

HIGHCHARTS SONIFICATION STUDIO: AN ONLINE, OPEN-SOURCE, EXTENSIBLE, AND ACCESSIBLE DATA SONIFICATION TOOL

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ABSTRACT

The Highcharts Sonification Studio is the culmination of a multi-year collaboration between Highsoft—the makers of Highcharts—and the Georgia Tech Sonification Lab, to develop an extensible, accessible, online spreadsheet and multimodal graphing platform for the auditory display, assistive technology, and STEM education community. The Highcharts Sonification Studio leverages advances in auditory display and sonification research as well as over 20 years of experience gained through developing the original Sonification Sandbox. We discuss the iterative design and evaluation process of the Highcharts Sonification Studio to ensure usability and accessibility, and highlight opportunities for growth of the tool and its use for research, art, and education within the ICAD community and beyond.

1. INTRODUCTION

Perhaps the most crucial capability for the sonification designer or researcher is the ability to convert data into sounds in a simple and straightforward manner. To support this fundamental need, several general-purpose data sonification software libraries and programs have been developed over the years (this is in addition to many more special-purpose or domain-specific tools). A few of the many examples that have been presented just at the ICAD conferences, especially in the early 2000s, include Listen [11] MUSART [6] Sonart [2], SKDtools [7], Interactive Sonification Toolkit [8], sMax [5], SIFT [3], Xsonify [4], SoniPy¹ [12], and Sonification Workstation [9]. See, also, Bearman and Brown’s interim summary in 2012 [1]. The various tools have differed in terms of capability, ease of use, target users (including technical knowledge), required operating system or underlying software platform, accessibility by diverse users, and more. Some of the tools have been primarily for creating sounds; others have been more multimodal.

For about 15 years the Georgia Tech Sonification Lab² developed and maintained the Sonification Sandbox³, a simple but very capable Java-based application to convert data (manipulated in a spreadsheet within the application) into multimodal (visual and auditory) graphs and charts [8, 10]. The Sonification Sandbox evolved into a platform, supporting a range of input methods (e.g., direct data feeds from stock tickers or weather stations), rendering approaches (e.g., MIDI, audio files), processing capabilities (e.g., automatic graph description) and export capabilities (e.g., saving the images, audio, text, etc., separately or in combinations). The platform supported a file format (Sonification Sandbox Project, with “.ssp” extension) so projects could be saved, re-opened and shared. This was particularly useful for teachers who wanted their students to be able to open up an existing project.

The evolution of the Internet, especially as it relates to the capabilities of web-based audio and persistent applications, has meant that much of what was previously done in a native application, or in Java, or in a tool like MATLAB⁴ or Max/MSP⁵ or Supercollider⁶ can now be done as an application written to run in a Web browser. This can make deploying and using such software easier, more cross-platform compatible, cheaper, and in many cases more accessible to users of screen readers and other assistive technology. It is also more straightforward to provide updates to the software, and can make it easier to extend the capabilities of the tool. On the other hand, advanced audio can still be a challenge in Web applications, so there may need to be tradeoffs in terms of access and availability versus sonification variety and sophistication.

A similar evolution has transpired for data visualization: data manipulation and the creation of visual graphs once required (often-expensive) native applications like Tableau⁷, Microsoft

¹ <https://www.sonification.com.au/sonipy/index.html>

² <http://sonify.psych.gatech.edu>

³ <http://sonify.psych.gatech.edu/research/sonification-sandbox/index.html>

⁴ <https://www.mathworks.com/products/matlab.html>

⁵ <https://cycling74.com/products/max>

⁶ <https://supercollider.github.io>

⁷ <https://www.tableau.com>

Excel¹, IBM SPSS², MATLAB, or R³. There has been a shift to online versions of these platforms (e.g., Tableau Server and Tableau Online), along with online toolkits such as D3⁴ and Highcharts⁵. These newer platforms often have very robust capabilities, and bring ease of use, ease of deployment, and greater accessibility.

In the past few years it has made a lot of sense to leverage the evolutions just described, and develop an online (Web-based), opensource, extensible, and accessible data manipulation, sonification, and visualization toolkit. Such a system could complement other tools and libraries still actively used by the ICAD community, and help bring sonification to an even wider audience, especially in situations of limited resources.

