EVALUATION OF A NON-VISUAL AUDITORY CHOROPLETH AND TRAVEL MAP VIEWER

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ABSTRACT

The auditory virtual reality interface of Audiom, a web-based map viewer, was evaluated by thirteen blind participants. In Audiom, the user is an avatar that navigates, using the arrow keys, through geographic data, as if they are playing a first-person, egocentric game. The research questions were: What will make blind users want to use Audiom maps? And Can participants demonstrate basic acquisition of spatial knowledge after viewing an auditory map? A dynamic choropleth map of state-level US COVID-19 data, and a detailed OpenStreetMap powered travel map, were evaluated. All participants agreed they wanted more maps of all kinds, in particular county-level COVID data, and they would use Audiom once some bugs were fixed and their few recommended features were added. Everyone wanted to see Audiom embedded in their existing travel and mapping applications. All participants were able to answer a question evaluating spatial knowledge. Participants also agreed this spatial information was not available in existing applications.

1. INTRODUCTION

There is an overwhelming need among the world's 285 million blind and visually impaired individuals (BVIs) to access and understand the numerous digital maps that are ubiquitous in daily life, like Google Maps [1], [2]. None of the existing map tools are usable to BVIs, with the major map developers only providing token access to the data for non-visual users [3]–[6]. The U.S. federal government and many states are required to purchase inclusive technology, but the web map components on every government website are only visual, and the unacceptable alternatives, such as a table or address search, that are infrequently provided, are only 20% effective, compared to the 100% effectiveness of the interface we present in this paper [7]–[11]. Some of the main reasons for this lack of inclusion are the limited research on non-visual maps, and no commercial non-visual map tool. This project, Audiom, was developed to be a cross-sensory visual, auditory, and text-based mapping tool that could show both thematic (geographic information coupled with variables, like choropleth maps) and referential (that focus on spatial relationships, such as travel maps) geographic maps [12], [13]. The auditory map was the primary focus of this study. The research questions behind this evaluation were: What will make blind users want to use Audiom maps? And Can participants demonstrate basic acquisition of spatial knowledge after viewing an Audiom map?

To evaluate spatial knowledge from viewing maps, the framework of "route, landmark, and survey knowledge" can be used. Siegel presents three types of knowledge that are critical to map comprehension [14]. First, landmark knowledge, the identification of geographic locations, such as home or a particular intersection. Landmark knowledge is the most basic level of knowledge and is based on perceptual stimuli, such as the sound of a fountain, the visual appearance of a house, or the smell of a restaurant. The second type, route knowledge, is the knowledge of landmarks in a particular order that comprises a minimal egocentric-based mental model. It is primarily represented as lines connecting landmarks. The final type, survey knowledge or gestalt knowledge, is a sophisticated mental representation of landmarks and routes judged as critical in navigation, organizing experiences, and possibly discovering alternative routes between landmarks. Maps enable the acquisition of all three of these types of knowledge. Brock et al. presents a list of questions to evaluate these three types of knowledge on maps [15]. These would include participants listing all the objects in a space, selecting the longest distance between two pairings of objects, and describing where objects are in relationship to one another. Zhao et al. extends their spatial knowledge evaluation to include multiple variables along with the spatial information [11]. This could include questions such as: find what city bordering Atlanta has the highest unemployment rate. A temporal dimension could be added to this question as well: find what city bordering Atlanta, including Atlanta, had the lowest sustained level of unemployment from 2010-2020. Any map interface should evaluate, at the minimum, the acquisition of these three types of spatial knowledge by the user.

Non-visual maps for BVIs historically consisted of raised-line tactile graphics that have been expensive and difficult to obtain [16]–[19]. In 2017, the Tactile Map Automation Production System (TMAPS) was launched to provide inexpensive neighborhood paper tactile maps to BVIs. Biggs et al. evaluated the effect TMAPS had on its users and found map usage for those BVIs with embossers at home who could freely emboss TMAPS increased from fewer than one map a year to over eighteen, and from fewer than one map a year to two for those ordering TMAPS from an embossing center [20]. Users described how GPS turn-by-turn directions are useful, but do not provide an overview of an area, and do not provide the confidence needed to go out. Users also asked for a way to digitally view TMAPS before embossing. The main problem with tactile maps is that they are required to be physically embossed on paper using an expensive embosser and have difficulty showing dynamic and complicated information [21], [22].

