Haptic Feedback to Overcome Barriers for Visually Impaired Users in Digital Audio Workstations

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Abstract

Challenges and accessibility barriers associated with Digital Audio Workstations (DAWs) for users who are Blind and Visually Impaired (BVI) are well established. However, there has been a lack of research that examines how musical hardware devices are used as assistive tools and their role in improving DAW workflows. Nineteen participants from the BVI community were interviewed to detail their workflows, highlighting methods, benefits, and challenges of integrating musical hardware devices within their DAW. Results found that sixteen participants are using at least one hardware device (e.g., Komplete Kontrol, and Softube Console 1) in their workflows as an accessibility tool for DAW features (e.g., FX parameters, automation, volume and pan). Such tools lead to improvements in efficiency and enhanced creativity. Participants' choice of hardware devices was influenced by multiple factors, such as technical specification, accessibility features, usability, and cost. Finally, we highlight suggestions for future research and development areas with a particular emphasis on proposing ways of implementing vibrotactile feedback that will enhance DAWs' accessibility.

1 Introduction

Music technology in the last 20 years has revolutionized music production and digital music-making, providing greater accessibility and opportunities for music creatives. The advent of affordable Digital Audio Workstations (DAWs) and compact music hardware, such as MIDI keyboards and surface controllers, have allowed more individuals to engage with digital music-making. Professional studios are no longer necessary, given that laptops equipped with powerful software have become capable substitutes. Integrating assistive technology and accessibility features within music software has also created new opportunities for users with visual impairments to pursue music production as a profession or hobby. However, various obstacles still remain and challenge the inclusion of visually impaired individuals within the field.

Current literature focuses on the challenges posed by the inaccessibility of DAWs, creating a notable gap in the comprehension of the valuable role hardware devices play in enabling visually impaired users to engage effectively in music production. Research by W. C. Payne et al. (2020), Metatla et al. (2013), Pedrini et al. (2020), and Saha and Piper (2020) has been conducted highlights the limitations of the accessibility features within DAWs. Audio features, such as volume meter levels or equalisation (EQ) that mainly provide visual information have been shown to be inaccessible (Saha & Piper, 2020). The use of screen readers (SR) can often be time-consuming and confusing as the music often covers the voice-over, and conversely. Blind and Visually Impaired (BVI) users commonly rely on music hardware equipment and tangible affordances to address these issues (Saha & Piper, 2020). Hardware and the sense of touch serve a pivotal role in how visually impaired users can navigate and engage with the DAWs (Tanaka, 2019). Studies such as Siedenburg et al. (2024) and Turchet et al. (2021) demonstrate the benefits of vibrotactile feedback, including enhanced enjoyment and perception in the accessibility of music creativity. Moreover, other researchers have explored further the impact of haptics to support

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accessibility through exploring tangible interactions for interacting with sound and making music (e.g., tangible MIDI sequencers (Haenselmann et al., 2009), game controllers (Kaiser et al., 2018), and HaptEQ (Karp & Pardo, 2017))(see 2.3). However, these approaches are typically bespoke and offer only temporary solutions. A wider comprehensive examination of hardware equipment is necessary to provide a holistic perspective on current accessibility challenges and potential solutions within the music technology field for BVI users.

To address this gap, we conducted 19 semi-structured interviews with BVI music producers to understand how they currently utilize existing hardware devices within their creative workflows, highlighting new insights on how to integrate haptic feedback in DAWs and other music technology tools. We present three themes capturing participants' experience with haptic feedback applications and how such technology can benefit and support DAWs. These findings provide a new perspective on the inclusive design of DAWs and music production ecosystems, serving as a platform for academia and industry to embrace more human-centred design practices to ensure that BVI users can actively and equitably participate in music production activities.

2 Related Work

2.1 Music Technology Applications and Practises

DAWs provide a comprehensive set of tools for music making, such as recording, editing, and mixing. They are often accompanied by a plethora of external plugins, audio processing tools, and virtual instruments. This wide range of choices empowers producers to select the ideal sound processing tool for their needs. Mainstream DAWs include Pro Tools, Logic Pro, Cubase, Ableton, and Reason, which all have large user bases and an established history within the field (Huber & Runstein, 2017). Other DAWs, such as Garage Band and Fl Studio, offer significant advancements for users who are exploring music-making and production. Among industry standards, Reaper might be considered the most cost-effective option (Sarah Keith & Mesker, 2022).

Hardware plays a crucial role in enhancing DAW functionality for supporting creativity and user interaction. It encompasses a wide range of tools supporting music production, including analogue and digital synthesizers, audio effect processors such as equalizers, reverb units, compressors, and MIDI instruments like keyboards, drum pads, and surface controllers. There is a wide range of audio interfaces, mixing consoles, studio monitors, microphones, sequencers, and samplers available on the market. De Man et al. (2019) highlight how each device has unique specifications, design and interaction methods, making them distinct and preferable to each user. MIDI controllers, for instance, offer physical interaction through knobs, faders, buttons, and sometimes modulator wheels allowing for intuitive control of audio parameters during the music-making process. Such hardware devices offer users an alternative to traditional mouse and keyboard interfaces which can be a less cumbersome and more accessible way of interacting with the DAWs (Huber, 2020).

Endless encoders, like those found in MIDI Keyboards Komplete Kontrol (Native-Instruments, 2024) and the Avid S1 mixing board (Avid, 2024) can rotate continuously without any physical stop. Such controllers make the reassignment to multiple parameters possible, offering the flexibility to access various functions of a DAW with the same physical interaction element. They also possess the capability to store a parameter's value, allowing users to recall it based on their specific requirements. Similarly, motorized faders (Figure:1) like these found in PreSonus Faderport 16 (PreSonus, 2024), and Behringer X-Touch (Behringer, 2024), although inherently possessing a fixed range of motion, can be assigned to multiple parameters, recall saved values and move automatically to the assigned value offering tactile feedback on the automation envelope of an audio track.

Surface controllers also enable tactile interaction with the DAW interfaces that provide multiple advantages such as efficient workflow through precision and adaptability to user's setup and interaction needs (Berthaut & Jones, 2016). For instance, motorized faders are commonly used for recording automation within the DAW, offering users a level of performative expression and accuracy that cannot be matched by a computer mouse or keyboard. However, the cost and physical space required for these devices can pose challenges to users. While these tools are widely used in professional music production workflows, there is a notable lack of academic research that rigorously explores their benefits and limitations.