2. HIGHCHARTS SONIFICATION STUDIO

The Highcharts Sonification Studio (HSS)⁶ is the culmination of a multi-year collaboration between Highsoft—the makers of Highcharts—and the Georgia Tech Sonification Lab, to develop an accessible, online spreadsheet and multimodal graphing platform for the auditory display, assistive technology, and STEM education community. Fundamentally, the HSS is a systematic re-implementation of the Sonification Sandbox, benefitting from the integration of Highsoft’s industry-leading web-based Highcharts technology with the Georgia Tech Sonification Lab’s expertise in sonification and interactive auditory displays. It was important to follow a stakeholder-based design process, and to involve sonification and visualization experts, usability and accessibility experts, and especially individuals who wear more than one of these hats. The intention is for this tool to be a free resource that can be leveraged and extended by the community, while also being supported by a company whose business is making widely available data tools, and is committed to adding sonification to those tools.

3. METHOD

The goal of this co-design process was to develop an accessible tool for exploring quantitative data through sonification. We anticipate that the HSS will be used by students, educators, practitioners, and researchers, each of whom may have varying levels of visual acuity. Thus, we sought to validate the utility and usability of the HSS through the inclusion of blind users, sighted users, and expert accessibility evaluators in the development process. This methodology helped us ensure that the HSS can satisfy a broad userbase while also adhering to modern accessibility and usability standards.

The original HSS design paralleled the latest (but now somewhat dated) version of the Sonification Sandbox, so the development of the HSS was quick. The basic layout is a data editor (spreadsheet style) in one tab, plus a multimodal graph (visual and audio) in a second tab. Preferences are accessed through additional tabs in the “Graph” tab, and can apply to either a specific data series or globally to the whole multimodal rendering. Not all of the Sandbox features are implemented in the Studio, though many of them are scheduled to be included as the software matures, and perhaps

as the community adds new features in the opensource context. The HSS is now at a stable version following the fruits of the iterative R&D phases described below.

The HSS is designed as a single-page web application, running solely on the client side of the browser, requiring no browser plugins to be installed, and no data exchange with a server. The application is compatible with most modern evergreen browsers. The HSS leverages the VueJS JavaScript/TypeScript framework for application structure and component handling, along with the Vuex library for application state management. The AG Grid library is used for the spreadsheet component, but is scheduled for replacement as of this writing. The Highcharts JS library is used for the charting capabilities, as well as for its sonification engine. The sonification engine in Highcharts JS is based on the WebAudio API, but defines additional abstractions and timeline handling.

This year-long study was conducted in 3 Phases. Phase 1 took place in March of 2020 included a series of usability investigations on HSS version 0.0.4 with blind and sighted participants and an expert accessibility evaluation. The insights gathered from Phase 1 were delivered to Highsoft to inform the design of future iterations of the HSS. Phase 2 took place in November of 2020 and included additional expert accessibility evaluations on HSS 0.0.9. Phase 3 took place in February of 2021 and included a final round of expert accessibility evaluations on HSS 0.0.11. The insights generated from each phase of research were delivered to Highsoft and informed the design of subsequent iterations of the HSS that were used in this study. In the following sections, we describe the evaluation of the HSS platform.

4. PHASE 1

4.1. Participants

Participants were recruited via university mailing lists, an internal collegiate participant pool, personal social networks, existing relationships, and snowball sampling. Participants from the internal participant pool received extra credit in a course for completing the study. To recruit individuals living with blindness or visual impairment (BVI), we consulted a local disability resource center to advertise our study. BVI participants received \$15 in compensation for their participation in the study. All participants were required to speak English proficiently, though they were not required to be Native English speakers. We required sighted participants to have normal or corrected to normal vision (contact lenses, glasses, LASIK, etc.), and we required BVI participants to have low-vision or be legally blind. All participants were required to have familiarity with spreadsheet platforms such as Microsoft Excel and Google Sheets. In total, 13 individuals participated in Phase 1: 12 sighted (Male = 8, Female = 4; Mean_{age} = 19.25, SD_{age} = 1.42, Range_{age}: 18 – 22) and 1 BVI (Female, Age = 34). The BVI participant self-identified as ‘totally-blind.’ This participant also reported using VoiceOver on iPhone and JAWS on Windows. Data from the BVI participant were analyzed independently.

