How Blind and Visually Impaired Composers, Producers, and Songwriters Leverage and Adapt Music Technology

William C. Payne
New York University
william.payne@nyu.edu

Alex Yixuan Xu
New York University
ayxx@nyu.edu

Fabiha Ahmed
New York University
fsa253@nyu.edu

Lisa Ye
New York University
ly1206@nyu.edu

Amy Hurst
New York University
amyhurst@nyu.edu

ABSTRACT

Today, music creation software and hardware are central to the workflow of most professional composers, producers, and songwriters. Music is an aural art form, but it is notated graphically, and highly visual mainstream technologies pose significant accessibility barriers to blind and visually impaired users. Very few studies address the current state of accessibility in music technologies, and fewer propose alternative designs. To address a lack of understanding about the experiences of blind and visually impaired music technology users, we conducted an interview study with 11 music creators who, we demonstrate, find ingenious workarounds to bend inaccessible technologies to their needs, but still face persistent barriers including a lack of options, a limited but persistent need for sighted help, and accessibility features that fail to cover all use cases. We reflect on our findings and present opportunities and guidelines to promote more inclusive design of future music technologies.

CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**; *Sound-based input / output*.

KEYWORDS

accessibility, blindness, visual impairments, music technology, music creation, music learning, design

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1 INTRODUCTION

Historically, the largest barrier to music technology was simply access to it, but today it is widespread, affordable, and used by experts and non-experts alike. No longer must one be born into a family of musicians (as Bach, Mozart, and Beethoven were) to study composition, nor must one find a record contract and studio (with engineers in tow) to make an album, as shown by countless modern artists with humble beginnings sharing music from their bedrooms.

Those who engage in original music creation have seen their processes totally transformed, simplified, and enhanced by music technology. Composers once wrote everything on pen-and-paper and relied on skilled human engravers to error-check and break multi-instrument scores into individual parts but now work independently on computers with advanced notation software. Producers once required recording studios with expensive mixers, synthesizers, and microphones but now can work on laptops running full-featured production environments called Digital Audio Workstations (DAWs) [47] such as Apple's GarageBand which is included freely with new Apple hardware [5]. Songwriters once relied on agents and recording engineers to make and release high-quality recordings but now may work independently using DAWs to record, mix, and master their songs and online platforms to reach wider audiences [62].

However, we are concerned that advances have not included accessiblity features for blind and visually impaired music makers. A recent review of accessible digital musical instruments (ADMIs) uncovered 83 unique instruments in research literature, but found only three developed for visually impaired users, concluding, that "relatively little has been done for persons with visual or hearing impairment" [32]. Prevalent software designs rely heavily on complicated graphic user interfaces and "WYSIWYG" interaction methods (e.g. drag-and-drop) suggesting that little or no vision ability may pose a usage barrier. Online user groups provide communal spaces for users to assist others encountering accessibility barriers in commercial products [64, 65], while Dancing Dots, a company that has existed for nearly 30 years, sells alternative products to blind and visually impaired music makers [24].

We conducted interviews with 11 music makers, consisting of composers, producers, and songwriters to understand how they leverage and adapt music technologies to achieve their expressive goals. Our participants found independence and creative freedom through increasingly accessible tools, but faced limited choices known to work with their assistive technologies, relied on sighted musicians in the final stages of music preparation, and reached limits where tools became inaccessible. These barriers form the

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basis of our discussion in which we describe the opportunity for novel designs that are multimodal, navigable, and inclusive.

1.1 Composing, Producing, Songwriting

We refer to those who engage in the act of original music creation, as *music makers* or *music creators*. Performers, including singers and instrumentalists, predominately play the works of others and are excluded from this study unless they also make original music. There are many ways to enact new music, but we will use the broad categories of *composer*, *producer*, and *songwriter* [76], to help group and understand our participants (Figure 1). The chief distinction between categories is the medium in which they work: written score, audio data, and performance respectively.

Composers write scores for musicians to read and perform (ranging from solo piano to string quartet to large orchestra) and focus on musical symbols often studying western music notation and music theory for many years. Notation software, such as Finale [49] and Sibelius [9], behave similarly to other document-making tools, providing methods for input (e.g. playing notes on a MIDI piano), formatting (e.g. spacing of measures and systems), validation (e.g. synthesized audio playback), and automatic error-correcting (e.g. preventing too many notes from filling a measure).

Producers work closely with technology throughout the process of completing an audio track and may be involved in creating original music, preproduction, recording, mixing, and mastering. Producers work predominately with two forms of data - MIDI data, which is easier to edit and consists of musical events that are synthesized in realtime on playback (when the user presses play inside the interface), and audio data, which has been recorded in advance. DAWS, such as Logic Pro X and Pro Tools [6, 8], provide ways of manipulating MIDI and audio data, support higher-level editing techniques such as adding effects and controlling volume levels for separate tracks (e.g. vocal track, drum track, etc.), and can be extended with third-party software, called plugins, that add additional features, instruments, and effects. Partly due to originating in professional recording studios, DAWs often use highly visual and complicated interfaces with hundreds if not thousands of onscreen inputs and signifiers.

Songwriters, ranging from folk singers to rappers, make and memorize music for themselves and do not adhere to one type of technology in the same way that composers use notation software and producers use DAWs. Songwriters might use several music technologies and tools like voice recorders or document editors to track melodic ideas or lyrics, or they might use no software.

The distinction between composing, songwriting, and producing is blurry [76]. Songwriters might record and edit themselves in a DAW (producing), producers might notate parts to share with a musician they intend to record (composing), and composers might write lyrics and perform their own work (songwriting). Some musicians may sit at the intersection of two or even three categories [1], and software tools, DAWs in particular, can be so fully-featured that one program may support dramatically different user types and workflows.

[1]Live music coders are one such example working directly with audio, performing live, and manipulating symbolic systems - albeit code rather than western notation.

1.2 Visual and Non-Visual Music Representations

As described above in section 1.1, composers and producers work with fundamentally different representations of music. In Figure 1, we represent a single, equivalent measure of music as if it were read by a sighted composer (Figure 1a1), a composer with reduced vision (a2), composer with no vision (a3), and a producer in both MIDI (b) and audio (c) forms. The measure consists of a single line of four quarter notes (durations equal to the beat), two short (*stacatto*) then two long (*legato*), that sound at a moderate tempo of 100 beats per minute rising in pitch and beginning quiet (*piano*) but gradually growing (*crescendo*) to loud (*forte*).