The current method for making maps on the web is by presenting a text representation. There are typically four methods that are used: providing a custom text description for a simple static map, providing turn-by-turn directions, providing a table of data, or having an address search that will show a list of nearby addresses or a single value at that address. Text descriptions can be attached to an image element, and describe the important features and relationships in a map [23]. Turn-by-turn directions present a list of instructions between points of interest [24]. Tabular data is the raw numeric information that is presented on thematic maps, and has columns for variables and rows for data points [9]. Address searchers will show users information about their location (like the air quality) or a list of nearby addresses [25]. There have been some attempts at creating interactive maps that pan and present a list of points in the frame to the user, but there is little adoption of these methods [4], [5]. Zhao et al. compared tables with a similar interface to Audiom's choropleth map, and found that seven BVI participants were 20% accurate at answering spatial knowledge questions using a table, vs 95% accurate when using their interface [11]. There has been little research comparing the effectiveness of these map types, but the address search and table, in particular, are missing the geographic information completely, and users without existing spatial knowledge are unable to understand the spatial trends [11].

2. PREVIOUS RESEARCH

Scalar Vector Graphics (SVGs) are individual HTML elements that can have a name and description attribute, and are often described as being accessible (they pass automated accessibility checkers), but they do not show the spatial information that is critical for map usage by default [26]. Calle et al. described a mobile interface that allowed the screen reader to access the features around the user's current location in an SVG format [27]. The user would tab through the features and hear the locations around their location. The users stated the application was easy to use, but gave little to no descriptions about the location. The research was performed on four BVI participants, and there were no questions or tasks evaluating spatial knowledge while using the map. Juan et al. also developed a system to present the geographic information of buildings to BVIs using SVG content [28]. The system grouped buildings together, and when the user selected a group, they could tab through the buildings and hear their names and descriptions. Other functionality was provided around describing what building the user was facing, and providing an interface to adjust the range around the user to look for buildings. No evaluation was performed with users, and it was unclear how spatial information could be communicated through this interface.

Digital auditory maps have had both referential and thematic prototypes. Feng et al. and Loeliger et al. presented a Windows-based referential travel map system powered by OpenStreetMap that allowed users to navigate along streets by a user defined distance and hear points of interest in spatial audio around them, represented by looping iconic sounds, such as clinking plates for restaurants [29], [30]. This idea of spatially presenting features was based on an evaluation performed in Heuten et al. [31]. As the user moved around the map, they would receive dialogs describing intersections, turns, and features using text to speech. Performance varied among the 72 participants, but by making the interface into a game, the authors were able to measure the acquisition of spatial knowledge. Difficulties participants had were with the automatic turning to follow roads, and lack of texture information for features.

Guerreiro et al. presented two speech-only referential map interfaces, a jumping interface that allowed users to move between points of interest (POIs) and intersections, and a walking mode that simulated someone walking the route [32]. What was unique about these interfaces is that they were both accessed via an iPhone, contrary to most other audio map interfaces that were exclusively accessed on a desktop or laptop computer. The system used the phone's gyroscope to determine the user's orientation, and users controlled the movement speed by tilting the phone. Participants preferred the walking mode, but admitted both would be useful. Participants performed well at physically navigating, and appreciated the access to spatial information this system gave. The problem was there were no bus/transportation POIs, participants had difficulty estimating distance, and the interface was slow to use.

Zhao et al. presented a Java application choropleth thematic map representing the population data in each U.S. state [11]. Their interface combined a table interface with a grid that had each state in its own square. Pressing the arrow keys would move between states, and would play a pitch correlated with the data in that state, along with a speech message stating the population number. Users could quickly switch between the table and map, and they could press a key to play a "gist", where all the states were played one at a time from left to right in a row. They evaluated the interface with seven BVI participants, and found the interface was 95% accurate when participants answered geographic questions, compared with the basic table in Excel which had 20% accuracy on similar geographic questions. Further, participants were able to describe themes on unfamiliar spatial data using iSonic, whereas the Excel table restricted participants to using their previous geographic knowledge to ascertain spatial relationships. Participants loved the system, and performed well using the table and geographic interface that were synced. They did not like the lack of geographic shapes, had difficulty performing variable correlation tasks, and found it difficult to learn the interface, spending an average of one hour and 49 minutes on the tutorials.