¹ <https://www.microsoft.com/en-us/microsoft-365/excel>

² <https://www.ibm.com/analytics/spss-statistics-software>

³ <https://www.r-project.org>

⁴ <https://d3js.org>

⁵ <https://www.highcharts.com>

⁶ <https://sonification.highcharts.com/>



4.2. Accessibility Expert

Accessibility experts were recruited via professional and academic networks. We disseminated an advertisement email that detailed our present need for accessibility experts and the overall goals of this research, leading to the procurement of one accessibility expert. This individual volunteered to examine the HSS. The expert accessibility evaluator was a professional consultant and vocational expert with over 18 years of experience as an assistive technology specialist, vision rehabilitation therapist, and orientation and mobility (O&M) specialist for individuals with vision loss. The expert accessibility evaluator self-identified as legally-blind. This individual will be referred to as AE1 from here on.

4.3. Apparatus

Usability study. We utilized the Google Chrome web browser to run HSS 0.0.4. This took place on a standard Windows 10 computer with a Full HD monitor, wired mouse and keyboard, and wireless speaker; a set of Sennheiser HD 280 Pro headphones were provided in scenarios that required a robust listening experience (e.g., spatial audio). Given that HSS 0.0.4 was an alpha release, we acknowledged the presence of software bugs and features still in development. Features with known usability issues were excluded from the benchmark tasks. *Task performance* was measured using the PURE usability scale, and *task usability* was evaluated against Nielsen’s UX heuristics. Researchers also recorded field notes on a lab notebook and used an audio recording device to record any utterances, opinions, and insights from participants.

Benchmark Task Description	Task Type
1 Navigate to the last cell in Column A of the data table	Interaction
2 Clear the data table	Interaction
3 Add a new row to the data table	Manipulation
4 Add 10 new rows to the data table	Manipulation
5 Key this dataset into the data table	Manipulation
6 Click the play button	Interaction
7 Click the loop button	Interaction
8 Click the pause button	Interaction
9 Adjust the volume to 90%	Manipulation
10 Click the play button	Interaction
11 While audio is playing, click the stop button	Manipulation
12 Export the dataset	Interaction
13 Navigate to the audio tab	Interaction
14 Enable the play marker	Interaction
15 Adjust the speed to 70%	Manipulation
16 Adjust the minimum frequency to 10%	Manipulation
17 Adjust the maximum frequency to 90%	Manipulation
18 Enable panning	Interaction
19 Adjust the pan width to 100%	Manipulation
20 Create a text description for Column A and then Column B	Manipulation
21 Click the speak button in the text description section	Interaction
22 Navigate to the column settings	Interaction
23 Navigate to the chart tab	Interaction
24 Change the type of chart	Interaction
25 Edit the title of chart	Manipulation
26 Add a subtitle	Manipulation
27 Add the title "Time" to the Y-axis	Manipulation
28 Add the title "Location" to the X-axis	Manipulation
29 Enable the legend and show data series labels	Manipulation
30 Move to the data series settings	Interaction
31 Label the data series	Manipulation
32 Change the color on the series	Manipulation
33 Change the series	Manipulation

Table 1: Summary of the 33 benchmark tasks completed during the usability investigations.

Expert evaluation. The expert evaluation was performed in-person at AE1’s office. The researcher encouraged AE1 to use his preferred technical configuration. The HSS was accessed on a Windows computer with dual monitors, keyboard, stereo

speakers, and wireless mouse. In contrast to the usability study, no restrictions were imposed during the expert evaluation. Thus, we advised AE1 to critically interrogate all aspects of the HSS. *Task usability* was evaluated against Nielsen’s UX heuristics. Researchers also recorded field notes, audio, and video.