Studies by Kalantari et al. (2018) and Papetti et al. (2021) indicate that vibrotactile feedback

Figure 1: Motorized Faders

Figure 2: Limited Range Encoders

can enhance the accessibility of music production tools by providing advanced non-visual interaction for understanding and manipulating sound. Many commercial companies leverage these insights to develop devices that promise an enhanced music experience. For example, wearable devices with vibrotactile feedback like the SubPac (Subpac, 2024) vibrate at low frequencies to create a tactile sensation of sound. Similarly, the Woojer (Woojer, 2024) and Feelbelt (Feelbelt, 2024) are belt-style devices that respond to audio frequencies, delivering immersive vibrations to the wearer. The Music: Not Impossible (Not Impossible Lab, 2024) haptic suit is designed specifically to help deaf and hard-of-hearing individuals enjoy live performances through a full-body sensory experience. Meanwhile, the SoundBrenner (Microdrivers, 2024) wearable metronome transmits tempo information directly to the user's wrist, making it a valuable tool for musicians.

These devices show great potential for augmenting digital music environments such as DAWs and serve as valuable accessibility tools by introducing a new sensory dimension for perceiving sound. However, their functionality is still limited to conveying specific information within DAW, such as sound intensity across certain frequency ranges. As a result, their primary applications remain focused on enhancing the experience of listening to or enjoying music in new ways. Due to the physical constraints of haptic technology, these devices are not yet flexible or modular enough, and they are limited to specific use case applications.

People with visual impairments are particularly interested in music making, considering it both as a hobby and an occupation (Metatla et al., 2013). To cater to this audience, music technology companies such as Native-Instruments (2024) and Softube (2024) have attempted to integrate inclusive design methods and accessibility design practices into their product design. However, despite these efforts, further research is needed to fully address BVI music producers' needs (Saha and Piper (2020); W. C. Payne et al. (2020)).

2.2 Accessibility in Music Technology

BVI individuals access digital information on computers primarily via screen reader applications such as *JAWS*, *NVDA*, and *VoiceOver* (Nick et al., 2012). A screen reader interprets the displayed context and converts it to synthesized speech or braille output. In order to function, developers need to integrate additional code *scripts* that facilitate screen readers in accessing the application's layout, text and user interface elements (Leonardis et al., 2018). The majority of commercially available DAWs are not designed to be compatible with screen readers, which poses a significant challenge (Saha & Piper, 2020). Among the few DAWs that support screen readers are Logic, Reaper, and ProTools (Pedrini et al. (2020); Harrison et al. (2023)) and most recently *Ableton Live*. Apple's *Logic* and the latest *Ableton's Live* application have embedded screen reader capabilities, making them accessible "out of the box". In the case of *Reaper* and *Protools*, the required *scripts* are developed by individuals in the form of plug-ins (e.g. *Osara* (Teh, 2024), *FloTools* (Chi et al., 2016)) to make applications accessible to screen readers. Pedrini et al. (2020) evaluated the accessibility of three DAWs (*Reaper, ProTools* and *Cubase*(no longer accessible)) through practical tests of mixing practices such as the use of transport, track navigation, waveform editing, sound level mixing and file configuration. Overall, Reaper has been found to be the most accessible of the three in both MacOS and Windows, with the MacOS operating system performing better in supporting accessibility tools such as voice synthesis and SR (Pedrini et al., 2020).

Across all DAW platforms, screen readers introduce a range of usability issues for BVI users. Metatla et al. (2013) identified, through four case studies, that interactions with screen readers are tedious and time-consuming. In particular, the authors reported that the voice feedback process highlights multiple irrelevant pieces of information before reaching the user's desired point of interaction (Metatla et al., 2013). Similarly, Saha and Piper (2020) and Harrison et al. (2023) also underline that the way information is presented through the screen reader is not sufficiently efficient given that information is being presented in a linear way (e.g. lists of parameters), thus causing delays and cognitive overload by requiring multiple steps for task completion and a high level of memorization. Pedrini et al. (2020), highlight how using a screen reader in DAWs results in two conflicting sources of audio feedback, one from the DAW's output and another from the screen reader, which increases cognitive load and decreases workflow efficiency.

W. C. Payne et al. (2020) highlighted the lack of the required *scripts*, resulting in users' inability to access the software or parts of it through a screen reader with no alternative. For instance, software updates often break accessibility features if new code is not accompanied by corresponding scripts for screen readers. Similarly, the majority of third-party plug-ins are not accessible for BVI users as the developers often do not consider inclusivity and accessibility due to extra cost and development time (W. C. Payne et al. (2020); Saha and Piper (2020); Harrison et al. (2023)). DAW's graphical interfaces also present additional accessibility constraints, as they often focus on visual cues, such as changes in colour or graphical icons to convey information. Without providing an alternative descriptive text, graphical information cannot be translated to text (Metatla et al. (2013); Saha and Piper (2020); Harrison et al. (2023)).

Given the limitations of screen readers, BVI producers often turn to hardware devices, including Braille displays and MIDI controllers, to create a multimodal interaction setup that reduces the cognitive load (W. C. Payne et al., 2020). Saha and Piper (2020) and Harrison et al. (2023) examined how users are "forced" to combine different tools to develop efficient workflows (e.g., a computer and a midi keyboard (Harrison et al., 2023)). However, this makes workflows unnecessarily complex, as users have to manage several pieces of equipment simultaneously. Although hardware tools are considered useful, they are often expensive, with some containing inaccessible interaction systems such as touchscreens. As a result, a system that depends on compatibility with a screen reader can be unreliable and present further accessibility issues (Saha & Piper, 2020). Harrison et al. (2023) specifically highlighted the tactile affordances proposed by analogue equipment to users and how they are lost in the digital domain. Nevertheless, BVI producers embrace the fact that tactile interaction (e.g., motorized faders, rotary encoders and buttons) allows the manipulation of the audio through bypassing a screen reader's voice feedback for certain tasks (Figures: 1, 2) (Harrison et al., 2023).

Current research highlights patterns of inaccessibility in music production, with a predominant focus on screen readers and the efforts to address key challenges (Saha and Piper (2020); Pedrini et al. (2020)). Harrison et al. (2023) examine the advantages of incorporating tactile interaction in the workflow of BVI users. Most existing studies, (e.g., W. C. Payne et al. (2022); Saha and Piper (2020)) also rely on small sample sizes and a lack of research bridging the gap between accessibility barriers in software and hardware accessibility.

Screen readers are the predominant way to make DAW accessible, and they remain an essential tool for enabling BVI users to interact with DAWs. However, the linearity and auditory manner of conveying information makes them inefficient, leading users to address their challenges through the use of complex, multimodal workflows. There is a lack of comprehensive research examining the interchange between software and hardware accessibility, with limited studies exploring how tactile interaction can better support BVI users in music production.