There are many applications BVIs use to assist with wayfinding, see Swobodzinski et al. for a comprehensive review, but none of the pre-trip planning functionality in any of these apps has been evaluated for spatial knowledge comprehension [33]. Apple Maps has a patented interface where users can move their finger around the screen and hear a tone when their finger goes over a street or intersection [34]. Ariadne GPS also requires the user to move their finger around the screen, although it plays different sounds and speech messages when the user goes over features [35]. Goodmaps has what's called a "look Around" feature, where one can set themselves at a location and physically rotate the phone to hear what's in that direction [36]. Google maps has an interaction for the computer and another for the phone. On maps.google.com on the computer, users have a box they move around the map with the arrow keys, and points of interest within that box are assigned a number. To hear information about a point of interest, the user presses the corresponding number on the keyboard and that point of interest is opened. On the phone, users select their destination, and are given a set of directions they can swipe through using their screen reader [4]. Microsoft SoundScape allows users to get an overview of what's around them in spatial audio at any point in time by either rotating their phone, or pressing a button to hear what's around. SoundScape also allows users to virtually move by intersection and hear what's around at each corner [37]. Future research needs to be done on these interfaces to evaluate their effectiveness at communicating spatial relationships.

The mapping systems described above provided some conventions that can be reused, but unfortunately none of the applications gained traction in the BVI community, and have not been reproduced in any commercial mapping application. The referential conventions that seemed most effective include representing points of interest with spatial sounds, using environmental sounds to represent objects, allowing for a walking mode, and enabling users to scan around their current location. The thematic map conventions that seemed most useful included the pitch representing data along with the speech saying the value, having a table along with the geographic map, and allowing users to navigate the geographic map with their arrow keys. The novel system described here, Audiom, aims to combine both referential and thematic interfaces into one platform, and use the most effective elements from the above interfaces while expanding functionality around shape recognition and customizability.

3. AUDIOM PLATFORM

Here is a video of the travel map:
https://www.youtube.com/watch?v=kY6w7U2uxYc&feature=emb_imp_woyt
Here is a video of the choropleth map:
https://www.youtube.com/watch?v=vISYiHcZM-U&feature=emb_imp_woyt
Here is the project site with interactive demos:
https://audiom.net/

The auditory viewer of Audiom was initially described in Biggs et al., and has subsequently been expanded and improved to the current version [38]. The previous interface was on a custom map of a playground with around 40 objects, had no statistical information or choropleth version, and was not connected to any live data source. The current version implements new features, such as turning on the ability to turn on borders of an object, providing distance information in menus, showing a menu of nearby objects, changing the scan to say distance information, and showing statistical information in a choropleth map. The current interface was programmed using JavaScript and works on any platform with a modern browser utilizing the Web Audio API (e.g., Chrome, Safari, or Firefox [39]). Audiom can be either self-voicing, or interfaced with any screen reader. The interface version that was evaluated here does require a keyboard to operate. The Audiom system was designed to build on the best aspects of prior systems, such as those found in Loeliger et al. [30], Zhao et al. [11], and Wilson et al. [40], and analyzing conventions present in audio games, which are games that have been made by and for blind individuals. Audio games present a set of auditory map conventions that have been tested by the commercial marketplace [41]. The auditory interface in Audiom has three modes of navigation that employ an egocentric (from the user's point of view) perspective to the user, which is more understandable to BVIs than an allocentric perspective (3rd-person view, or how visual maps are presented) [38], [41]–[44].

