggesting the need to consider the variety of data-related goals in addition to the accessibility of different data representations. For BVI users integrating or making comparisons across graphs, having to take multiple navigation steps compound with the mental load of internalizing descriptions or trend sounds. Data representations could take advantage of inherent HTML header tags or links to facilitate jumping between points in the data and across different plots. Screen reader users already commonly use these features to skim through textual content [65], and providing similar functionality in data representations could greatly enhance their exploration.

5.9 Factors that affect confidence

Confidence played a role in participants' exploration and use of data in their decision-making. We detail several of these factors.

Unfamiliar representations and tools. First, unfamiliar representations such as sonification reduced participants' confidence in their interpretation (P1, P2, P8, P9, P10). As P10 described it, “*I like hearing graphs through sonification it's just something I'm not all that used to, so it may take me awhile to be a more discriminate listener*”. On the other hand, familiar structures provided a way

for participants to confirm their interpretations and increase their confidence. Participants new to sonification (P6, P9, P12) often used the tabular data to check assumptions. Other participants (P1, P5) wanted to download the data and explore it using more familiar tools (e.g. Excel). These tools provided an environment where participants knew what to expect and how to apply known operations, making screen reader navigation faster and interpretation easier.

Relying on others' accuracy and quality of interpretation. Second, participants were less confident using representations where they rely on somebody else's subjective interpretations, such as alt text of data graphics (P3, P5, P10, P12). As P3 described it, *"I'm a little cautious about the description because people who provide the description have to be skilled enough doing it... it needs to be done well."* Participants also recognized how descriptions may only capture what the author chose to include and thus also limit their interpretation, *"somebody had to input that and somebody had to decide which data points were worth mentioning"* (P10). Participants appreciated representations where they were able to make their own interpretations, *"sonified leaves all the language out of it so I can make my own interpretation"* (P5), or provide a method to validate others' interpretations such as through access to the raw data.

Discrepancies in data. Third, data discrepancies within the websites made participants question the reliability of the information or their own interpretations of the data. For example, when users listened to the sonification and wanted to associate the sounds to numerical values, they would check the graph's alt text that described the graph's axis range (P3-P5, P7, P8, P10, P11). In one of the websites, the graph sonification was updated daily but the alt text had not yet been updated. P3 described how they could not tell whether this was a mistake in *"my perception of the sonification"* or whether *"that's just an error"*. Reflecting on this P3 said, *"I'm not being able to trust what's right. Did they just make a mistake in not updating the dates or why is it that there is a discrepancy...?"*

5.9.1 Takeaways. Users need ways to increase their confidence and confirm their interpretation. Factors that reduce users' confidence include relying on others' data interpretations, data discrepancies, and unfamiliar representations and tools. Particularly during times of crisis, building user trust and confidence in accurate information is critical. Several participants were keenly aware of the subjectivity of certain types of information, and one way to build confidence is to provide data tables and downloadable files per accessibility guidelines [2, 50] that enable people to interpret data through familiar methods and tools directly. More generally, as social media and news sources struggle to contain widespread misinformation [39, 56, 103], broadening data literacy can empower individuals to explore, interpret, and evaluate data-driven sources on their own. Several participants indicated that new technologies, such as sonification, can help people understand data in new ways. Leveraging accessible websites to teach data concepts can empower users to more confidently evaluate their data-driven sources and access new types of information.

5.10 Diversity of preferences for consumption

Participants had diverse preferences for representations, modalities, and levels of abstraction to understand the information and make a decision. Though many of these preferences were influenced by

participants' prior knowledge, experiences, skills, and confidence discussed in prior themes, in this section, we focus directly on these diverse needs and preferences as considerations for broadening data engagement on the web.