2.3 Multimodal Interaction

Multimodal interaction techniques hold significant potential to improve usability and enrich user experiences across a wide range of applications. Integrating the three primary senses used in human-computer interactions (i.e., hearing, sight, and touch) can provide a flexible and intuitive user interface, allowing individuals to select the most suitable modality for both their preferences and the specific task at hand (Rafael & Almeida, 2021). Tu and Luo (2024) explore the design principles for designing a multisensory interaction for digital interfaces for elderly people who face multiple accessibility barriers across the spectrum of their senses, showcasing the ways different sensory inputs and outputs can facilitate an easier and more inclusive life for people with disabilities. In music, Frid (2019)'s systematic review revealed that 53% of 83 assistive digital instruments studied include a multimodal design approach.

Focusing on visual impairment, multimodality is an important accessibility design method for lowering the cognitive load (Mesquita et al., 2018). Audio and haptics often work in synergy improving communication with computer applications when visual interaction is not feasible or preferred (Baldwin et al., 2017). To highlight the role of tactile experiences in multimodality, Braille displays, for example, allow information to be split between two sensory experiences of hearing and touch, allowing faster and more discrete access to information (W. C. Payne et al., 2020). Similar examples around the enhancement of audio feedback with vibrotactile feedback emerge from the comprehensive review of Kuriakose et al. (2020) in multimodal approaches to spatial navigation where 13 projects have been identified including tactile or vibrotactile feedback as part of the system. Moreover, research is focused on finding ways to transmit more information quickly through vibrotactile feedback to enhance the accessibility of mobile phones and other touchscreen devices (González-Cañete et al., 2021). Vibrotactile feedback is also being used in combination with audio in the field of entertainment (e.g., gaming (Sánchez, 2023) to support the spatial orientation of the user or to notify about events. In music Harrison et al. (2023) highlight how the use of commercial music hardware devices (surface controllers, and midi keyboards) can support the established accessibility tools such as screen readers or screen magnification tools, enabling a more efficient workflow that allows users to focus more on their audio processing tasks.

A variety of research projects explore the possibilities of alternative assistive tools to make DAWs more accessible by utilizing multimodal interactions. The *Moose* by O'Modhraim (O'Modhrain & Gillespie, 1997) suggested a motorized system that facilitates interaction in a 2D axis like the mouse. Haenselmann et al. (2009), with the *zero-vision sequencer*, suggested a MIDI instrument that combines performance and sequencing functionality so that users do not need to port across platforms. Since 2010, several research projects have highlighted the need for tangibility in music processing and production. They explore the possibilities of existing or novice technology and apply user feedback, producing outputs that inform future developments regarding the usability of different technological tools. Some projects directly relate to DAWs and focus on better interaction with audio effects. *HapticEQ* (Karp & Pardo, 2017) suggests an interaction with a flexible chain that can generate an EQ curve that will be read by computer vision; *TouchEQ* (Pesek & De Man, 2021) uses haptic equipment, whilst *TanvasTouch* (Tanvas, 2024) utilises a touchscreen that offers localized and textural haptic feedback. Lucas et al. (2019) tested bespoke 3D-printed knob cups, and Kaiser et al. (2018) used an Xbox 360 controller to interact with transport functions. (Tanaka & Parkinson, 2016) developed a device, the *Haptic Wave*, consisting of a motorized fader that moves in a 2D axis, providing information about the waveform parameters, and facilitating the editing process. Alongside music production projects, haptic interaction has been used for compositional purposes - for instance, Karpodini and Michailidis (2022) proposed 3D printed representations of graphical scores' parts in a table, whilst W. Payne et al. (2019) redesigned the Groove Pizza application by adding keyboard interaction to make it more accessible. Although individual case studies provide valuable information about the benefits of haptic feedback and multimodality in both assistive tools and music-making tools, they lack comprehensive research on how technology design and multimodal interaction synergistically contribute to the overall usability and inclusivity of these tools. Another major limitation of these studies is the sustainability and a lack of longitudinal evaluations. Most projects remain at a research prototype stage and rarely transition into widely accessible, long-term solutions. In addition, most studies contain small sample sizes, the biggest sample size found in Tanaka and Parkinson (2016) 11 participants and in Pesek and De Man (2021) 15 participants, and they rely on qualitative and participatory design approaches. Whilst these are informative, they do not currently provide robust quantitative evidence to demonstrate a system's usability and the effectiveness of its multimodal design.

From the relative work, it is clear that emerging trends in music technology, haptics, and assistive technologies are beginning to merge. Existing studies provide valuable insights into the accessibility barriers faced by BVI users when interacting with DAWs, particularly with regard to the limitations of current software and hardware. However, few studies delve into the use of hardware devices to improve workflows, presenting a clear gap for further research into the interplay between software and hardware accessibility in music production environments. This paper highlights the benefits and challenges of the use of hardware devices in music production by BVI users. It explores the use of specific features, such as encoders and faders, while also contributing to the discussion of incorporating vibrotactile feedback in future designs to enhance accessibility.

3 Methods

We conducted interviews with 19 visually impaired participants to better understand their workflow when using music hardware devices in DAWs.

3.1 Procedure

Participants were recruited through an open call published in forums for BVI users that focus on addressing accessibility challenges for different DAWs. The recruitment criteria for this study required participants to be either blind or have low vision, use accessibility tools, (e.g., screen readers and magnification tools) and have knowledge of using DAWs regardless of their level of experience. This results in a specialized and relatively small population. Nineteen participants expressed an interest in joining the study. This aligns with other studies, including visually impaired users, which have worked with similar sample sizes (Saha and Piper (2020) - 18 participants; Harrison et al. (2023) - 20 participants; W. C. Payne et al. (2020) - 11 participants). We endorse that a sample of this size enables a thorough thematic analysis and provides meaningful insights into this underrepresented group.

After agreeing to participate, participants were provided with a questionnaire containing information about the study, demographic questions and a consent form. The demographic questionnaire collected data around age, gender, occupation, country of residence, and primary DAW and primary screen reader used. Questionnaires were presented via a Microsoft Form and as plain text versions distributed via email. Upon receiving the consent form, we proceed in arranging a suitable date and time for the interview via email communication. To accommodate participants' preferences, we conducted two in-person interviews and 17 online interviews using their preferred method (13 using MS Teams, 3 using Zoom and 1 using FaceTime). Each interview lasted an average of 90 minutes. Institutional Review Board approval was obtained to conduct the study.