1.2.1 *Composers: Notated Music.*

In traditional western notation (Figure 1a1), notes, containing rhythmic, pitch, and duration information, are placed on a six-line staff while global parameters, including time signatures, key signatures and clefs, are displayed to the left of notes at the beginning of a measure (and not shown when redundant). Other symbols are placed above/below the staff including dynamics (changes in volume and intensity) shown below and tempo markings (changes in speed and timing) shown above. Large print music is an enlarged version of standard music, but creating a large print score is more complicated than simply auto-resizing a standard score. Following the instructions of a large print transcriber and specialist at FMDG Music School, we created Figure 1a2), in which we doubled the staff size, increased, emboldened, and changed fonts, thickened the hairpin (crescendo marking), and re-positioned the tempo text preventing elements from clashing. Not demonstrated, large-print transcribers also adjust spacing, paper orientation/size, and number of measures and systems per page. Furthermore, individuals with different kinds and degrees of vision loss may prefer custom variations of large print.

Braille music (Figure 1a3) encodes virtually all of the information in visual scores. First invented in the early 19th century, braille music codes have existed, changed, and grown over the course of nearly 200 years [35] with the most recent North American standards set in 2015 [71]. Braille music utilizes the same six-position cell system as other forms of braille with its own distinct syntax. Confusingly, pitch classes in braille music (ranging from A–G) use different symbols than letters in literary braille. (The pitch C matches the letter D for instance.) The top two rows of braille music note cells encode pitch information, while the bottom row encodes rhythm. Octaves and expressive symbols precede the notes they apply to, but can be omitted to save space provided there is no ambiguity following common stylistic procedures. Finally, global music parameters are usually declared at the top of the page. In Figure 1a3), the tempo and time signature are represented in the top line, while the bottom line contains everything else beginning with the octave, piano symbol (two characters), start of crescendo (two characters), staccato symbol, and finally the quarter note on the pitch A in the 7th position. Braille music notation typically uses a combination of literary, nemeth [4], and music braille.

Many programs convert visual scores to braille, reducing, but not removing the need for human transcribers (e.g. [36]). Automated processes still require human input for more complicated musical scores, such as the left and right hand parts of a piano score that may be presented differently (e.g. measure by measure or line by

Table 1: Music Creation Categories

Type	Primary Result	Tech Requirements	Software Examples
Composition	Notated Score	Note and symbol input; Formatting and validation; MIDI I/O	Finale, Sibelius, Lime
Production	Audio File	Audio editing, mixing, and mastering; Effects and plugins; MIDI I/O	Logic, ProTools, Sonar
Songwriting	Performance	Live hardware/software control; Storing and sorting song ideas	Music Memo, MainStage

line), depending on preference and music context [71]. Furthermore, automated conversion processes require underlying musical data structures like MIDI or MusicXML, while publishers only sell music in paper or PDF formats. Open Music Retrieval (OMR) algorithms can gather data from images and recordings, but the state of the art is still highly inaccurate [19, 54]. A few dedicated technologies, such as the Braille Music Notator [68] support direct braille music editing, but mainstream notation technologies, including Finale and Sibelius, do not currently support braille music.

1.2.2 Producers: MIDI and Audio. In DAWs, producers work with separate regions of MIDI and audio data demarcated by color. As shown in Figure 1b), MIDI data is typically edited in a grid called a piano roll where MIDI events are visualized as blocks using horizontal position, vertical position, color, and length to represent timing, pitch, velocity, and duration respectively. MIDI events are added and edited with external MIDI controllers and drag-and-drop commands. Audio regions show digital audio, variations in air pressure captured at a high sampling rate, and are hard to discern. For instance, in Figure 1c), there appear four discrete events that grow in amplitude but no indication of music. DAWs provide precise editing capabilities with drag-and-drop controls allowing users to reposition audio regions, cut out and glue in specific chunks, and stretch/shrink regions.

Music representations used in DAWs do not have standardized low vision/non-visual equivalents, yet DAWs may provide non-visual access depending on developer commitment and integration with system accessibility features. For example, in the current version of Logic Pro X (10.4.1), VoiceOver can output MIDI information with text-to-speech as a user sequentially navigates through a list of events or mouses over events in the piano roll. Audio regions are more difficult to access with keyboard alone. Regions of MIDI and audio can easily be enlarged, but as Figure 1b) reflects, Logic Pro X is not color-blind friendly using a spectrum of green to red to represent moderately quiet to loud MIDI velocities.

2 RELATED WORK

Our findings and discussion expand on three bodies of related work. We demonstrate how the needs of blind and visually impaired music makers are not being met despite innovations in educational technologies intended to lower barriers for original music creation. We contribute detailed knowledge of music technology usage not present or out-of-date in existing studies of blind musicians. We identify a lack of accessible electronic instruments developed for non-visual use and discuss design recommendations intended to motivate new advancements.

2.1 Lowering Barriers - Music Education and Technology

Music educators, conscious of the fact that music technology is increasingly used by novices inside and outside the classroom, develop pedagogies and learning tools to lower barriers to music making [14, 62]. One strand of research, inspired by the work of Jean Bamberger, who observed children inventing their own music notations, questions whether the act of learning to create music should begin with the low-level symbolic rules of its written system, which, as Bamberger argues, obscure our pre-existing conceptions of music [12, 13]. People who lack music theory training still perceive musical processes like melodies and grooves. However, notating melodies and grooves in a traditional score first requires mastery over a low-level, syntactic system of pitches, intervals, and durations - events that ironically only advanced musicians perceive by ear. Alternative representations of music have enabled novices, including children, to compose entire, original scores [2]. For example, Impromptu is a music creation environment and curriculum in which users construct melodies and rhythms with "tuneblocks" that represent different portions of a song [13], while Hyperscore is a computer-assisted composition system interacted with via drawing and editing curves [28]. Unfortunately, these innovations are highly visual and unlikely to meaningfully engage blind and visually impaired music makers.