Varied preferences in the level of data abstraction needed to complete data task. While some participants expressed that key takeaways were sufficient (P5, P7), others expressed the need to investigate the progression of specific data values over time (P1, P10, P11). P10 stated that *"the nice thing about looking through the table is that I can see the actual numbers, and somehow that makes it more concrete for me."* Participants, many of whom wanted access to specific values, recommended broadening the level of data abstraction available through sonified graphs by adding the ability to zoom in on sections, retrieve values, and add speech annotations.

Varied preferences in the modality used to interact with the data. Some participants preferred hearing descriptions of the graphs (P2, P3, P7), while others appreciated being able to gain an overview of the trends through sonification without the mental load of associating words to graphical concepts (P1, P4, P9, P12). P2 contextualizes her preferences to her prior experiences, stating *"To me, I don't have a lot of experience [with] graphs so I always go by verbal description."* In contrast, P12 described having to *"be very cognitively engaged"* in order to comprehend the data, and a benefit of sonification is that they *"wouldn't need to know English."* Sonification, unlike alt text, provides a more direct perceptual mapping. While certain modalities such as speech require higher cognitive loads to interpret and remember, factors such as prior experience and familiarity discussed in 5.7 also contribute to user preferences and are important to consider.

Leveraging insights from multiple representations to fill gaps in understanding. A number of participants used representations of broader-level information, such as sonification and alt text, to contextualize and inform more detailed explorations of the table (P3, P6, P7, P9-P11). As P11 put it, *"the description really paints a picture of the graph in my mind and the table actually gives the real values."* Most participants also used textual descriptions to gather contextual information missing from the sonification (P2-P8, P11, P12) in two ways: retrieve both trends and snapshot summaries of current statistics, and contextualize what they heard using the alt text description of axes ranges. Enabled by the fact that the representations convey data on different levels of abstraction, we observed how participants complement their understanding of the data by making use of multiple representations.

5.10.1 Takeaways. Participants preferences for different modalities and levels of data abstraction affected how participants interacted with the various data representations available. While much research progress has been made investigating more compelling methods for users to interact with data, many challenges such as the lack of standardization, authoring support, and awareness hinder their quick dissemination to the public. During times of crisis when providing immediate access is important, our findings show that participants can integrate information from more standard representations with existing web-support to form deeper understandings of data. We found that almost all participants leveraged insights from multiple representations to complement information gaps of each individual representation (P3-P12).

6 DISCUSSION

Data accessibility has been an important topic of research for several decades. In light of the COVID-19 health crisis, dissemination of data-driven information became even more essential to not only domain experts, but also the general public. We postulated that this increase in prominence of data might have exacerbated the accessibility gap for the BVI community and exposed new issues that may otherwise have been difficult to study. Our findings and observations during this critical period of time provide an understanding of the impact access or inaccess has on the BVI community.

6.1 The importance of access

BVI users observed broader lack of accessibility to sources of reliable data in publicly available websites at early onset of the pandemic, echoing findings of earlier COVID-19 work [43, 53]. Widespread concern indicated by survey respondents and BVI users' participation in advocacy efforts further emphasizes the importance placed by the community to ensure proper dissemination. Historically, PWD have had to widely advocate for their needs to affect change [84]. In times of crisis, when demands in society and needs are changing rapidly, this places an even larger burden on the BVI community on asserting their need to make informed decisions and maintain their safety.

6.2 An ecosystem for access now and in crisis

At the same time, the extreme demand for information and the rapid pace at which it was being disseminated also placed a burden on the content creators. Several of the websites we used as a *site* to examine these issues were created by independent organizations and individuals, many of whom were offering their time and effort as a public service while also being impacted by the health crisis. While accessible non-visual ways to present a variety of data graphics have largely been investigated in research [36, 77, 78, 102, 105], few have been translated to standard web tools for use in practice. The lack of web guidelines and public websites using multimodal representations and supporting data-driven tasks for screen reader users leaves content creators with a lack of guidance or precedent to rely on. We advocate for greater efforts to integrate accessible data features into everyday web tools in a way that web-developers can easily incorporate into their workflows rather than having to bootstrap resources together from disparate tools and guidelines. Prior studies conducted during other times of crisis have also maintained that proper infrastructure had not been in place to ensure PWD have access to essential information [93, 99]. We observed from both the survey and contextual inquiry how community groups, allies, and blindness organizations can fill this important need for BVI users. A common workaround when BVI users encountered inaccessible graphics in news articles was to compliment their use and understanding with information and data from community and blindness organizations. Examining more closely how these groups incorporate accessibility throughout their client-facing services and amplifying their work can provide a model for practitioners looking for recommendations. Particularly as COVID-19 was a global crisis in which there were many national efforts that BVI users could rely on to be informed, attention towards how local