3.2 Interviews

The interview was structured in four key areas: (1) exploring participants' background around music and accessibility, (2) discussing their use of hardware equipment with DAW workflows, (3) participants providing a demonstration of their DAW, and (4) examining their use of haptic technologies within a DAW context. The interviews employed a semi-structured approach, allowing for flexibility to explore participants' needs and challenges more deeply. This approach enabled us to skip or add questions as needed, based on the natural flow of conversation and participants' experiences (Lazar et al., 2017). This flexibility extended to the third part of the interview, where we incorporated contextual inquiry by asking participants to demonstrate their workflow. During this section, we observed how participants interacted with various areas of the DAW and identified their workarounds to overcome accessibility barriers. The level of detail in the demonstrations varied based on participants' experience, ability to share their screen, and current setup during the interview.

Interview structure

Part 1-Participants' background: Participants were asked about their visual impairment condition and whether they were comfortable discussing it. We then question the level of engagement with music and music production, including prior studies and current practice. Participants were also asked to elaborate further, with examples, on their DAW usage, which DAWs they have previously used and why, and the screen readers they are using and are familiar with. The design of this part is based on previous studies' presentation of the participants' profiles overview with information such as visual impairment, type of work and experience with DAW (Saha & Piper, 2020) and musical background, knowledge of printed music, computer accessibility and age (W. C. Payne et al., 2020). Additionally, Part 1 served as an opportunity for the interviewer to learn about the participants' backgrounds and allowed interviewees to feel more comfortable and foster trust.

Part 2-Use of hardware equipment: The second part of the interview included questions on how they use different hardware in their workflow, such as controllers, keyboards, or Braille displays and which aspects of the DAWs they control. We followed up with two structured questions: 1) What is the role of tactile experience when using the specific hardware, and 2) how has the evolution of hardware technology (i.e., analogue-digital) influenced their practice? The questions in this part expand upon the latest to-date research by Harrison et al. (2023). We evaluated the findings of this research and identified areas requiring further exploration, particularly focusing on the specific hardware features that enhance efficiency. This aspect was designed to remain flexible, as it largely depends on the expertise and insights of the interviewees.

Part 3-Demonstration of DAW: Participants were then asked to demonstrate their workflow within their preferred DAW, particularly the effective and ineffective aspects of the DAW's accessibility. We then focused on specific processes of music production activities that have been mentioned in the literature that lack accessibility features (Oltheten (2018); Saha and Piper (2020)). These elements were EQ, compressor, reverb, automation, recording, editing waveform, midi, and access to actions such as panning and solo/muted. Part 3 served as a bridge between interview segments, helping the interviewer gain deeper insights while also prompting participants to recall challenges they may have previously overlooked and to consider potential solutions. The questions were inspired by the work of Harrison et al. (2023), who primarily used demonstration as their main method of data collection. However, we limited this approach to Part 3 to maintain focus on the key research questions in Parts 2 and 4, which centred on the use of hardware devices and the future application of haptic technologies in participants' workflows.

Part 4-Haptic technologies in the workflow: Participants were asked about their familiarity with haptic technology and, more specifically, vibrotactile feedback found in smartphones, smartwatches, gaming, or other accessibility tools. Participants were then introduced to the idea of wearable technology with vibrotactile feedback, such as a smartwatch, and asked to imagine where this technology could facilitate faster and more convenient DAW workflows. We base this section on the initial stages of participatory design workshops such as those in the studies of Metatla et al. (2016) and Tanaka and Parkinson (2016). Participants drew on familiar technologies like smartphones and smartwatches to envision how similar devices could be integrated into their DAW workflows.

3.3 Analysis

Interviews were conducted in two languages, 16 in English and 3 in Greek. Microsoft Stream was used for transcribing interview recordings conducted in English, whilst interviews conducted in Greek were transcribed and translated by two of the authors, who are native Greek speakers.

A thematic analysis was performed to analyse the data collected. The researcher engaged in a comprehensive analysis process by reading the interview transcriptions and listening to the recordings, in alignment with the "repeated reading" process highlighted by Braun and Clarke (2006). We then utilised an inductive approach via Nvivo (Jackson & Bazeley, 2019) to identify codes and themes emerging from the data (Terry & Hayfield, 2021). After completing the coding procedure, the researcher scrutinized the potential merging of codes into themes. In this step, any codes without significant support from the data were discarded. Finally, the formalised themes have been named, and appropriate examples among the factoids have been selected to support the theme's presentation. After completing the coding procedure, we concluded with three key themes representing the primary insights of the participants.

4 Findings

We initially present the analysis of participants' profiles, including age group, location, gender, impairment, experience with music production, preferred DAW (e.g., Logic, Reaper), screen reader (e.g., NVDA, VoiceOver), and experiences with haptic feedback, as well as the hardware devices they are using (e.g., Komplete Kontrol, Softube), including analysis of the companies, models, and specifications. We then present themes around the use of the hardware devices, limitations of their specifications, interaction with screen readers, and the role of tactile feedback affordances in their workflow. Finally, we present themes around the opportunities and limitations of incorporating haptic feedback into DAWs.

4.1 Participants' Information

The participants were aged between 18 and over 65 (see Table 1). Seventeen users self-identified as male, and two as female. Participants were located in North America (6), the UK (7), and Central and Eastern Europe (5). Seventeen have congenital blindness (CB), one with acquired blindness (LB), and one with lower vision (LV). Participants were categorized into different age groups. Demographic information, such as age and location, offers valuable insights into the factors that impact participants' familiarity with technology, which consequently influences their perspectives on emerging technologies. However, this information alone cannot support a generalization of participants' traits. For that reason, we focus primarily on users' self-evaluation of experience with technology to understand better their insights.

The main DAWs used by participants include Reaper (9), Logic (6), ProTools (3) and Cubase (1). Twelve participants also self-identified as advanced or experts with DAWs, five as intermediate and two as beginners. All participants use screen readers to interact with DAWs, including VoiceOver(12), NVDA(14), and JAWs(9). 18 participants also use haptic feedback to enhance accessibility in their everyday lives with smartphones ((iPhone(15) and Android(3)), smartwatches (9), gaming consoles (8) and other tools such as vibrating power bank and Liquid Level Indicator (4). Table 1 Summarises participant details.