Alternatively, entry-level text-based music programming environments, designed to teach audio concepts and computational thinking through music creation, may be more accessible to screen readers. EarSketch combines a DAW with an integrated development environment (IDE) enabling common procedures, like adding tracks and editing effects, to be controlled with code [30]. Code Jumper, a tangible, music coding environment, is developed explicitly for blind and visually impaired children [3]. Novice-friendly coding environments that support music creation may be inflexible and inexpressive if they are not developed with a conception of music cognition and just as challenging as western notation if they use similar low-level symbolic systems [60]. To be clear, our contribution through this research does not contain claims regarding how to teach music. Instead, it complements recent developments in music education literature intended to make music making more approachable and inclusive through novel technology designs.

2.2 Experiences of Blind and Visually Impaired Musicians

Many studies of blind and visually impaired musicians do not discuss technology, but describe the challenges of accessing and memorizing sheet music and the experiences of those who study at a

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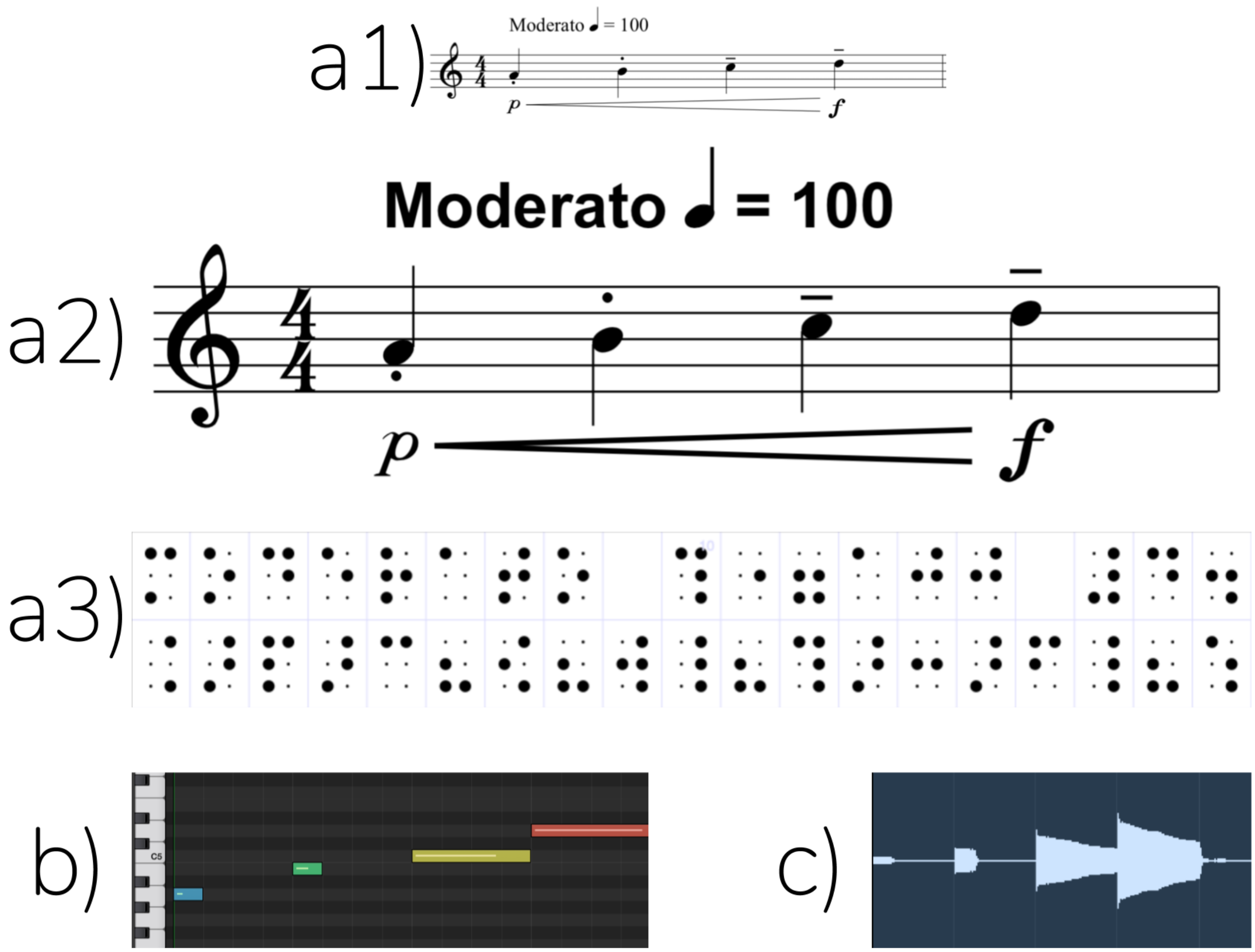

Figure 1: One identical measure of music in notation, MIDI, and audio representations - A1) standard notation (made in Lime), A2) large print (Lime, after consulting large print specialist), A3) braille music (Braille Music Notator), B) MIDI Piano Roll (Logic Pro X), C) audio waveform visualizing piano recording (Logic Pro X)

mainstream school or school for the blind, e.g. [1, 50, 53]. Touching on technology practices, Baker and Green conducted a wide-ranging, multi-year study of blind musicians finding in a survey of 191 international musicians that most used assistive technology in relation to their music-making including screen readers, braille note-takers, and digital magnifiers for enlarging music [10]. To gain further insight into music technology practices, they spoke with two composers and one producer who discussed experiences using Sibelius with a third-party accessibility tool called Sibelius Speaking, text-based synthesizers on MS-DOS, and analogue recording equipment [37]. The three music makers faced in common a lack of formal educational opportunities and taught themselves music technologies with the aid of informal networks of other blind creators. However, the interviews contained little technical detail of how participants used music and assistive technologies and does not represent the current state of accessibility in music technology. For instance, as of this writing, Sibelius Speaking is defunct and

Sibelius does not support screen readers [23]. In addition to the studies listed above, both the National Federation of the Blind and Royal National Institute of Blind People provide resources to musicians including assistance for those who wish to acquire braille music and find accessible software [55, 67].