groups effectively interact to disseminate information would be critical in the event of more localized future crises.

6.3 Confidence and trust in available content

Our findings reaffirmed that spatial representations are particularly difficult to access for BVI users; often leaving users with low expectations for their accessibility. Most of the visualizations that participants and survey respondents indicate having interacted with focused on time series data depicting trends on the progression of cases, deaths, hospitalizations, etc. Available representations did not include other forms of spatial graphics commonly used to convey data about the pandemic [4, 64], such as maps of hotspots. This leaves a large part of information inaccessible. As a result, we also observed how BVI users more often look to other sources of information. These sources include radio and news videos, which add an additional layer of interpretation that can often vary in the depth of information and contextualization presented. Several respondents questioned the objectivity of the media sources they encountered and expressed a desire to understand what is true through more objective sources. During times of crisis where misinformation has globally proliferated through social media and news sources [39, 56, 103], we observed that broadening access to data sources in ways that users can form their own interpretation enables users to gain confidence in the information they consume.

Examining more closely BVI users interacting with data on the web, we observed remaining barriers that affect users' strategies and takeaways. In the next sections, we discuss our findings in a broader context from the COVID-19 health crisis and point to important areas of further work needed to address accessibility barriers now and in future times of crisis.

6.4 Enriching access

Throughout the study, users described several challenges with inaccessible data presented on the web. Some of these issues are well documented in prior work [23, 61] and can be addressed by following guidelines [2, 50]. However, our findings emphasize how simply providing access is not sufficient. Users want more ways to engage in a diversity of data-related tasks and goals. There is a need to not just address the accessibility issues but also to provide more effective methods of interaction. These echo similar affirmations in prior work on the intricate relationship between accessibility and usability of the web for BVI users [20, 63, 94].

Several opportunities exist for creating richer screen reader interactions with alt text and tabular data on the web, especially for complex datasets. These representations offer limited affordances for data-oriented tasks and more often place a larger cognitive burden on users [29, 33, 58]. Interactive representations could be a potential solution. Godfrey et al. explored an interactive hierarchical navigation model to break down data exploration over multiple layers of abstraction [44]. Morris et al. introduced a taxonomy of relevant properties for augmenting non visual representations [69]. While that work did not focus on data representations, some of the proposed interactions such as "progressive detail" and "question & answer" could be suitable for enhancing screen reader interactions with both alt text and tabular data, and echoed recommendations

made by several of the participants. These techniques could provide users better access to different levels of abstractions and regions of interest in the data, as well as address the cognitive burden of filtering through dense representations.

6.5 Novel modalities & interactions

Data journalism and web-based representations reach wide audiences with varying data literacy [85]. We made observations on the impact of data literacy on understanding and the importance of users being able to make associations between the various representations and data literacy concepts. Audio-driven narratives could offer an opportunity towards making data concepts even more approachable. Data-driven stories have been increasingly used in journalism to communicate data insights in a way that is engaging to both novices (through context) and experts (through the data) [81]. Interactive and multimodal audio narratives that provide context through speech and data through sonification could broaden access to data on the web while supporting data literacy skills. Prior in-lab controlled studies have shown success at conveying spatial information using sonification [40, 72, 106] and our observations support these findings even with users that had minimal training or experience.