Code	Age Group	Country	VI	Experience	DAW	SR	HFE
P1	39-44	UK	CB	Advanced	Logic	VoiceOver	SP, SW, G
P2	65+	USA	CB	Intermediate	Logic	VoiceOver	SP
P3	32-38	UK	CB	Advanced	Reaper	NVDA	SP
P4	32-38	UK	CB	Intermediate	Reaper	NVDA	SP
P5	25-31	USA	CB	Advanced	Logic	VoiceOver	SP, SW, G, O
P6	32-38	UK	CB	Expert	Protools	VoiceOver	SP
P7	55-64	Canada	CB	Beginner	Logic	VoiceOver	SP, SW
P8	39-44	USA	CB	Expert	Sonar	JAWs	SP, SW, G, O
P9	18-24	UK	CB	Advanced	Logic	VoiceOver	SP, SW
P10	18-24	Poland	CB	Intermediate	ProTools	NVDA	SP, SW
P11	25-31	Greece	LV	Advanced	Cubase	NVDA	SP
P12	18-24	Greece	CB	Intermediate	Reaper	NVDA	SP, G
P13	32-38	UK	CB	Advanced	Reaper	NVDA	SP,SW,O
P14	32-38	Hungary	CB	Expert	Reaper	NVDA	SP, SW, G
P15	45-54	USA	CB	Advanced	Reaper	NVDA	SP
P16	32-38	UK	CB	Expert	Reaper	NVDA	SP, SW, G, O
P17	45-54	Germany	CB	Intermediate	Logic	VoiceOver	SP
P18	25-31	Greece	CB-HL	Beginner	Reaper	NVDA	SP, SW, G
P19	65+	USA	AB	Advanced	Reaper	JAWs	na

Table 1: **Participants' Information.**
CB = Congenital Blindness, **LV** = Lower Vision, **HL** = Hearing Loss, **AB** = Acquired Blindness, **HFE** =Haptic Feedback Experience, **SP**= smartphone, **SW**= Smartwatch, **G**= Gaming, **O**=other.

4.2 Hardware

Sixteen participants indicated that they use some form of hardware device in their workflow. Participants highlighted a combination of 25 different hardware models they utilise, while six models remained unidentified due to insufficient information provided by the participants (see Table 2 and Appendix A). Among the hardware devices reported, thirteen participants specifically mentioned using a Native Instruments Komplete Kontrol device, with five using this as their sole hardware device while others used additional hardware devices in their workflow. 16 of the keyboard devices identified include controlling surfaces, knobs, faders, buttons, and modulation wheels, while 12 are non-keyboard controllers with only knobs, faders, and buttons. Among the remaining hardware models, there is one keyboard with no additional controllers and two audio effects hardware. Table 2 summarizes the identified hardware devices and presents the type of tactile interaction they offer (keyboard and control Surface), the type of technology (digital, analogue or hybrid), the type of the individual components (encoders and faders) and finally the number of units identified by the participants.

Model	**Type**	**Technology**	**Controllers**	**Units**
Akai MPK	Keyboard with Control Surface	Digital	Limited Range Encoders	1
Arturia Keylab MKII	Keyboard with Control Surface	Digital	Motorized Faders, Endless Encoders	1
Avid S1	Control Surface	Digital	Motorized Faders, Endless Encoders	1
Avid S3	Control Surface	Digital	Motorized Faders, Endless Encoders	1
Behringer XTouch	Control Surface	Digital	Motorized Faders	2
Mackie C4	Control Surface	Hybrid	Motorized Faders, Limited Range Encoders	1
Mackie Control Surface	Control Surface	Hybrid	n/a	1
NI Komplete Kontrol S61	Keyboard with Control Surface	Digital	Endless Encoders	4
NI Komplete Kontrol S88	Keyboard with Control Surface	Digital	Endless Encoders	4
NI Komplete Kontrol n/a	Keyboard with Control Surface	Digital	Endless Encoders	3
NI Komplete Kontrol A61	Keyboard with Control Surface	Digital	Endless Encoders	2
NI Komplete Kontrol M32	Keyboard with Control Surface	Digital	Endless Encoders	3
NI Komplete Kontrol S25	Keyboard with Control Surface	Digital	Endless Encoders	1
Korg M3	Keyboard with Control Surface	Digital	n/a	1

Model	Type	Technology	Controllers	Units
Korg mikroKey	Keyboard	Digital	n/a	1
Korg miniLogue	Keyboard with Control Surface	Analogue	Potentiometers	1
Korg nanoKontrol	Control Surface	Digital	Limited Range Encoders	1
Novation Circuit Rhythm	Control Surface	Digital	Endless Encoders	1
Novation SL61-MP3	Keyboard with Control Surface	Digital	Endless Encoders	1
Rolland Jupiter x	Keyboard with Control Surface	Digital	Non-motorized Faders, Limited Range Encoders	1
Rolland Phantom 8	Keyboard with Control Surface	Digital	Non-motorized Faders, Limited Range Encoders	1
Rolland RD-700SX	Keyboard with Control Surface	Digital	Non-motorized Faders, Limited Range Encoders	1
Rolland Drum Machine	Control Surface	Digital	n/a	1
Softube console 1	Control Surface	Digital	Motorized Faders, Endless Encoders	2
Softube console 1 fader	Control Surface	Digital	Motorized Faders, Endless Encoders	1
Bricasti M7	Effect	Digital	Limited Range Encoders	1
Cassio CTS500	Keyboard with Control Surface	Digital	Limited Range Encoders	1
Kurzweil K2661	Keyboard with Control Surface	Digital	n/a	1
NI Machine MK3	Control Surface	Digital	Endless Encoders	1
Nektar Impact LX	Keyboard with Control Surface	Digital	Non-motorized Faders, Limited Range Encoders	1
Pultech EQ	Effect	Analogue	Limited Range Encoders	1

Table 2: **Participants' Musical Hardware Devices**
Digital: Digital interfaces and interactive with DAWs, **Analogue**: Operate using traditional electrical signals, not interactive with DAW, **Hybrid**: A combination of software that allows interaction with DAW and analogue features such as motorized faders

4.3 Themes

The thematic analysis outlined three main themes: 1) Music hardware device usage and technology, 2) Tactile feedback experiences, and 3) Haptic feedback in the DAW.

4.3.1 Music Hardware Device Usage and Technology

The first theme provides insights on four topics related to the devices used by participants, the role of their technical specifications, the comparison of analogue and digital devices, and the specific use of the device Komplete Kontrol.