Users are represented in the space as an avatar that moves a user-defined distance (e.g., 2 meters on the travel street map, or 50 kilometers on the choropleth map) when the arrow keys are pressed (up-arrow to move north, down-arrow to go south, left-arrow to go west, etc.). All objects are given a name, such as "Fillmore Street," that is announced by the user's screen reader as a spearcon and rendered in text as the user moves over the object [45]–[47]. Users can open an object menu of all the objects in the map by pressing "m", and a menu of nearby objects can be opened by pressing "shift+m". As users arrow through the objects, the short sound of that object (the sound heard when the user moves over the object) plays. Users can get directions to an object by hitting enter on the object in either menu, and choosing "Directions" from the submenu. They then get directions such as: "Joya is 35 meters, ahead and to the right." As participants navigate, they can press "d" again to hear the updated distance and direction. Both the choropleth and travel map use the same interface, but there are a few distinct differences.

To use the travel map, users enter an address in a Google Maps autocomplete embedded on the project website, then hit Enter on the address [48]. All map features in the environment that fall within a 1km bounding box centered around the user are then returned from OpenStreetMap (OSM) [49]. The travel map utilizes binaural audio to represent objects in space around the user by playing a looping auditory icon representing the object, such as dishes clinking for a restaurant [[29]; @ Gaver1986]. The looping sound is positioned to always be at the nearest point to the user on the polygon, and is centered while the user is inside the polygon. Objects can also be represented by a short "step" auditory icon that is representative of the object or surface underfoot, such as a metallic footstep for a set of bleachers or an asphalt footstep for a road, as the user moves over the object [50], [51]. These conventions improve on the interface in Loeliger et al. by allowing free navigation around the space, rather than constraining users to the road's or pathway's line string [30]. Borders for objects can be activated or deactivated by pressing "b", and users can be constrained to an object if they wish. When borders are on and users hit the border, a collision sound plays, and the user stays at their current location. Roads in OSM are expanded to have size, similar to how visual roads are represented as one or two pixels wide. Users can also scan to hear the name, distance, and direction to the nearby objects. For example: "Joya At 339 University Avenue is right here, University Avenue is 4 meters, directly behind, La Strada At 335 University Avenue is 5 meters, directly behind, Medallion Rug Gallery At 353 is 10.6 meters, ahead and to the right, Wells Fargo is 17.9 meters, behind and to the left…" This scan functionality is similar to the "survey" feature in many Multi User Dungeons (MUDs) [47].

The choropleth map has both a tabular view and geographic view that are connected, similar to the iSonic platform [11]. In the tabular view, each row is one of the US states, and each column is a statistic about the state, such as total cases, deaths per one million, or total tests. Each cell has the exact number that refreshes every 24 hours from [52], and plays a pitch relative to other pitches in the column, so users can identify whether the state has higher or lower values than other states. Users can jump to the top or bottom of the column by pressing ctrl+up or ctrl+down arrow keys, and they can sort columns by ascending or descending by hitting enter on the column header. When users hit enter on a cell, their location is jumped to the geographic view in the center of the state, and the statistic on the geographic map switches to be the same as the cell the user is on. The user can then use their arrow keys to navigate by 50km around the map. As users move to a new location, the state's relative pitch from the tabular view will play, along with the state name, followed by the number and statistic type. Users are then able to identify the spatial relationships between objects, and identify how the selected variable changes over space.

In Biggs et al.; the authors performed a basic evaluation of Audiom [38]. Ten BVIs used the Audiom system in audio mode to explore a custom-built map with around 50 features. Participants were able to find features (thus displaying landmark knowledge) and describe relationships between irregularly shaped features [38]. Ninety percent of the participants were able to verbalize an accurate overview of the map (thus displaying survey knowledge), in contrast to only routes and landmarks such as in Guerreiro et al.; and 70% were able to follow and describe a curved pathway (thus displaying route knowledge) [32]. The current evaluation looked at how users of the latest Audiom version interacted with map data not explicitly made for Audiom, and with over a thousand features per square kilometer.

4. CURRENT EVALUATION METHOD

The research questions this evaluation aimed to answer were: 1) What will make blind users want to use Audiom maps? And 2) Can participants demonstrate basic acquisition of spatial knowledge after viewing an Audiom map? Past research on Audiom from Biggs et al. was on a custom dataset from a playground in Palo Alto CA, something not relatable to participants [38]. The version evaluated here can show any address in the world, and shows real-time COVID-19 data over the United States. This more relatable information was used as the foundation of the research question of what will make participants want to use Audiom. The second question of demonstrating spatial knowledge was inspired by the framework of landmark, route, and survey knowledge from Brock et al. [15]. Could similar questions be used to evaluate spatial knowledge in a digital auditory interface?