While there is a lot of potential for leveraging sound to better communicate spatial information on the web, our observations also point to key challenges towards enabling these interactions. One immediate need is establishing more standardized techniques of mapping data values to different sound properties or provide users with a better understanding of these mappings. Mismatches and lack of training lead users to misinterpret the data and/or reduce their confidence in the insights gained. Another challenge is developing authoring tools that support the creators of these interactions. Though several web-based audio libraries exist [10, 15, 17], these follow a musical framework rather than a data-driven framework. Mapping musical parameters to salient data graphic features is non-intuitive requires knowledge in auditory perception [29].

6.6 Multiple representations & modalities

We observed how users leveraged multiple representations to fill in for the gaps inherent in one another and altogether gain a more holistic understanding. Thus, we recommend using representations in tandem to complement their respective strengths and shortcomings, in addition to fulfilling users' diverse preferences for data abstraction and modalities. However, this process using existing technologies often require users to retain multiple pieces of information as they navigate between the representations. A promising area of research is investigating how to make more explicit the connections between multiple complementary representations. Providing more tightly coordinated views could accommodate for users' diverse needs and preferences for learning.

Another way to provide more holistic overviews of data is to leverage multimodality. Multiple modality channels can be used to delineate between the different levels of abstraction. Past work has largely considered multiple sensory modalities as a way to leverage strengths across sensory systems [18, 45, 67] but less so on leveraging multiple communication channels within the same sensory modality. Investigating multimodal ways of conveying data

on multiple levels of abstraction through different web-compatible communication channels could also improve how data is conveyed.

7 LIMITATIONS & FUTURE WORK

While our online survey reached 127 users and provided an informative sample of perspectives, there are limitations when considering the findings in light of our sample and study design. First, the range of visual abilities is diverse and users rely on different assistive technologies in different ways. All participants were screen reader users and in the contextual inquiry, most observations were made with participants using JAWS (one of several screen readers). Second, self-selection bias can affect the range of perspectives captured by our study. Participants that opted to participate might have a particular interest in the topic. Third, in the contextual inquiry, we used a think-aloud protocol and two of the experimenters were present for conducting the study and note-taking, both of which may affect users actions. Expanding on the methods used to investigate this topic (e.g. case studies, diary studies, instrumented websites for automated data collection, critical incident analysis, etc) could add to the dimension of findings and perspectives reported.

The space of data visualization and journalism in the web is also broad. The perspectives we heard from users through the survey may be limited by what users have been aware of or encountered. For example, we did not hear from any survey respondents about their interaction with data graphics using SVG elements, which have become prevalent with interactive web visualizations. It might be that these are entirely inaccessible to BVI users or that given the lack of accessibility in this domain, users don't seek out this particular type of content. Moreover since we focused on data representations that are available based on standards and survey responses, the contextual inquiry findings may be under-representing the range of interactions BVI users may come across on the web.

8 CONCLUSION

Data visualization has taken great prominence as a means of effective communication and has played a vital role broadcasting the progression of COVID-19. Its rise has been enabled by advances in design and theories that make them approachable to the general public, as well as technology developments that make it easier for authors to create engaging and interactive visualizations. Accessible data representations, on the other hand, have lagged behind, leaving areas of information out of reach for many BVI users. In this work, we report on the experiences of BVI users accessing data representations available on the web during the early period of the COVID-19 pandemic. Our study highlights: 1) the impact that information access inequities have on the BVI community when exacerbated by a time of crisis, and 2) the important need to make larger strides towards improving the technologies and modalities available to disseminate information accessibly on the web.

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A APPENDIX: CONTEXTUAL INQUIRY DEMOGRAPHICS AND COVID-19 WEBSITES CODED BY ACCESSIBILITY FEATURES

Table 1 summarizes demographics for participants of the contextual inquiry. Table 2 summarizes websites visited during the contextual inquiry and their accessibility features.