Harware Usage for BVI Users Fourteen participants reported that they mainly control plugin parameters such as filter, EQ (equaliser), pitch modulation, reverb and compression using encoders and faders provided by each hardware device (Figure 3). For example, P16 described how using the motorized faders of Behringer Xtouch offers ease of accessing the values of the parameters. Five participants also highlighted that they use these features to control panning and volume levels, while five other participants to record or recall automation. The most commonly used devices for these functionalities are the Behringer Xtouch, Korg and Mackie devices. P3 emphasized that, *"any kind of pitch manipulation like tuning is easiest just slowly to slide your hand down on the fader and have it corrected that way, rather than going into the parameters and saying at this point you should be that level"*. Four participants also mentioned using hardware device components to navigate the list of VST plug-ins and their available presets more efficiently. P15 described part of his production process: *"I use drums (software instruments) in my recordings, some Native instruments and some other drums. If I am using the Komplete Kontrol keyboard, I can choose the sound that I want and control the levels of the various drums very easily by simply turning a knob"*. Particularly, eight users of Komplete Kontrol reported that this device helps them access plug-ins that are not accessible in another way. P10 commented on the usability of Komplete Kontrol that it gives *"...the ability to move around the Native Instruments plugging and some other plugging that uses the NKS format"*. NKS format allows plug-ins to be compatible with Komplete Kontrol devices (Native Instruments, 2024). P15 raised concerns around accessibility: *"There are some plug-ins that are very inaccessible; for example, I've heard of a program that is the favourite of Hans Zimmer, but when I load it in Reaper, I couldn't access the presets. Using it in conjunction with Komplete Kontrol, I have access to all presets and can also make changes to them"*. Finally, some reported using hardware devices such as Xtouch (Behringer, 2024) and Mackie (Mackie, 2024) to control the transport bar (play, stop, record, forward and other essential functions of the app) (P2).

Twelve participants use two or more devices. A comparison of the equipment reveals that no devices combine all the specifications needed to be fully accessible or to help the workflow effectively. Nine participants have a Komplete Kontrol keyboard and an additional device, which is a controller with a motorized fader (e.g.; Mackie 2024, Behringer 2024, Softube 2024, Avid 2024). For example, P9 has a Komplete Kontrol A61 and an m32 that they can carry with them due to the smaller size. P17 has an Avid S3 and a Komplete Kontrol device and commented that *"with Avid S3, I can control plug-ins and I got comfortable with that, but the problem is that there is no accessibility, no verbal feedback, so I use it only to do some modifications on my sounds"*.

Figure 3: The use of Hardware devices in DAW

The role of hardware specifications: We identified a series of different encoders and fader technologies that influence the accessibility and the preference of the device by visually impaired users. This includes two types of encoders, the limited range encoders with start and finish points and endless encoders, which rotate infinitely and two types of faders, motorized and non-motorized (see section 2.1). Thirteen devices have limited-range encoders, 8 have endless encoders, 6 have motorized faders and four non-motorized (Table 2). Each distinct technology affords these devices a unique tactile interaction style and level of tactile feedback they offer.

Participants referred to the advantages and disadvantages of the two types of encoders, highlighting the importance of the balance between tactile and voice feedback in hardware design. Behringer XTouch (Behringer, 2024) has endless encoders, which, for some users, might be an obstacle. P16 mentioned *"the pans are just endless encoders, so again, you kind of need speech feedback for those"*, pointing out that the need to have voice feedback when using a knob cancels out the usability of the tactile feedback. P19 adds about Komplete Kontrol that *"all this new feedback that has been put into some of these programs, I just found it to be too much"*, supporting the need to balance the provided information on the two sensory modalities.

Regarding the overall presence of a fader in a device, its tactile feedback was found to be preferred over its absence. P14, a user of a Korg nanoKontrol (Korg, 2024), expresses how this piece of hardware helps through splitting information up into two modalities, audio and haptic - *"very often when I want to focus on something, it would be really nice if there was a way to split things up and with nanoKontrol to an extent, I can split things. For instance, modulation, panning or setting volume, I don't need to worry about listening to the percentage values being spoken. It's just a lot easier knowing that I use a knob and it works. It also frees up my ear in a way I can focus on the music."*. However, the only action that can be taken with this device is momentary because of the non-motorized faders, which usually record automation to manually mapped parameters. P14 stated that: *"...it's absolutely a momentary thing. I would be really happy if they were motorized because that could, I think, improve things. At the moment, I just haven't found an affordable motorised one, and it would be as mappable as another control."*.

Four interviewees highlighted the debate between motorized and non-motorized fader. P16 mentions how the motorized fader of the XTouch (Behringer, 2024) facilitates the editing of the automation process as faders represent the position of the automation line each time a small adjustment can be made by moving the fader. *"Because they're motorized faders, and they move to represent the position of the parameters and can kind of feel a representation of how the knobs are set that way. And then sometimes I end up just making the adjustments I wanna make on the faders"* (P16). P8 mentions the use of a motorized fader with Mackie and how, in this case, automation is facilitated: *"I also will write automation. It's got moving. I have motorized faders on the Mackie. So if I wanna fade something out inside the computer, I'll use those faders and draw the automation like that."* (P8).

Likewise, using motorized and non-motorized faders brings attention to a distinct issue - the economic barrier, as devices with motorized faders tend to be much more costly (P13).

The Analogue Experience: Music technology started with the use of analogue equipment. Such equipment does not offer voice feedback, but it often represents information in the form of tactile feedback. P8 stated, *"... processors are fairly accessible because they're not screen driven. So there are VU meters or lights and stuff like that that I can't use. But I don't need them because I can hear what needs to happen."* The way the knobs and faders are aligned and mapped in a fixed position on the device helps users feel secure about what they are doing:

> *"At the beginning of the third knob to the left always does the same thing. So once you memorize that piece of equipment, you know it works; it works the same way all the time. So I have a lot of that."* (P8)
>
> *"There was a board in front of me of knobs and faders and switches and buttons, and once you memorize where all of these things are, then at your disposal. You don't have to go through a menu. You don't have to do anything. It's right there "* (P19).

Some participants (P15, P16) have learned music production this way, so when all the tactile feedback is transformed into graphic representations, they look for effective alternatives. P16 describes how he gradually moved from analogue to digital, looking for the ideal combination of DAW and hardware to facilitate his workflow and the corresponding barriers:

> *"I started on like analogue hardware obviously, and then when I first started using a DAW was Pro Tools, and I pretty much had to have a control surface at that point to be productive. So I spent a good few years with a surface there. And then, when I moved over to Sonar for a brief period, I was able to use the same surface, and that kind of made that transition a little bit smoother. And then I arrived in Reaper, and man, their control Surface integration is bad, and it's still bad today. So I kind of just pretty much stopped using a surface at that point. The reason I've picked it up again recently and started exploring it again recently is that there's this open-source project called CSI Control Surface Integrator. Will I ever go back to using a surface full-time? I don't know. It kind of depends on how smoothly this CSI project goes".*

At the same time, many participants also advocated for digital technology by comparing it with analogue and describing its limitations. Two users (P8, P14) work in a studio environment and highlight barriers caused by the analogue equipment. For instance, P14 stated that interacting with objects like cables and plugging them into the different hardware is difficult for a BVI producer: *"digital is more accessible than analogue – when in the studio there are a lot of problems to move around, you need help from sighted to interact with objects just as cables"*. P8 also mentioned that help is needed (from sighted people) when recording large bands (such as a big band) with multiple inputs in his studio to quickly check the volume levels.