The questions around spatial knowledge were meant to act as a pilot for future experimental studies. Different questions were evaluated with the travel map between participants, but the questions all participants answered on the choropleth map were: What state bordering California has the highest number of COVID cases per one million? (This evaluated if participants understood variables presented on the geographic map and could connect them with the spatial relationship between features.) And, What are the top three states with Cases per one million? (This evaluated if users could operate the table). The questions that were asked related to the travel map were based on [15] and included: Using clock face directions, where is Sliderbar when positioned on Joya? What is farther away as the crow flies: Medallion Rug Gallery, and JP Morgan, or CVS Pharmacy, and Letter Perfect? These questions evaluated survey knowledge (one of the three spatial knowledge categories described by [14]), along with route and landmark knowledge. Survey knowledge is the understanding of the gestalt relationships between features, enabling discovery of alternative routes and the ability to combine routes.

Thirteen BVIs evaluated this platform out of fourteen total, P12 did not complete the evaluation:

Table 1: Participants

Attribute	Age	Hispanic or Latino	Racial category	Gender	Vision Level	Have Read	Travel Aid	Travel Skill
P1	62	n	White	f	Light perception	y	Dog	4
P2	42	n	White	m	Totally blind	y	Cane	3
P3	25	n	White	m	Light perception	n	Cane	3
P4	20			m	Totally blind	n	Cane	3
P5	64	n	White	f	Low vision	y	Cane	5
P6	30	n	Asian	f	Light perception	n	Cane	4
P7	57	n	Black or African American	m	Light perception	y	Dog	5
P8	40	n	White	f	Low vision	y	Cane	3
P9	68	n	White	m	See shapes	n	Dog	5
P10	31	y	White	nb	Light perception	n	Cane	4
P11	33	n	White	f	Totally blind	y	Cane	4
P13	34	n	Asian	m	See shapes	y	Dog	5
P14	48	n	White	m	See shapes	n	Dog	4

Participants were selected using a convenience sampling and effort was made to include a diverse sample. Six participants were between the age of 20-39, four participants were between the ages of 40-59, and three participants were over the age of 60. There were five females, seven males, and one non binary gendered participant. There were nine participants who identified as white, two Asian, one Black or African American, and one participant without a response. There were two participants who had low vision, three that could see shapes, and eight that were light perception or totally blind. Seven participants had experience reading visual maps, and six had never seen a visual map. There were five dog guide users and eight cane users. On a scale of 1-5, where five was extremely good, and one was not at all, four participants rated their travel skill as a three, five as a four, and four as a five.

The evaluation took around one hour, was performed and recorded over Zoom with participants sharing their sound, and was approved by the institutional review board at the Smith-Kettlewell Eye Research Institute. Participants were compensated $30 per hour for participation. This mixed-methods study consisted of four parts: 1) Participants completed a demographic survey along with questions about their feelings around travel; 2) Participants were interviewed, using a semi structured interview, about their feelings and travel process; 3) Participants reviewed both the COVID-19 choropleth map and travel map, and answered basic questions about spatial relationships between features; 4) Participants gave feedback on what they liked, didn't like, thought needed improved, wanted before recommending it to friends, and wanted before using it themselves.

Interviews were evaluated using an inductive thematic coding technique [53]. There were three phases to the coding process: 1) Interviews P1 through P4 were coded by two independent coders, then compared to achieve an inter-coder reliability of 100%. Initial inter-coder reliability went from 54.26% on P2 to 80.43% on P4 with an average of 67.01%. The remainder of the interviews were coded by one independent coder, and compared with the researcher's notes. Codes included short phrases that quoted and summarized the main points such as: "I would only want a map when going on trips". This process distilled interviews into meaningful phrases that could easily be grouped; 2) Codes were then categorized/grouped by the researcher into statements such as: "Only want map when traveling". 3) Finally, categories were grouped into six themes: Past behavior; Future behavior; Feature requests; Liked Features; Bugs; and Comments on traveling apps. Because the research question centered around what would make participants want to use Audiom, easy to fix bugs and features were implemented as time went on, so later participants could focus on more important aspects of the platform. P1-4 searched for an address of their choosing, but this often landed them in a map with less than a hundred features. P4 explained that the travel map "is pretty bare". Although traveling through sparsely populated data needs to be improved, the system performed better in more dense areas. After P4, all participants searched for "Joya Palo Alto", a restaurant in a map with over 1100 features.