B APPENDIX: EXAMPLE OF WEBSITES VISITED DURING CONTEXTUAL INQUIRY

	Described Level of Vision	Gender	Age Group	Braille display	Screen reader	Tactile Graphics Expertise	Audio Graphics Expertise	SGL Avg (1-6)	Additional Websites Used
1	totally blind	Male	65-74	Y	JAWS	Expert	Advanced beginner	5.4	CVStates [64]
2	totally blind	Female	65-74	Y	JAWS	Advanced beginner	No experience	1.8	N/A
3	totally blind	Female	25-34	Y	JAWS	Expert	Proficient	4.6	N/A
4	Optic Nerve Hypoplasia	Male	25-34	N	NVDA	Proficient	Advanced beginner	4.2	N/A
5	totally blind	Female	45-54	N	JAWS	Advanced beginner	No experience	4.6	N/A
6	totally blind	Male	18-24	N	VoiceOver	Competent	Advanced beginner	4.4	N/A
7	totally blind	Female	35-44	N	JAWS	Proficient	Competent	4.2	COVID Act Now [8]
8	totally blind	Female	55-64	N	JAWS	Advanced beginner	Advanced beginner	3.6	Chicago Tracker [6]
9	light perception only	Female	35-44	N	JAWS	Expert	Proficient	4.2	who.int [16]
10	totally blind	Female	55-64	Y	JAWS	Proficient	Competent	3.8	CVStats [64], MN Tracker [11]
11	totally blind	Male	25-34	Y	JAWS	Expert	Expert	5.4	CVStats [64]
12	Extremely low ~vision, right above light perception	Male	25-34	N	NVDA	Proficient	Expert	4.6	CVStats [64], covid.ski [4], Canada Covid Tracker [7]

Table 1: Demographics for participants of the contextual inquiry

Website	Mention	Accessibility Branded	Tabular				Sonification				Data Graphic								Summaries	
			historical data	sortable	filterable	csv download	interactive	panning	retrievable values	time indicator	svg	alt text	graphic title	plot type	labels/units/ranges	axes increments	colors/patterns	trends/values	snapshot	interpretations
CVStats [64]	Task	Y	N	Y	N	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Accessible Data [3]		Y	Y	N	N	Y	-	-	-	-	N	Y	Y	Y	Y	Y	Y	Y	-	-
covid.ski [4]		Y	N	N	N	N	N	Y	N	Y	N	Y	Y	Y	Y	N	N	N	Y	N
COVID Act Now [8]	Interview	N	N	Y	N	N	-	-	-	-	Y	N	Y+	N	N	N	N	N	Y	Y
who.int [16]		N	N	Y	N	Y	-	-	-	-	Y	N	Y+	N	N	N	N	N	Y	N
CDC Data Tracker [5]		N	Y	Y	N	Y	-	-	-	-	Y	N	Y+	N	N	N	N	N	Y	N
Chicago Latest [6]		N	N	N	N	N	-	-	-	-	Y	N	N	N	N	N	N	N	Y	N
MN Health Tracker [11]		N	Y	N	N	N	-	-	-	-	N	Y	Y	N	N	N	N	N	Y	N
COVID Tracking [9]	Survey	N	Y	N	N	Y	-	-	-	-	Y	N	Y	N	N	N	N	N	Y	N
CA Accessible Library [7]		Y	Y	N	N	Y*	Y*	Y*	Y*	Y*	N	Y	Y	Y+	Y+	Y+	Y+	Y+	N	N
SAS COVID Hotspots [13]		N	Y	N	N	Y*	Y*	Y*	Y*	Y*	N	Y	Y	Y*	Y*	N	N	N	Y	N

* Requires plugin installation + Outside of alt-text - Not Applicable

Table 2: Websites visited during the contextual inquiry and the accessibility features each provided at the time of access.