Similarly, P19 describes how the use of analogue devices relies on hearing the sound. Although sometimes this is what a producer needs, there are moments, such as the peak of the sound levels, where there is no further indication than a visual light in the console *"It may be what you are hearing in your earphones may sound great, but it's way above 0db and the meters are already going into the red. But you don't know that because your accessibility isn't telling you that".* This can lead to many disruptions in the process of mixing and mastering.

The use of Komplete Kontrol:

Participants described Komplete Kontrol as the most accessible piece of hardware, with 13 out of 16 users owning one or more models of the Komplete Kontrol series and 4 out of them using only one. These three motivations were highlighted: the easy navigation through long menu lists (P1, P4, P15, P17) due to the quick rotation of the encoder, the access to often inaccessible otherwise plug-ins (P1, P9, P14), and voice feedback for each controller (P7, P8, P10, P13, P15). The flexibility of the hardware to tailor the voice feedback according to preference appears to be a significant factor in its popularity: *"Basically for me, it's about the accessibility and the options and the doors it opens to me."* (P1), and voice feedback for each controller (P1, P7, P8, P10, P13, P15).

> *"I love what native instruments have done because, of course, the hybrid setup. It is the best thing that happened to us in recent years in the music industry because we can touch the knob and find out what this knob is doing, and it can be turned off, of course, if someone doesn't want to hear that. But you can check what you are doing now."*(P10)
>
> *"Because it gives me confidence that what I'm doing is the right thing. Because if I'm tapping on a screen, I'm not always sure that I'm going to hit the right icon, and then it takes me a few attempts to do. If I'm pressing a button on the keyboard and I know that's the browser button, that's going to work to show me a list of products and presets. I can use the little directional curse of things just to find my way through them. That helps the navigation a lot."*(P13)

Native Instrument launched the integration of accessibility features to its devices in 2016, and at that moment, according to the company's evaluations, only 1 in 20 users of Komplete Kontrol were visually impaired (Access, K., 2023). This sustained effort in accessibility created a series of forums and online articles that users can use to help each other. P10 stated that virtual instruments are now widely used within the community and that they think *"...it's a great invention, they have done something great and I wouldn't start making music without it. So I'm very thankful for that"*

4.3.2 Tactile feedback experiences:

The importance of tactile interaction: Seven out of nineteen participants (P3, P9, P12, P13, P14, P15, P19) directly commented on the importance of tactile interaction within their workflow, which makes it faster and more efficient for them to work. P13 commented on improvements in their working process in terms of speech and efficiency, while P14 and P15 both referred to the navigation, *"the more ways we can have access to information in an environment where it's just absolutely chaotic"* (P14); *"It is also just the idea that it's right there instead of having to dive into a menu."* (P15). P3 and P14 expressed views around tangible methods for interacting with sound: *"I feel like a hands-on element is needed because you are doing something that you feel at one with that"*(P3); *"sometimes it is really good to have a physical representation of how far parameters can go, and there is a tactile feedback, for instance when you press a button"*(P14).

Voice feedback over Tactile feedback: Ten participants mentioned issues arising from using a screen reader in addition to hardware devices. When using hardware, users receive voice feedback, which expresses a parameter's value at each position. Users intentionally exclude this information to avoid cognitive overload as it overlaps with the audio content being processed at the time: *"Obviously, I'm listening to the effect. To me, those numbers never really meant anything. Anyway, it's more about how it sounds."* (P19). P14 also describes, *"...it also frees up my ear in a way it is because I can focus on the music."*

The balance between hardware usage and a screen reader plays a significant role in the workflow and the level of accessibility provided by specific hardware. P10 stated a preference for using a Mackie control surface that does not provide voice feedback:

> *"if I would like to do some automation, even volume automation, I prefer to do that using control surface because it's quite hard to do it with voice-over...-Mixing is also easier if you have your faders under your fingers rather than moving around with Voiceover and hearing it basically all the time. So, I think it's better to have the ability to touch it and to do it manually."*

Newer technologies like the Komplete Kontrol include voice feedback when accessing the hardware devices. Participants commented that although most of the time, hardware is mostly more accessible when providing voice feedback, it can also be problematic when it obstructs listening to the actual sound: *"What I do, sometimes, I don't always need to hear the speech, so sometimes I hear roughly the speech while that makes sense. So I'm actually listening to the music and mixing with my ears as opposed to listening to numbers. Sometimes I have to listen to numbers like, for example, when I'm metering and I want to make sure something is not clipping and stuff. But generally, it is nice to work with the controllers"* (P6). Three participants used a Braille display with their DAW to put labels and markers in tracks, split the information into two modalities, and concentrated more on the audio without the voice feedback from the screen reader: *"When I do some sound editing, you don't want to hear the voice, frequency, volumes, etc. So, you turn off the voice, and you have the Braille display showing you the information."* (P18).

Challenges and Preferences in Assistive Devices and Equipment: Three participants (P5, P7, P19) highlighted that they believe that the Braille displays will present efficiency challenges, slow down their working practices and that they do not want to have one more device in their workflow (P5, P7, P19). They discussed how they must move around to access information across multiple pieces of equipment and the additional equipment they would potentially need to carry outside the house. Similar to the Braille display, they also comment on the disadvantages of music hardware use: *"Changing environment takes more time, and so it is important to me to be able to stay within the same environment."*(P7). Another argument is about the portability of the equipment. For instance, three participants (P1, P5, P9) felt that it is essential to have their music on the go and accessible anywhere without needing to carry around large keyboards or controllers: *"I like the fact that if I can get the same sound in software, then I can carry my laptop on stage with me"*(P1).

Affordability Barriers in accessing Braille Displays and Music Equipment Hardware devices are often costly compared with low-cost or free software and plugins. The prices of the devices we identified in this study ranged from £60 to £4200, with an average price of around £800 (Appendix: A). Three out of 19 users highlighted that they do not own any hardware devices due to affordability challenges. For example, P18 emphasised the cost of controllers with motorized faders as a particular issue: *"At the moment, I just haven't found an affordable, one that is motorized, and it would be as mappable as another control."*

Braille displays are also often expensive, priced from £1200 to £3000 (Royal National Institute of Blind People (RNIB), 2024) with seven participants highlighting that they do not use a Braille display.