2.3 Accessible Music Technologies

Researchers are increasingly committed to improving and measuring accessibility in music technology [48], building on a long history of music technologies supporting expressive and creative channels for people with disabilities. Most famously, Clara Rockmore, a classically trained musician who gave up the violin due to tendinitis, turned to the Theremin, an electronic instrument controlled without physical contact, and became its most prolific performer touring the world in the early 20th century [52]. A recent review of accessible digital musical instruments (ADMIs) categorized 83 unique instruments by interface type (e.g. tangible, touchless, brain controlled), integrated sensors (e.g. touch, accelerometer, camera), and feedback modality (47% audio only, 48.2% audio with tactile or visual) [32]. While the largest percentage of ADMIs focused on user groups with physical impairments, only 3.6% of focused on people with visual impairments. Tangible computer music interfaces have explored non-visual interactions with MIDI [39], audio equalization [45], and tabletop collaboration [58]. Notably, the Haptic Wave, a tangible interface for navigating regions of audio, was developed, tested, and evaluated alongside blind and visually impaired music creators [73]. Unlike the previous examples, the non-visual Groove Pizza does not use additional hardware beyond a computer and instead supports beat making through keyboard input and auditory output, including sonification and text-to-speech [61]. Given an overall lack of music technologies designed and tested with blind and visually impaired music creators, this study sets out to explore the current state and determine optimal paths for future work.

3 METHODOLOGY

In order to understand the music making strategies and experiences of people with vision impairments, we interviewed 11 adults with limited or no vision who had at least one prior experience making an original piece of music with technology. We conducted interviews remotely and identified participants through contacting relevant institutions including the Assistive Music Technology (AMT) Program for Blind and Visually Impaired Musicians at the Berklee College of Music and FMDG School, a community music school for blind and visually impaired learners, and asked participants to recommend others for the study. Each interview was scheduled to last an hour consisting of a discussion about experience writing music, tools and technologies the participant has tried, and techniques they use to improve access.

We requested that the participant come prepared to discuss an original composition in the interview, and we encouraged them to send a recording if one was available. First, in a warm-up, the participant discussed the intricacies of the piece they prepared including process, timeline, technologies, performances, and challenges faced along the way. From there, we asked demographic questions to gain an understanding of music experience and training, music literacy, and AT use. Using answers from the first two sections, we determined whether the participant used technology primarily for composition, production, or songwriting purposes. Since participants could fall into multiple categories, we ordered the next set of questions by which they adhered to most, enabling us to ask focused questions under time constraints and reducing the risk of alienating a participant. For instance, a participant who did not discuss notation would not be asked on the nuances on various techniques for preparing sheet music. Finally, we asked each participant to imagine future technologies to improve their specific practice.

3.1 Overview of Participants

Participants (listed in Table 2) had diverse musical backgrounds and styles ranging from classical (P1, P4, P5), jazz (P2, P9, P11), pop (P3, P7, P8), and rock (P6, P10). Those we interviewed who lost vision early in life studied braille music at schools for the blind (P4, P5, P7). Two who lost vision later in life eventually learned braille music (P3, P10) though only P3 uses it regularly in compositions and arrangements. Three others who lost vision later in life (P6, P8, P11) do not know braille music and do not find it necessary for their practice. Those with more vision (P1, P2, P9), all read sheet music though only P2 described performing with large print music, while P1 described needing to find new alternatives due to relatively recent severity of vision loss. As discussed in Limitations (6), only one participant is female (P8).

3.2 Overview of Music Technology Used

Participants described using a range of software. Tools used by producers included Logic Pro X (P1, P9), GarageBand (P2), and ProTools (P11) (all mainstream products sold on macOS), REAPER for Linux known for its affordability and customization options (P8), and Sonar for Windows, a product once marketed explicitly to blind users through Dancing Dots, but no longer included on the company's store (P3, P4) [5, 6, 21, 24]. Composers used another Dancing Dots product Lime for Windows (P3, P4, P5, P7) and the industry standard Finale on macOS (P2) [24, 49]. Songwriters used Sonar on Windows for recording themselves and their bands (P6, P10), and they also used iPhone apps including Music Memos for keeping and tracking short musical ideas (P6) and iReel Pro for learning guitar chord progressions (P10) [7, 24, 74]. As detailed below in Section 4.3.1, many of the products listed above are not compatible with screen readers causing most participants to acquire supplementary tools including third-party scripts that implement increased screen reader access and keyboard functionality. Of those who use a mouse cursor for navigation, P2 and P9 found Apple Zoom and VoiceOver sufficient. While all used external MIDI keyboards, connected via USB, to facilitate note input, two hardware platforms warrant special mention: First, central to their process, P1 and P11 identified the Komplete Kontrol system, a MIDI keyboard and software environment with built-in accessibility features including speech output and expanded tactile control with knobs and sliders [56]. Second, P8 described the Gemini module, a physical synthesizer with a WiFi connection enabling her to play it with a MIDI keyboard and control its parameters online in an accessible web application [38].

Table 2: Participants

ID	Type(s)*	Highest Formal Training	Print Music Format	Computer Access	Age Over/Under 50
P1	C, P	Master in Composition	large print	mouse/magnification	under
P2	C	Master in Jazz	large print	mouse/magnification	under
P3	P, C, S	School for the Blind	braille	keyboard/screen reader	over
P4	P, C	School for the Blind	braille	keyboard/screen reader	over
P5	C	Bachelor in Composition	braille	keyboard/screen reader	under
P6	S	Lessons/Self Taught	none (does not read)	keyboard/screen reader	over
P7	C	BM Jazz	braille	keyboard/screen reader	over
P8	P	Lessons	none (previously large print)	keyboard/screen reader	over
P9	P	Audio Production Diploma	large print	mouse/magnification	over
P10	S	School for the Blind	braille	keyboard/screen reader	over
P11	P, S	Bachelor in Audio Engineering	braille	keyboard/screen reader	over

*C = Composer, P = Producer, S = Songwriter | Ordered by what they adhere to most

3.3 Analysis

Our approach to analysis resembles Braun and Clark's Thematic Analysis Approach [17] in that we value flexibility over rigid rules, view 'researcher judgement [as] necessary to determine what a theme is,' and treat analysis as a 'recursive process' moving back and forth between searching, identifying, and defining themes. Unlike Braun and Clark's approach, we did not produce a visual thematic mapping, and instead collaborated remotely within spreadsheets and brainstorming documents. Each interview was conducted by two researchers, recorded, and transcribed verbatim. Immediately following each interview, the pair discussed and listed initial ideas for making sense of and categorizing what they heard. Then, in weekly meetings the entire research team reported back, discussing interviews in relation to each other and updating themes based on the current set of data. Once interviews were completed, the team reviewed and generated a set of themes that took into account the experiences and perspectives of all participants. Finally, in producing this report, we continued to refine/clarify themes, selected especially pertinent examples and quotations, and drew connections with existing literature.