		Nielsen’s 10 UX Heuristics									
		H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
	1				X						
	2			X	X	X				X	
	3	X			X						
	4	X			X						
	5	X			X	X			X		
	6	X	X		X				X		
	7	X	X	X	X						
	8	X	X		X				X		
	9	X			X						
	10	X	X		X				X		
	11	X	X	X	X	X			X		
	12	X									
	13										
	14		X		X				X		
	15	X	X		X						X
	16	X	X		X						X
	17	X	X		X						X
	18		X								
	19	X									
	20				X				X		
	21	X		X					X		
	22										
	23	X							X		
	24	X			X				X		
	25				X						
	26				X						
	27				X						
	28				X						
	29										
	30										
	31				X						
	32	X	X		X			X	X		
	33		X								

Table 2: Summary of heuristic violations identified during the usability investigations.

4.4. Benchmark Tasks

The 33 benchmark tasks were designed to prompt user interactions with UI elements and features we deemed critical to the core usability of the HSS platform. Tasks were classified as either an *Interaction* or a *Manipulation*. *Interaction* tasks required users to identify a UI element and interact with it. *Manipulation* tasks required users to identify a UI element, modify its settings or data, and then observe system feedback. In total, task list included 15 *Interaction* tasks and 18 *Manipulation* tasks. After the participant completed a task, the researcher issued a usability score based on the task’s perceived difficulty. These scores ranged from 1 (Simple) to 3 (Difficult). A list of all 33 benchmark tasks is provided in Table 1.

4.5. Procedure

Usability study. Upon arriving at the research facility, participants were instructed to confirm that they met the study criteria (see Section 5.1). The researcher then read aloud the Informed Consent document to the participant and the participant signed the document. Participants were then presented HSS 0.0.4 on a lab computer. The researcher advised the participant to explore the interface for 2 minutes and verbalize any thoughts. This think-aloud process was encouraged throughout the study. Participants then performed

33 benchmark tasks (see Table 1) with minimal intervention from the researcher. After completing each task, the researcher scored the task and recorded observations of the process. Participants were allowed to ask questions as they completed each task. However, the researcher was instructed to turn the question back to the participant to understand their conceptual model of the issue. For example:

Participant: What does this button do?

Researcher: That’s a great question! What do you think it does?

Participant: I think it replays the audio?

Researcher: Interesting, what is it about the button that makes you think that?

This think-aloud process was integral to the study. As the participants performed each task, they were asked to verbalize their thoughts about the task’s difficulty and what would have made it easier to complete. These qualitative findings were interpreted via thematic analysis. In all, this study took approximately 1 hour to complete.

Expert evaluation. Upon arriving to AE1’s office, the researcher provided the Informed Consent document to AE1 who then signed the document. AE1 accessed HSS 0.0.4 on their personal computer. The researcher advised the expert to verbalize their feedback, suggestions, and opinions as they carried out the evaluation – similar to the think-aloud process used in the usability study. After completing the evaluation, we interviewed the participant about their opinions of the HSS overall and any suggested improvements. These qualitative findings were interpreted, and usability insights were derived. In all, the expert evaluation took approximately 1 hour to complete.

Theme	Examples of Expert Feedback from Phase 1 Research
H1	- Provide visual and auditory feedback into the UI media buttons - After adding rows to the data, you ought to provide feedback to indicate that the action was successful
H2	- Be cautious about using the terms ‘frequency’ and ‘panning’ in the UI; these concepts cannot be assumed to be universally understood, especially students
H3	- Provide an Undo or Redo to reverse accidental errors
H4	- Microsoft Excel and Google Sheets are industry standards for spreadsheets; it may be beneficial to
H5	- Provide a confirmation dialog before exiting the webpage
H6	<i>No examples emerged from the data</i>
H7	- Provide a default set of colors for user to choose from; the color wheel should be an alternative way to select chart colors
H8	- Maintain a high contrast ratio of 4.5:1 to satisfy WCAG standards
H9	<i>No examples emerged from the data</i>
H10	- Provide a tutorial that introduce users to the tool

Table 3: Summary of accessibility expert feedback from Phase 1 research.

4.6. Findings and Discussion

4.6.1. Task Performance

Sighted Participants. 29 of the 33 tasks (87.9%) received perfect ratings on the PURE usability scale, indicating that the vast majority of tasks required minimal effort to complete. Of those 29 tasks, 14 were *Interaction* tasks (48.3%) and 15 were *Manipulation* tasks (51.7%). 14 of the 15 *Interaction* tasks (93.3%) and 15 of the 18 *Manipulation* tasks (83.3%) received perfect ratings. The 4 remaining tasks (12.1%) that received poor usability ratings were *Tasks 5, 3, and 11 (Manipulations)* and *Task 7 (Interaction)*.