5. RESULTS

There were 58 categories of codes with two or more participants in agreement, 37 of which were feature requests. Below is a table with codes that had six or more participants mention it. Because the questions were open-ended, the responses were broad and only agreed on a few items. This only meant that the feature request was not explicitly mentioned by the participant; it doesn't mean participants don't agree it should be a feature. The next step in this line of research is to survey participants with a list of feature requests, and have them sort the requests in priority.

Table 2: Category Counts

Category	Count	Type
I want more maps	13	Feature requests
Want City and or County COVID data	13	Feature requests
I would use Audiom now or when bugs are fixed	13	Future behavior
Want mobile app	10	Feature requests
I use travel apps, like Google Maps, to plan trips	9	Past behavior
I have hardly traveled since the pandemic began	7	Past behavior
Add more/make better sounds	7	Feature requests
Want to place beacons/points	6	Feature requests
Want to jump between features	6	Feature requests
I would like to filter features on the travel map	6	Feature requests
I want more features in the data	6	Feature requests
The map provides access to info that I didn't have access to before.	6	Liked Features

The detailed code book can be found at: https://www.openicpsr.org/openicpsr/project/172881/version/V1/view

All thirteen participants stated they wanted more maps in general. The one question that asked participants about their desire for maps was: "What kinds of trips would you want maps for?" Responses to this question included: " For my lifestyle I think in general what would be helpful [for kinds of trips I would want maps for] is indoor navigation especially hotels and airports… Large buildings [would be useful to have maps for] basically specifically hotels or other types of lodging." and "[I want] Everything [on a map]. Where am I and where's my stuff?" Six participants provided a broad request like this, wanting maps for "unknown locations" or "from where I know to where I don't know". Many kinds of desired maps were mentioned throughout the interviews including: indoor, transit, hiking, park, campsite, walking, crime, climate, temperature, service outage, fire, ocean, and weather. Wilderness maps, including hiking, campgrounds, and parks were desired by three participants explicitly: "I like to hike and don't have any kind of map for those [trails]." All participants wanted county or city data for the COVID-19 Choropleth map, along with the state information.

P10 described: "[On the COVID map, I would like] Neighborhood, city to city, block to block, and county information." P2 mentioned: "it might be useful [to have a county map] because we have a lot of counties in the bay area and often there are rules where you can go out based on the county." All participants admitted they would use the COVID map if it had more localized information. Other participants, such as P6, explained: "If we go back into lockdown I would definitely look into it [choropleth maps] when I travel to make sure cases are low and for safety reasons." Relating to both the choropleth and travel map, P11 stated: "I could see a lot of people [using the maps] as an iPhone app."

Ten of thirteen participants wanted a mobile app of some kind. Several participants, such as P3, emphasized "I would use [the travel map] if it were an iPhone app… Most blind people like using their phones for independent traveling." P1 described how they would use the mobile app: "I wish there was an app that would list nearby points of interest [while driving]." P2 further described: "[I would like pre-trip planning and turn-by-turn directions] together in the same app." When asked what a mobile interface could look like, P6 described: "you could slide your finger around and the sound would change as you move around the screen." P2 described a hands-free interface: "I would like to be able to ask [my phone] to create a map or add a point of interest and have it do it for me… If I could just ask my phone what [COVID-19 information I want] that would be awesome." P13 expanded: "I'd like to be able to use one app for all the major things I need."