4 FINDINGS

We organize our findings into three broad themes. First we describe our participants' perspectives on the current state of music making including music creation software and braille music, then we identify successful strategies our participants used to achieve creative goals, and finally we address barriers our participants faced resulting from inaccessible music technologies.

4.1 Current Music Making Practices

Our participants described how they use assistive technologies to make music, and the benefits of Braille music.

4.1.1 Before and After Computer-Based Music Creation Tools. Our older participants remembered past eras in which making original music was significantly harder or impossible due to a lack of any accessible software. Accessible notation software has enabled composers to finally create standard and braille music to share with other musicians: P3 described writing a song in the 90s in which he composed and memorized a keyboard part while a collaborator sang and wrote lyrics. Using Lime with Lime Aloud and GOODFEEL, accessbility scripts discussed further in 4.2.1, P3 recently arranged the song for chorus and band and heard his work from 30 years ago performed live in concert. P7 remembered a frustrating experience composing an original big band piece on a tight timeline during his undergraduate studies in jazz. With no way of converting his written braille music to standard scores, outside of waiting weeks for a transcriber, he was forced to verbally convey his ideas to another musician in the band. This resulted in mismatches between all of the musicians' parts (*"I started hearing things I never wrote"*), leading to a chaotic final rehearsal (*"...people running around the stage with pencils trying to cross out measures."*).

For composers who also use production software, accessible DAWs have meant they can input and synthesize recordings of music that previously existed only in braille: P4 described a score that he originally notated with a slate and stylus and never performed for an audience. Once he acquired a synthesizer program on a machine running MS-DOS, he not only shared the recording in a Lighthouse Guild performance, he expanded the piece with new variations allowing it to live beyond the braille scores he has since lost. P4 now also experiments with code and generative music.

4.1.2 Braille Music Knowledge is not a Prerequisite for Producing or Songwriting. As defined above, composers (and performers) work in notation, and reading and writing braille music remain essential skills. However, our participants, including braille music readers, did not believe that everybody, especially adults, need learn it: *"If that's for you, then you do it. If it's not for you, I'm not going to push you."* -P4 (learned braille music at an early age).

P6, a guitarist and songwriter, decided to learn music after losing his vision in his early 20's. His attempt at learning braille music did not pan out, but he is not bothered today. He successfully communicates musical ideas with other bandmates through improvising and sending recordings, makes albums, and performs live. Similarly, P11, a producer who lost his vision in his early twenties, described how literary braille granted him studio independence since he could label/find CD's and gear manuals, but did not believe music braille could enhance his practice. Finally, P8, a classically-trained pianist who read standard music close-up and uncomfortably until vision loss made reading impossible, is adamantly opposed to learning braille music due to sensitive fingers that make touching braille for prolonged periods "unpleasant." Instead she carved out a new path sans-notation working more in electronic paradigms, converting from soloist to collaborator and improviser, and improving her aural skills (abilities to perceive musical qualities like melody, harmony, and rhythm through sound).

One participant, P7, remembered that mainstream teachers were unfamiliar with practices for teaching blind students, did not know braille music, and "*were totally unprepared to teach [him].*" He perceived a gap between opportunities afforded to young sighted musicians and non-sighted musicians in schools. While sighted learners are exposed to notation in school band, choir, or orchestra, blind learners must show a special interest in braille music and must find strong advocates (or advocate for themselves) to receive guidance in notation. Furthermore, P7 pointed out that many students receive limited braille instruction in general, and that music braille often competes for time with literary braille and nemeth braille. While those who lost vision early (P4, P5, P7) were fortunate to take lessons in braille music, not everyone is afforded such an opportunity. P10 hoped to learn braille music during private guitar lessons and requested that his sighted teacher notate scores in Lime which he could use to produce braille scores. The teacher refused and instead preferred to invent his own notation.

4.2 Successful Strategies for Overcoming Accessibility Barriers

Our participants described their workarounds for inaccessible software and techniques they developed to share and create music.

4.2.1 Third Party Accessibility Scripts. Most relied on third party software, we refer to as accessibility scripts, to add accessibility features and/or screen reader support currently lacking in a commercial music product. The most common scripts were developed for the production software Sonar and the notation software Lime (called Lime Lighter, Lime Aloud, and GOODFEEL) sold by Dancing Dots[2]. Sonar's accessibility scripts ensure most interface elements are labelled and provides keyboard macros to speed up navigation and certain tasks like adding a new instrument track. P6, a songwriter, detailed how he could manipulate various audio effects like reverb, compression, and panning with his keyboard in Sonar achieving the right sound for his voice and guitar. Lime Lighter magnifies portions of a score displaying in Lime for low-vision users. Lime Aloud pairs with a specific screen reader JAWS [29] to sonify the content of an in-progress score with text-to-speech and music output. Finally, GOODFEEL displays the current line of music on a braille device, letting one touch a digital score, and can convert and export an entire piece to braille format. P7 described how Lime Aloud and GOODFEEL enabled him to compose an original piece of music and produce standard, large print, and braille parts during a workshop for vision-impaired musicians. Outside of Dancing Dots, P11 introduced us to Flo Tools, an open-source library of scripts that implement thousands of hot-keys and automations streamlining his workflow in Pro Tools with VoiceOver [75].

[2]Detailed further in 4.3.1, Sonar is out-of-date and no longer sold by Dancing Dots. Furthermore, Dancing Dots has acquired the source code to Lime.

4.2.2 Culture of Sharing Music Technology Expertise. While some with programming knowledge contributed to broadening access to music technology (P7, P10, P11), others utilized a unique expertise in music technology to aid blind and visually impaired musicians in their communities. P2 and P5 work as transcribers producing large-print and braille music respectively. P2 uses Finale to tweak the layout of large print scores precisely to the preferences of individual musicians. P5 rigorously checks and modifies the braille music output generated from Music XML files with GOODFEEL ensuring that it aligns with standards set in the most recent Braille Music Code. Furthermore, P4 uses Sonar to make high quality synthesized audio recordings of individual parts to aid members of his chorus in learning music by ear. Our findings suggest a culture of utilizing and sharing technology expertise to benefit others also seen in prior work [37].