BVI Participant. 13 of the 33 tasks (39.4%) received perfect PURE ratings, indicating that a majority of the tasks were difficult to complete. Of those 13 tasks, 6 were *Interaction* tasks (46.2%) and 7 were *Manipulation* tasks (53.8%). The remaining 20 tasks received poor ratings; 9 (45.0%) were *Interactions* and 11 (55.0%) were *Manipulations*. *Tasks 1, 5, 11, and 21* could not be completed and required intervention from the researcher in order to progress. This participant encountered several screen reader accessibility issues during the usability study, and all were documented in the field notes.

Theme	Examples of Expert Feedback from Phase 2 Research
H1	- The timeout delay on all UI elements (spinboxes, comboboxes) should be consistent across the interface
H2	- The ‘Speak’ button on the Chart Tab deactivate when the system is being used with a screen reader - The ‘Instrument’ metaphor may not be appropriate. Sine wave, sawtooth wave, etc. are not instruments.
H3	- Provide an Undo or Redo to reverse accidental errors*
H4	- Provide users a way to easily switch between multiple charts; this is likely something person would want to do when visualizing data - Provide ‘right-click’ functionality for common actions; this is standard in many spreadsheet tools.
H5	<i>No examples emerged from the data</i>
H6	- When adding rows to the data table, pressing the Enter key should activate the ‘Add’ button
H7	- Provide global hotkeys for core features, such as Play, Pause, Volume Up and Down, etc. - Provide the ability to save settings and data within the web browser
H8	<i>No examples emerged from the data</i>
H9	<i>No examples emerged from the data</i>
H10	- Provide a Landing Page to help orient the user upon reaching the website - Provide an FAQ for users to resolve common issues

Table 4: Summary of accessibility expert feedback from Phase 2 research.

4.6.2. Task Usability

Usability study. Field notes and audio recordings from the usability study and the expert evaluation were interpreted through thematic analysis, leveraging Nielsen’s usability heuristics as a thematic framework. Data from the 33 tasks were independently analyzed and assigned codes based on the heuristics that were violated. For example, while performing *Task 8 (Click the pause button)*, P13 stated:

Why are the pause and play buttons 2 different buttons? They’re usually the same button [on other media apps].

In this case, the sample was assigned 2 codes: *Consistency and standards* (H4) and *Aesthetic and minimalist design* (H8), indicating violations of those 2 heuristics (see Table 2).

Expert evaluation. Due to the procedural differences for the expert evaluation, field notes and recordings were first interpreted through thematic analysis to identify Nielsen violations and then through inductive coding to further classify the usability issue. For example, while assessing the responsiveness of the HSS at extreme magnification levels, AE1 stated:

Now what I’m testing is the responsiveness of the page. For these kinds of [accessibility] tools, you should at least be able to reach 200% [magnification] without [the website] breaking.

In this case, the sample was assigned the primary code *Consistency and standards* (H4) and the subcode *Screen Magnification*.

These coding strategies helped us identify specific areas of the HSS that needed to be addressed which facilitated the delivery

of design recommendations and actionable insights to Highsoft.

5. PHASE 2

5.1. Accessibility Experts

Accessibility experts were recruited via professional and academic networks. Advertisement emails were disseminated and lead to the procurement of three additional accessibility experts, in addition to AE1 who agreed to return. Each of these individuals volunteered to examine the updated HSS platform. The experts' credentials include:

AE2 – founder and active consultant at an accessibility firm; AE3 – accessibility engineer at a medical research institute; AE4 – human-computer interaction and accessibility researcher at a major technology company. AE2 and AE3 self-identified as legally-blind.

5.2. Apparatus

HSS 0.0.9 addressed many of the usability issues present in HSS 0.0.4 and included a moderate overhaul of the HSS user interface. In contrast to Phase 1, all expert evaluations were performed remotely using the Zoom¹ video client. Prior to the expert evaluations, researchers e-mailed an updated link to HSS 0.0.9 so that the experts could confirm compatibility with their computers. Experts were advised to critically interrogate all aspects of the HSS. Researchers recorded field notes, audio, and video.