Nine of the thirteen participants used traveling applications, such as Google Maps, Apple Maps, BlindSquare, SoundScape, Sendero Maps, Lazarillo, and local public transit applications, and six participants still commented "[these maps] are more interesting [than existing tools] because they allow you to explore and learn what you don't know you're looking for." P13 explained: "I would use the heat map just to visualize the geographical features of the states." P7 also explained: "I don't have glance ability. This [travel map] is almost giving me the ability to have glance ability." P9 further added: "[The travel map is] great to be modernizing because it's not something blind people have, there just isn't a way to replicate what sighted people have with Google Maps." P2 expanded: "I like that you can actually get an idea of what is next to each other geographically, because my geography sucks… The ability to understand geographically which things are in which direction… Is really useful for me because I have difficulty understanding where things are relative to other things." P2, P7 and P13 all indicated they had been able to read visual maps at one point. P3 commented "Getting directions from point A to point B [using the travel map] is what excites me the most." P3 then added: "I think [the travel map] will become exponentially more useful as it develops more."

The feature requests were, for the most part, unique to each participant. Because the questions that inspired feature requests were so open-ended e.g., "What needs to be improved with these maps?" and "What would make you want to use these maps?" and the interfaces were so complex, the variation was not surprising. Seven participants wanted more and better sounds: "Make different street sounds for different types of streets" and "When I get to an intersection [on the travel map] will I get a car sound?… When you get to a building that had multiple places in the same door, it [could] give you a certain sound that there was more than one thing in there, and you could go inside and check it out for yourself." Six participants mentioned "I would like to be able to jump to bordering states with one click." Six participants stated: "You should add beacons to different addresses" and "I would like to have reference point." Six participants also wanted to "view nearby places sorted by category." P11 added: "I would like a filter for just things like ATMs, coffee shops and museums." Six participants wanted more features and better data. P4 described the situation: "It'll be very interesting once there's more data [for the travel map]… How frequently I use the travel map would depend on how much data is available." Participants expressed wanting trashcans, light poles, stairs, and doors, as well as sidewalks. Finally, Notably, only three participants (P6, P10, and P14) mentioned tactile maps, with P6 asking for integration between Audiom and a tactile map, preferably integrating with the TMAPS [20]. P10 expressed their dislike of tactile maps: "[The issue with tactile maps is] I feel like the intended user never looked at a draft of the tactile map [because] sometimes [the transcriber] will use textures that have so much busyness that doesn't need to be happening or extra detail that doesn't need to be there." five participants complained that the data was too dirty. P14, when viewing roads that overlapped with buildings explained: " It's hard to know when I'm in a building or on the street."

For the question of: "What state bordering California has the highest COVID cases", all participants answered correctly. P10, P13, and P14 managed to give the clock face direction to one object over 20 meters away while standing on another object. This task was asked of four participants, P9 didn't respond.

6. DISCUSSION

Both the travel and choropleth maps were extremely well received by participants, and everyone wanted to see more development done on both interfaces. It is clear that BVIs do not consider any of the existing travel applications, previously mentioned auditory interfaces, or existing map accessibility techniques on the web (such as a table) equivalent to, or acceptable, as a map. For travel maps, it didn't matter if participants had a low or high travel skill, they all wanted maps. The maps BVIs expressed wanting were not limited to travel maps either, they wanted climate and fire maps as well. Without climate maps, BVIs are blocked from fully participating in professions such as climatology, oceanology, or meteorology. All these professions are data-centric and it is convention that dictates a visual only representation. Fire, flood, hurricane, air quality, and service outage maps are also completely inaccessible to BVIs, and not having this information is often life or death. When a hurricane is rapidly approaching, how is a BVI supposed to know when they should leave? How can they determine a safe route to get to a secure location, especially when roads are washed out? With major climate events occurring more often, it is critical that inequitable access to information be alleviated. BVIs are clearly asking for more maps, and with auditory interfaces like Audiom, it should soon be possible to end the dearth of non-visual maps for BVIs.

The choropleth map in this evaluation was a state map, but all participants asked for a more granular view. This raises complications around presentation, such as how to represent hierarchy, e.g., a city that's in a county that's in a state. Also, the US has almost 20,000 cities, how should those be presented on one map? There are many questions around how to clearly display this data, but it is critical for the sonification community to tackle these practical applications of sonification.