4.2.3 Individual and "DIY" Solutions. Some developed novel techniques and tools based on individual needs and skills. Those who currently perform original music, P2 and P7, developed a practice of regularly recording themselves to assist in generating, iterating, and remembering musical ideas using GarageBand and Music Memos respectively. P4 takes advantage of the fact that braille music uses the same cell system as other forms of braille and he extends general-use technologies like his braille note taker to sketch out musical ideas. *"Braille is Braille. How you interpret the dot patterns is completely up to you. Dot one can represent the letter A, it can represent the number one, or it can represent first finger."* -P4.

Similarly, P5 uses Duxbury, a braille translation software, to adjust and finalize braille music scores, giving him a level of control beyond that which Lime affords [25]. P10, frustrated with an inability to read chord charts in the application iReel on his iPhone and keep both hands on his guitar, made recordings of himself speaking the chords in time to a metronome, in effect developing an ad hoc auditory display that he could play with. Finally, P8 wished she possessed more of a DIY mindset back when she read notated music, imagining an extended stand that could position the music directly in view while she maintained playing position.

4.3 Achieving Musical Goals is Still Hampered by Significant Accessibility Barriers

Despite notable improvements and an upward trend in music technology accessibility, our participants discussed interfaces that lacked common accessibility considerations, (e.g. in Logic - a complicated design with multiple windows (P1) and portions unreadable by VoiceOver (P3)) and annoyances with assistive music technologies (e.g. in Lime, errors introduced when importing a MusicXML file (P10) and braille export not adhering to recent braille music standards (P5)). More significantly our participants, especially those unable to use a mouse to navigate graphic user interfaces (all except for P1, P2, and P9), described occasions when these barriers prevented them from fully realizing musical ideas.

4.3.1 Lack of Choice When Accessibility Scripts are Not Standard and Software/System Dependent. Multiple participants reported a frustration that Dancing Dots products, including Lime and Sonar, lag behind mainstream products in terms of features and widespread use: *"That's just been one of the major challenges of working in Lime* *to begin with. Because even for a sighted person, one has to be dragging things around pretty constantly, unlike in other mainstream software programs like Sibelius or Finale, which is what most other students at my college are using but have proven not accessible over time."* -P5.

Dancing Dots products are designed for blind and visually impaired users and provide technology support and community while mainstream products are not always known to be accessible or compatible with one's operating system or screen reader. Still, Dancing Dots products are not used universally by our participants. Scripts for Lime and Sonar are built on JAWS and require a Windows device. Those who operate on different platforms, including P8 (Linux) and P11 (macOS), described the tradeoff of having to wait for scripts that support the inexpensive DAW Reaper and the industry-standard notation software Sibelius respectively. Accessibility scripts that are developed by third parties may cease to work when the software they support changes. Sonar switched developers in 2017 [18], and the accessibility scripts supporting it ceased updates even earlier. As a result, a JAWS-compatible version only runs on Windows 7. P3, P4, P5, and P6 all have held out on updating their operating systems or have maintained a dedicated Windows machine solely to access Sonar. *"[Sonar] is actually the main barrier for me upgrading from Windows 7, because I have to have Sonar 8.5 and JAWS 16 to be able to run with that script."* -P5.

Accessibility features are also at risk when operating systems update. P11 remembered when Apple updated its OS from version 9 to 10, significantly altering the system's screen reader support and suddenly preventing him from accessing anything in ProTools below the top menu. While its developer Avid retooled accessibility over the span of two years and determined to support screen readers going forward, the most accessible version of ProTools is on macOS in part because of the community-driven Flo Tools which was developed with Keyboard Maestro, a macOS software for programming automations and keyboard macros [75]. Finally, assistive technologies used in tandem with software may have unpredictable effects. P9 remembered occasions when his screen magnifier, ZoomText for Windows, took up so much processing power it caused audio glitches during playback, forcing him to alternate between seeing and hearing his music. Furthermore, while P1 and P11 praised the Komplete Kontrol keyboard's accessibility mode, both lamented how it does not work outside of Native Instrument software, a disappointment given that standardized protocols ensure that hardware devices like Digital Analog Converters (DACs) and MIDI keyboards typically work across all operating systems and music software.

4.3.2 Challenges Preparing and Accessing Sheet Music for Composers. Many blind composers we spoke to did not feel totally independent, especially when preparing music to be read by sighted musicians. P2, P3, P4, P5, and P7 all described how sighted assistance became necessary at the final stage of preparing a manuscript to ensure correctness of layouts and element placement and received indirect assistance, e.g. from musicians who handed back scores with notes (P2), and direct assistance, e.g. from a sighted colleague who made fixes directly in Lime (P3). Most notation software uses a graphic user interface with a 'WYSIWYG' paradigm in which visual elements, like text and expression symbols, are not always positioned properly when created or updated when formatting changes occur (Figure 2), and must be corrected through drag-and-drop - an input method not available to most of our participants. P8 uses text-based alternatives including an open source engraver LilyPond, but finds it very demanding[3] [34]. *"If you've ever looked at one of those ASCII files, that's a tremendous intellectual achievement to keep that that level of detail in your head."* -P8.

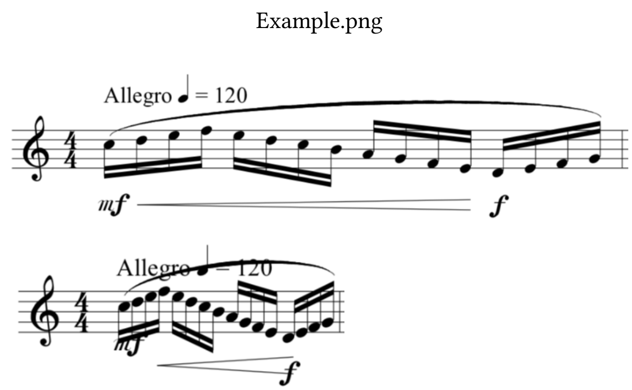

Figure 2: Two measures of music shown contain exactly the same elements. While the first is properly formatted, the second is too narrow with markings that lack vertical alignment and proper spacing.