5.3. Procedure

The expert evaluation procedures for Phases 1 and 2 were effectively identical. The only difference was the use of Zoom to facilitate the evaluations.

5.4. Findings and Discussion

Field notes and video recordings were first interpreted through thematic analysis to identify Nielsen violations and then through inductive coding to further classify the usability issue. Given that HSS 0.0.9 was such a significant update of HSS 0.0.4, we anticipated a more rigorous interrogation during the expert evaluations. Table 4 provides a summary of usability findings. Much of the expert feedback concerned the accessibility of UI elements, inclusion of confirmation dialogs boxes to prevent unintentional actions, hotkeys and shortcuts for frequently used actions, and undo and redo functionality. AE4 indicated that the help button text ought to be evaluated to the ensure that the content accurately reflects the action described.

6. PHASE 3

6.1. Accessibility Experts

Accessibility experts were recruited via professional and academic networks. Advertisement emails were disseminated

and lead to the procurement of one additional accessibility expert (AE5), in addition to AE3 who agreed to return. These individuals both volunteered to examine the updated HSS platform. AE5 has over 20 years of experience designing and evaluating multimodal displays.

6.2. Apparatus

HSS 0.0.11 was a minor update to the HSS 0.0.9 that included improved stability and addressed some critical usability issues that were identified in Phase 2. Similar to Phase 2, all expert evaluations were performed remotely using the Zoom video client. Prior to the expert evaluations, researchers e-mailed an updated link to HSS 0.0.11 so that the experts could confirm compatibility with their computers. Researchers recorded field notes, audio, and video.

6.3. Procedure

Given the similarities between HSS 0.0.11 and 0.0.9, we opted for an informal accessibility evaluation in which the researcher, the evaluator, and the Highsoft accessibility lead (HS1) walked through the HSS and discussed strategies for scaling the tool and improving its accessibility. This format allowed the researchers and Highsoft to gain valuable insights from the evaluators, as opposed to belaboring usability issues that Highsoft was addressing at the time. Insights from the sessions were derived and reported to Highsoft. In all, each expert evaluation took approximately 1 hour to complete.

6.4. Findings and Discussion

Feedback from AE3 focused on best practices for implementing an accessible data table into the HSS. Many of the usability issues that were identified throughout this study were attributed to the inaccessibility of the data table. Regarding the implementation of a custom data table, AE3 stated:

Forgo ARIA grid and build a custom interface, similar to Google Sheets. This is complex but allows the most user-friendly experience.

HS1 and AE3 both agreed that the commercially available data tables lack the robustness required for use in the HSS and that a custom data table would lead to the best results overall. Feedback from AE5 was concerned with creating a sense of membership and community around the HSS. In particular, AE5 advocated for a marketing strategy whereby HSS users are encouraged to become active community members and contributors, comparable to the communities present on Wikipedia and Reddit. In this framework, HSS community members are users who promote use of the tool to their peers, help other users with troubleshooting, and provide feedback to Highsoft about issues they'd like to see resolved. These community members would be paramount to the success of the community, serving as pseudo-proxies between the userbase and the development team. Contributors are users who actively develop extensions and plugins to meet their personal needs. Contributors would then make these extensions available to the HSS community for use on their personal HSS. AE5 and HS1 noted that the success of this strategy is contingent upon the mutual commitment to actively maintain the HSS. To this end, AE5 recommended that Highsoft create a community forum where users could provide feedback on