The Audiom interface utilized a keyboard, but participants clearly wanted a mobile version. Thanks to the web platform, adding a cross-platform touch interface is possible [54]. P2 also described a hands-free version of Audiom, where verbal querying would replace the keyboard. This interaction raises the possibility of making an auditory map controlled using a personal assistant like Siri or Alexa, which could be easier for sighted users to comprehend [55].

The 100% accuracy rate among BVIs using the choropleth map answering the question, "What state bordering California has the highest COVID cases per one million?" shows that the Audiom choropleth interface can effectively communicate single-variate geo-referenced data, similar to the 95% accuracy rate in iSonic. The participants in Zhao et al. answered similar questions on a table with only 20% accuracy, so there seems to be a clear advantage when using an auditory map over a table, and more complicated questions of spatial relationships are not necessary to show the audio map advantage over tables [11]. More difficult questions on single-variate geo-referenced data could be to recognize trends over the northeast or southwest of the United States, or have participants identify a path of high statistics through the center of the country. Multivariate, and time-sequenced data will enable more difficult questions. More validation needs to be performed, but these preliminary results are promising and suggest that it's possible to represent geo-referenced data 100% accessibly on the web without relying on the 20% effective tables [9].

The travel map was less effective, but participants were positive that with some of the feature requests implemented, the travel map could become their main pre-trip planning tool. As P11 described: " I can get everywhere I need to go but I don't go everywhere I want to go". P7 seconded: "[When describing the benefits of using interactive maps] I'd explain how they [blind people] actually travel [inconveniently in comparison to when interactive maps are used]… When people travel better when they have a vision impairment, they feel better." Participants also wanted GPS and Audiom integrated together: "I want apps on my phone… If [the travel map] was connected to a GPS on my phone I would use it while exploring". Existing travel applications should include an auditory map along with the look-around feature and turn-by-turn directions. Participants also complained that data was "dirty" and missing critical information such as doors and sidewalks, echoing participants in Biggs [56]. Using a tool like the Audiom travel map, BVIs will have inexpensive maps that can increase confidence and spatial knowledge, which should encourage greater community travel.

Virtual reality applications could also utilize similar conventions around navigating virtual environments as the travel map, rather than attempting to utilize the existing browser semantics. The Audiom interface sent messages to the screen reader through Aria Live Regions, and only used semantic lists and grids when those were explicitly called for [57]. The interfaces in Biggs et al. provides a better description of the possible navigation possibilities in Audio Games, which are auditory VR [41]. With so much focus being given to the Metaverse, BVIs need to be included. As of now, not a single VR platform is accessible to BVIs.

7. CONCLUSION

BVIs have repeatedly demanded more maps across numerous studies, and the BVI participants in this evaluation all indicated that Audiom has the potential to provide access to this information across multiple contexts. Government agencies, such as the CDC and NOAA, should use an auditory interface, like Audiom, to show their maps, rather than alt-text or tables. VR applications should also utilize an auditory interface, like Audiom, to enable BVIs to navigate and interact independently. Participants all wanted to see Audiom, or other digital auditory maps, improved and integrated into other applications, including turn-by-turn navigation apps, Google maps, and websites. The ability to view more granular COVID data, and view the map on the phone, were the two most requested features, other than wanting more maps in general. There is a clear demand for digital non-visual maps by BVIs, and the amount of research into this area is minimal. Focus needs to be on creating other types of mapping interfaces, such as true heatmaps, contour plots, density maps, and animated time-series maps. All studies from now on evaluating non-visual map interfaces should have spatial knowledge acquisition (landmark, route, and survey) as a variable. Without spatial knowledge measurement, the practical usefulness of the map is questionable. Future work with Audiom will consist of implementing feature requests, applying Audiom in different contexts, expanding the complexity of data (such as temporal and multivariate data), building the ability for BVIs to create their own maps, and working to improve the data source for the travel map. Audiom also will be evaluated in experimental trials. Existing accessibility approaches, such as alt-text, turn-by-turn directions, nearest address search, and data tables do not provide equal access to maps, and an interface, like Audiom, should be considered the accessible and legally compliant option for representing geographic data non-visually.

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10. CONFLICT OF INTEREST STATEMENT

BB is the founder of XR Navigation, a company aiming to commercialize Audiom. Learn more at audiom.net.

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