4.3.3 Ceilings on Expression: Going Beyond What Accessibility Features Support. Finally, and perhaps most dishearteningly, some discussed instances in which technologies limited or blocked attempts at realizing expressive goals and effectively capped the fundamental elements of their medium - the symbols composers use and the sounds producers manipulate. In Lime/GOODFEEL, P5 could not output notes written outside the western chromatic scale to achieve a middle eastern sound. GOODFEEL cannot represent any custom symbols that a composer invents to direct unorthodox performance techniques. While P5 ultimately achieved a desired result in Duxbury to alter the braille cells directly, he did so with heavy research consulting the Braille Music Code [71]. Furthermore, three producers, P1, P3, and P11, discussed an absence of accessibility standards in third-party plugins: *"I can't tell you how many times somebody wants to access a plugin and the parameters are not made accessible. They're not visible, you can't get to the presets, whatever. That is the biggest obstacle that blind musicians face right now."* -P11.

Plugins define an individual's sound capabilities and can include sample libraries (such as huge collections of acoustic instrument recordings), advanced synthesizers, and custom effects (e.g. reverbs, distortions, compressors, etc.). Plugins are often opened from within a DAW but edited in a separate window that may be inaccessible to a screen reader. P3 described having no way of knowing in advance whether a plugin might be accessible or not and feeling afraid to purchase a new product he'd likely have to return. Furthermore, plugins are usually bundled with presets, hand-crafted starting points, with helpful labels like 'thumping bass' or 'swelling pads,' intended to aid producers on their quest for the right sound. Given that presets are implemented differently across plugins and selected

[3] LilyPond is to Finale what LaTeX is to Word.

within a plugin's interface, inaccessible plugins are frozen to one default setting for screen reader users. One hack, described by P11, is for a sighted user is to make duplicates of a plugin and re-save each with a different preset providing a screen reader user more options but not edit capability.

5 DISCUSSION

Our participants agreed that music creation technologies are more accessible to blind and visually impaired music makers than ever before. Commercial developers, including Apple, Native Instruments, and Avid, are more likely to support screen readers, companies like Dancing Dots continue to sell products that diverse users can depend upon, and open-source developers are innovating with platforms like Flo Tools. Yet, accessibility is not equity, and our participants discussed experiences that were far from user-friendly. The composers we spoke to relied on sighted assistance more than producers or songwriters to complete projects, while producers described the most complicated tools and demanding interactions. Participants with no vision could face insurmountable barriers, like unusable plugins, while those with some vision still changed their practice and workflow to reduce frustration and/or discomfort. We see opportunities for innovations in multimodal interaction methods, non-visual navigation techniques, inclusive designs, and industry/end user partnerships ensuring that blind and visually impaired music makers do not lack the opportunities afforded to their sighted peers.

5.1 Need for Multimodal Interactions

Our participants used interfaces that were designed to be accessed visually, and they faced many interaction problems that could be addressed with better integration of tactile and auditory modalities. Established principals for multimodal design state that interfaces should be designed for the "broadest range of users and contexts of use" [66]. Music technologies clearly put blind and visually impaired users at a disadvantage. Most notably, screen reader users do not have enough hands to play their instrument and read their interface in parallel. This problem is not unsolvable: P10's spoken music hack demonstrates a multimodal interface better adapted to his abilities and music making environment (4.2.3). Furthermore, in designing systems with multimodal input and output, established research guides us to consider the advantages and disadvantages of different modalities, and utilize multiple channels in ways that reduce cognitive load [59]. For example, visual interfaces should not be replaced entirely with auditory displays given limited human abilities to process multiple streams of audio [26, 57, 77], while audio-tactile interfaces should not mandate a super human with four hands. Our participants offered multimodal interaction ideas that better capitalize on physical abilities and sensory affordances - for instance continuing to input notes with a MIDI keyboard while using speech recognition for other symbols in place of drag-and-drop (P2), and using audio playback in tandem with a braille display to hear the overall piece and feel specific elements and instruments, in effect receiving complementary information across two channels (P7). As we develop accessible, multimodal music interactions, we can draw from design principles and examples gathered from related work [20, 22] as long as we meaningfully engage end users. The Haptic Wave offers one positive example of a tactile interface developed with the participation of blind and visually impaired users across many iterations [73].

5.2 Improve Navigation

The challenge of navigating large pieces of music inside complicated interfaces is amplified without vision. We see two opportunities for improving navigation: First, interfaces, specifically those used in production, need to be simpler and and more customizable. Second, musical data needs to be accessed in ways that align with how we naturally process music, rather than through large, ordered lists of events read sequntially by screen readers.

5.2.1 Interface Navigation for Producers. Reflecting the experiences of producers we spoke to, P11 found even simple navigation tasks overly complex using ProTools with VoiceOver: *"If a sighted user is looking at a screen and you ask them, where are we in the song, they will instantly, in a fraction of a second, look straight up at the top of the window and say, 'Oh, we're at the four minute and 30-second mark,' so it takes them no time to gather that information, whereas the screen reader user would have to navigate to the counter display cluster, interact with it, go to the main counter field, read that field - It could take a range of time. They might be close to it so they only have to move over one or two elements and they'll be there, or they might be at the bottom of the window, and they have to kind of go to the top and then navigate across. So it could take three seconds, it could take five seconds, it could take seven seconds. I mean, it really depends on several factors."* -P11.

Flo Tools, a third-party library, sets out to improve Pro Tools navigation with additional keyboard controls, but in seeking to address the needs all screen readers users, Flo Tools implements an overwhelming number of macros and automations, nearly one thousand by P11's estimate. While production environments are broad and feature-rich, the participants we spoke to used them in distinct, limited ways. For example, P6 primarily works with his own voice and guitar, needing few layers and instruments but precise control over one set of effects. Conversely, P9 shared with us a recording containing many instruments and relied on controls to isolate and compare various layers. Specific controls clearly should not be equidistant or even available for everyone. Developers might provide users choice to begin with simplified, micro-environments that start with necessary features and extend optionally, and/or develop responsive, ability-based interfaces that learn from and adapt to the specific tools, techniques, and modalities used [78].