¹ <https://zoom.us/>

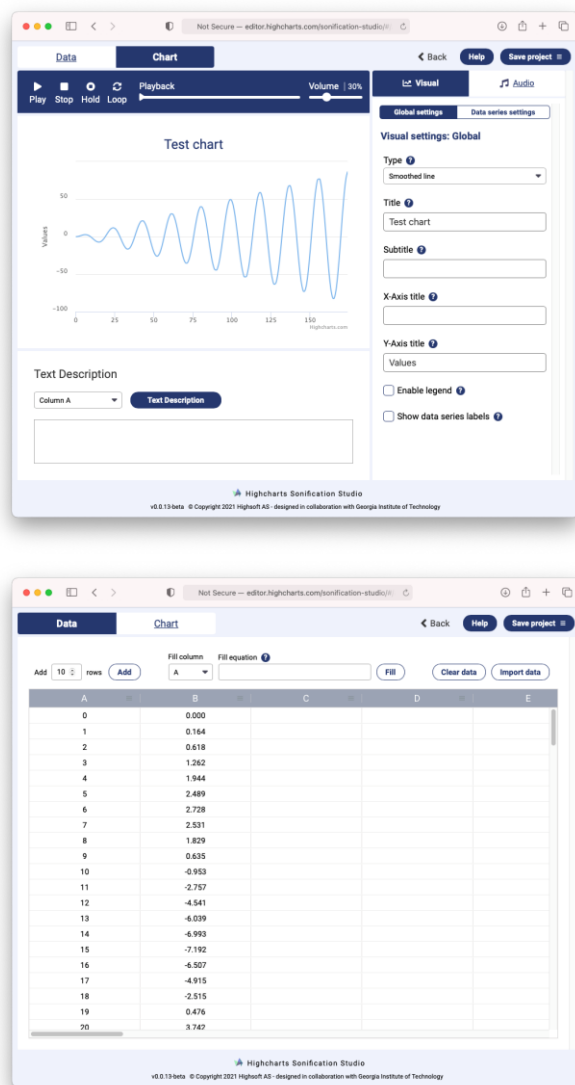


Figure 1. Screen capture of the Highcharts Sonification Studio, developed by Highsoft in collaboration with the Georgia Tech Sonification Lab. Top panel shows the Chart tab, with visual graph, audio play controls, and settings. The lower panel shows the data grid (spreadsheet) and import and export functions.

the HSS and discuss ideas for features they'd wish to see implemented in the future.

7. SUMMARY AND DISCUSSION

In this paper, we present the iterative development and repeated evaluations of the new Highcharts Sonification Studio. The Georgia Tech Sonification Lab and Highsoft engaged in a multiyear effort to produce a new and improved web-based version of the Sonification Sandbox. From the outset, both parties pursued the generation of a platform that adhered to modern usability standards and was equipped with state-of-the-art data sonification and data analysis features. This study was designed to engage with potential users and stakeholders of the Highcharts Sonification Studio. Phase 1

included usability evaluations with 13 participants, and an expert accessibility evaluation. These studies revealed several usability and accessibility issues, highlighting the importance of involving primary stakeholders in the research process. Results from the usability investigations revealed that sighted participants experienced far fewer usability issues than the BVI participant. While all sighted participants were able to complete each task fairly easily, the BVI participant encountered severe usability issues. The expert evaluations further revealed that the system required improved compatibility with common screenreaders such as JAWS and NVDA. These insights were interpreted, analyzed, and delivered to Highsoft to be implemented in subsequent iterations of the Highcharts Sonification Studio. Highsoft delivered a much more refined version 0.0.9 that was to be evaluated during Phase 2. The HSS 0.0.9 was evaluated by 4 expert accessibility evaluators. Their feedback concerned core functionality, such as system feedback, error prevention, individual settings, and customization, though they acknowledged vast improvements in the system's overall usability. Phase 2 insights were once again delivered to Highsoft for further refinement. Phase 3 included a round of informal expert accessibility evaluations with the Highsoft accessibility lead that concerned strategies for improving the accessibility of the data table and the creation of an HSS community. As of March 2021, a very solid and functional public beta of the Highcharts Sonification Studio is available¹ for use by the community (see Figure 1). While this version is essentially ready for final release, the iterative evaluation and development process continues with an ever-expanding cohort of users and evaluators. The software source code will be made open source, to further expand the use and expansion of the Highcharts Sonification Studio within the ICAD community and beyond. We believe that this collaborative and rigorous combination of research and iterative development has brought a potentially powerful and widely useful sonification and data visualization tool to our collective hands. We are excited to announce this software, and look forward to seeing it serve the community for science, art, and STEM education.

8. ACKNOWLEDGMENT

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¹ <https://sonification.highcharts.com/>

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