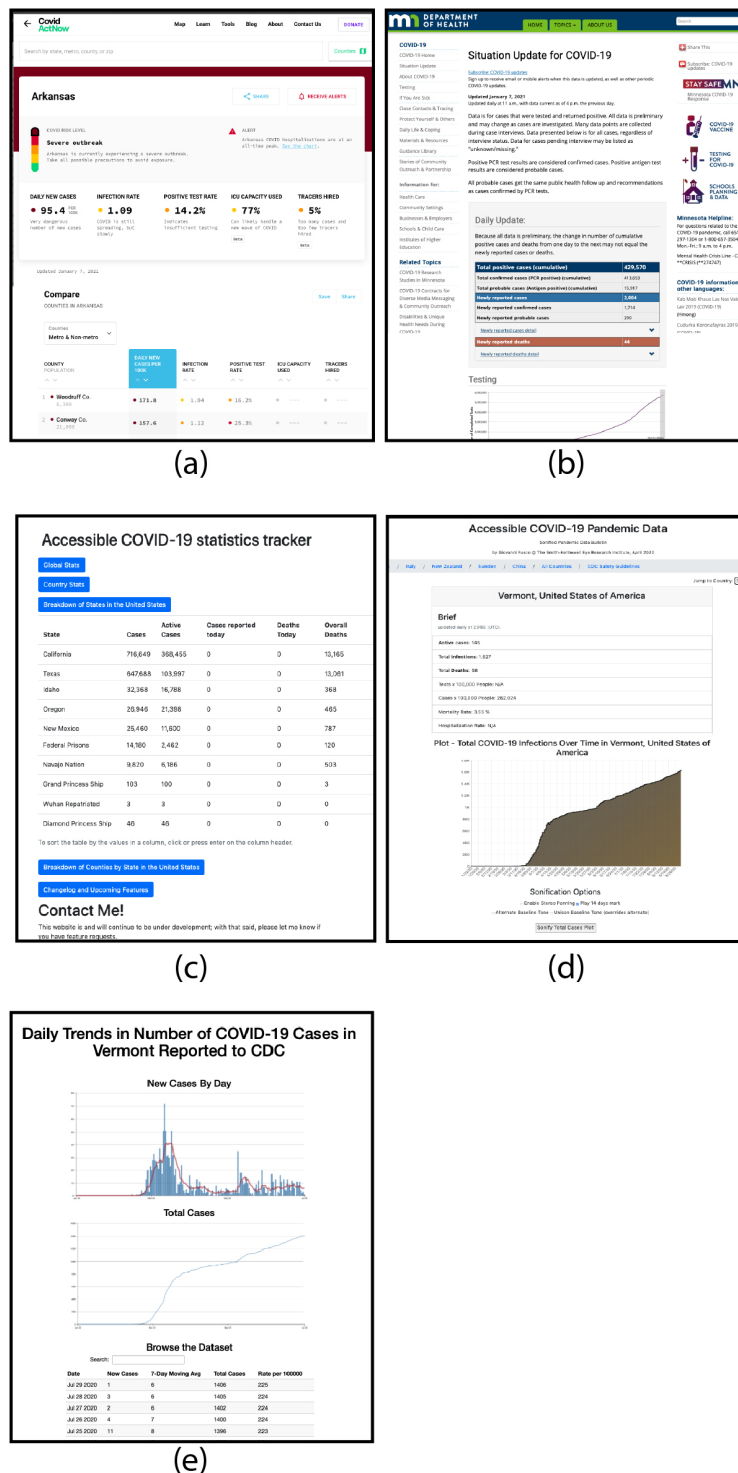


Figure 3: Sample of websites visited during the contextual inquiry. a) COVID ACT NOW presented data primarily through tables and provided a brief summary. b) MN Department of Health Situation Update provided a summary in the form of text and key statistics. c) CV Stats provided tabular data. d) COVID SKI provided access to sonification of different data charts as well as summarized tabular data. e) Accessible Data provided access to image descriptions and tabular data.