5.2.2 Music Navigation for All Music Makers. Currently, non-visual music navigation could be described as the equivalent of reading a sentence one letter or some arbitrary number of letters at a time. When scanning a musical score, experienced sighted composers and musicians use a combination of strategies to gather and retain knowledge at the low-level (e.g. identifying notes, rhythms, intervals), mid-level (e.g. chunking events into melodies and grooves), and high-level (e.g. recognizing repeating themes and categorizing sections) through redirecting gaze between wide and focused regions [72]. Our participants described navigating music as highly sequential and low-level, either note-by-note in a score or second-by-second with a CD (P8), and editing music as a slow process involving iterating long lists (P3) or losing patience and instead re-recording entire sections (P6). We see first an opportunity to build on the visual music creation environments developed by music education researchers (2.1) and reimagine their designs with alternate modalities. Second, we need to develop ways of generating musical syntax trees in real time that enable screen reader users to navigate across musical materials in a similar manner to well-tagged documents. Music theorists have already considered techniques for systematically classifying musical hierarchies [40, 46] and have even developed programming interfaces for offline music analysis that parse MusicXML files, the same file format underlying automatic conversion between visual and braille scores [69]. We also may explore music input methods that aid users in tagging their works as they write, simplifying listening and editing processes later.

5.3 Design for Accessibility Early: Inclusive Design, Universal Output

We encourage researchers to design more music tools with explicit intent to include diverse users. In short, we promote an *inclusive* design approach [42]. Music technology is an excellent domain for inclusive experiments that build on assistive devices and/or target small user groups because electronic musician communities have long held a "plug anything into anything" mantra. Most music software and hardware use universal protocols, including MIDI, MusicXML, and Open Sound Control (OSC), and we have yet to use a major programming language that does not contain open-source libraries supporting them. In the same way that the XBox Adaptive Controller plays the same games as other controllers [51], inclusive instruments and interfaces that support standardized protocols pair easily with other tools while conveying numerous benefits. Constrained environments that use common metaphors and procedures may further scaffold the learning process as a novice moves to more sophisticated musical tools. For instance, the Groove Pizza is constrained to a three-instrument drum sequencer, but exports MIDI files to bring drum tracks into projects with more instruments, [41], while music video games, in which users input commands to "perform" songs, share many concepts and similarities to MIDI environments providing an entry point into more formal music practices [63]. Furthermore, inclusive designs may enable those with diverse abilities to contribute to collaborations with tools that work specifically for them, but output in formats that work for everyone. For example, the accessible instrument Skoog sends MIDI messages over Bluetooth to play music in GarageBand, allowing those with limited motor control to collaborate in a shared DAW [43]. P8, an experienced coder exemplifying collaborative approaches, used Linux command line tools to crop, manipulate, and export audio in a manner such that "*much of the rest was done with sighted colleagues and ProTools.*"

5.4 Keep Communication Open Between End-Users and Developers

As described in 4.3, developers who do not prioritize accessibility put end-users at a disadvantage with limited and unreliable products. Companies who hope to innovate, support consumers, and expand their user base should regularly engage with end-users of diverse abilities in the design, development, and maintenance of products. From our discussions with P1 and P11, Native Instruments, behind the Komplete Kontrol system, emerges as a paradigm for including end-users throughout development and advertising accessibility as a primary feature [44]. Given the cost of high-end music equipment and the size of a community user group accessing Komplete Kontrol accessibility features, P11 estimated significant financial benefits for the company.

Other participants discussed experiences making recommendations and/or demonstrating workflows to developers who reached out. For example, P3 communicated with Yamaha in designing a new keyboard while P2 demonstrated how he uses Finale on macOS with Zoom to its developer Makemusic over video chat reporting to us that they added new background options to reduce eye strain and colorblind friendly palettes [33], but "*the other suggestions I have made, I don't think they've implemented them yet, but they told me they would keep it in mind.*" -P2.

New developments around Avid products demonstrate how researchers, developers, and end-users can organize, set clear expectations and responsibilities, and progress on shared goals. The open source library Flo Tools exists not on its own, but alongside an agreement with Avid dating back over ten years to when the release of Mac OS X broke accessibility in ProTools and P11 demonstrated his lack of access to a room of developers. Furthermore, a new partnership between the Assistive Music Technology Program at the Berklee College of Music and Avid sets out invent and test non-visual interaction methods and finally make the notation software Sibelius accessible, with Avid committing in advance to follow and maintain guidelines put forth by researchers [70]. Without such partnerships/commitments, researchers should be wary of independently developing accessibility scripts for commercial products given the likelihood of scripts becoming out-of-date and stranding users in old versions and operating systems, as has happened with Sonar and Sibelius previously.

6 LIMITATIONS AND FUTURE WORK

This research focuses narrowly on highly-experienced composers, producers, and songwriters. Participants are typically older than 50, (8/11), and possibly more prone to using older technologies though we did not observe an obvious trend given that the three younger participants were not aware of different technologies. In future work, researchers may observe the experiences of novices as they encounter challenges in learning music and technology simultaneously. Furthermore, while we did not explicitly seek male perspectives, participants are overwhelmingly male (10/11). Women have long been underrepresented in sound and music computing fields observed in studies on students enrolled in undergraduate music technology programs [16], authors published in sound and computing conferences [27, 31], and composers taught in higher education curricula [15]. Yet, in an international survey of 191 blind and visually impaired musicians, Baker and Green did not find an overwhelming difference, as "42.04 percent of the female and 55.40 percent of the male questionnaire respondents indicated that they used various music-making technologies readily" [11]. Future research should set out more explicitly to include other gendered perspectives. Finally, this work does not for the most part address the social implications of accessible music technology - a potential area for further study given both highly-collaborative and highly-competitive aspects of music professions - and the finding that many participants contribute music technology expertise in local and online communities. In general, as described in our discussion, we feel there is a need for wide-ranging, multi-modal, innovative, and unorthodox prototypes that test assumptions of accessible design, target small, diverse user groups, and break far away, with clear intent, from overwhelming visual mainstream technologies.

7 CONCLUSION

We presented an interview study with 11 blind and visually impaired composers, producers, and songwriters who discussed experiences composing original works using niche and/or mainstream technologies. While participants perceived an improved landscape for accessible music technology, they still faced a limited selection of tools resulting from mainstream products with limited screen reader support and niche products that became discontinued, required sighted aid in certain situations like preparing scores, and reached expressive boundaries within technologies in which attempts at customization exceeded existing accessibility features. We recommend that researchers explore interfaces that support input and output using adaptable combinations of visual, audio, and tactile modalities, and consider non-visual interface navigation and music navigation as separate challenges both mandatory to lower barriers for blind and visually impaired music makers. Finally, we encourage researchers to develop prototypes with novel interaction methods that maintain standard music data protocols (in short, inclusive designs with universal connections), and establish partnerships and commitments with first-party developers.

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