> *"If I had the money, I would give them to a Braille display."* (P12)
>
> *"I just got it from library; they're supposed to be early readers."* (P5)
>
> *"They're interesting because they are expensive for what they are, but they're also very useful."* (P9)

4.3.3 Haptic Feedback for DAWs

Participants proposed features and functions for DAWs where haptic feedback could be used in conjunction with other assistive technologies like screen readers or as a replacement and an introduction of a completely new interaction process. They also suggested a wide variety of speculative tools, including various forms of haptic feedback and haptic interaction.

Furthermore, they identified nine possible functionalities in the DAW that would benefit from haptic feedback applications (Figure 4). Some ideas were common among the participants, with one idea (peak meter) being mentioned by almost half of the participants.

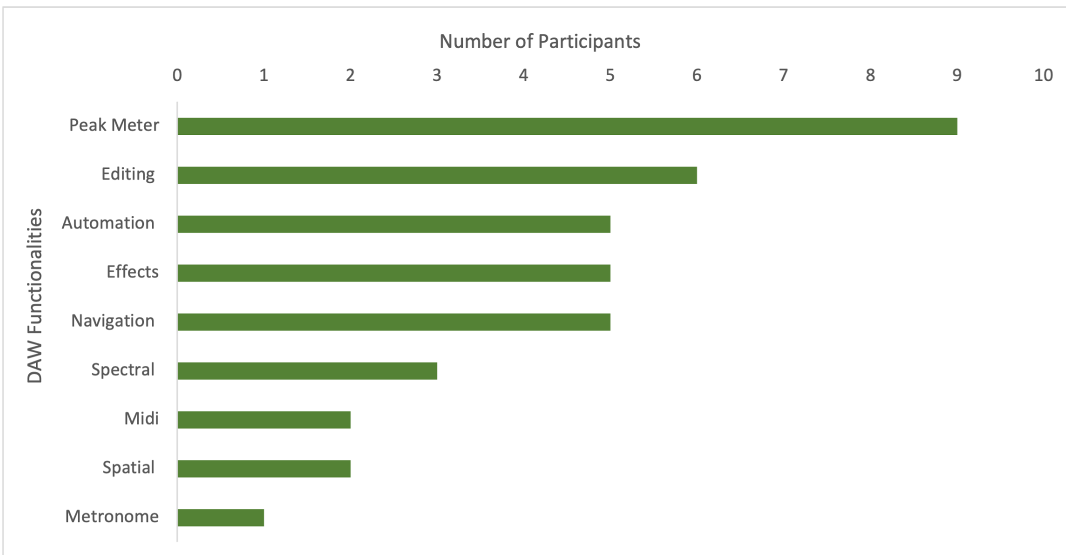

Figure 4: DAW Functionalities that need Accessibility enhancement through haptic feedback

Peak Meter: Nine participants suggested that they prefer vibrotactile feedback to inform them about the peaking of the sound. Seven participants suggested vibration to convey information from the peak meter instead of the screen reader (P1, P3, P8, P9, P10, P12, P15).

> *"Sometimes you don't want sound feedback, especially when recording yourself.[...]For example, you set a level, and when you're clipping you have some feedback on your watch to be able to feel."*(P10).
>
> *"To have something, when the recording bar (meter) is green or red to get an indication. It's annoying to hear the voice feedback when you are recording"*(P12).

Apart from live recording levels, three participants mentioned the use of feedback for the peak of the sound while mixing, both in the mixing channel and also on the waveform (P2, P14, P15). *"If you have a distortion in music and then you have like a peak watcher or something, I could see that with vibration."*

Lastly, participants who use analogue equipment in recording studios mentioned the need for a peak watcher on the consoles. The process for identifying the peak here is more complex in comparison to digital software. The participants suggested using a device that can identify the different indications of a volume unit meter(VU) and convey information related to the amplitude of the sound.

> *"You can put a little light sensor over the meter and clamp it down, and then it would vibrate at 0dB, vibrate at 2dB, whatever it is you want. So that would be very helpful for people like myself who are working in big commercial spaces."*(P8).

> *"I think for analogue equipment it could also be very, very useful because a lot of times you know there is no feedback. For a lot of things, like when there is clipping in sound, although you know that it could be heard but still... Combining light detector with the vibration, and they would vibrate if the light is on or off, it's an idea"*(P14).

Waveform: Editing a waveform is a process that heavily relies on visual feedback. Six participants expressed the desire to have some tactile experience of the waveform to be able to edit it more easily. Most comments are around the access of the waveform itself and the possibility of feeling its form. They describe a variety of ways they would like to experience the waveform by specifying the information of the waveform they seek to perceive, loudness, curve, and peak (P1, P7, P9, P11). P1 suggests using the amplitude of vibration to understand the variations in the sound amplitude while interacting with the waveform. P6, P7 and P15 suggest a tactile representation of a waveform (e.g. *"Maybe you can have a physical, embossed representation of the waveform. So basically, you can feel and touch what people are seeing"*(P6)). P6 also suggested a touch-screen-based interaction for navigating and editing the waveform

> *"Another nice thing we can do is like a touch screen. So, for example, if you feel the waveform, you can actually edit the waveform by moving your finger on the waveforms, shrinking it, making it smaller, pinching to make it smaller, or you know, different types of gestures, different gestures to actually interact and edit the waveform. I think it would be great in real-time."*(P6)

Automation: Automation in DAWs relies on visual interaction by drawing envelopes over the visually represented waveform. This is also represented through the motorized faders. However, when BVI users need to experience the recorded automation, motorized faders require a delicate touch in order not to alter what's written, which often creates frustration (P9). When there is no tactile feedback from motorized faders, P15 describes the difficulty of remembering the automation in old projects that want to revisit or reuse *"I guess maybe another interesting thing would be to have it trigger when you go past automation events on a particular track"*. P9 suggested a way of expressing automation through vibrations *"If it was like automation of a parameter and it was, you know, increasing the level or decreasing the level, the haptic could increase or decrease in intensity depending on the positions."*.

Effects: Adding haptic feedback to a plug-in is a complex idea since it combines many parameters with different values. Participants suggest two ways of approaching this idea: (1) the one-to-one mapping of vibration and parameter and (2) the use of vibration as an indication of a threshold. Equalizer is the most common effect that has been discussed. Participants suggested different vibration representations for the changes in the Frequency bands.

> *"So you could have a lower pitch for, say, peak (frequency band) one, slightly higher for peak two, peak three, peak four."*(P1)

> *"You can just do like one short for peak one and then two shorts and three shorts and four shorts"*(P1)

> *"It only gives feedback; for example, when you reach 100 Hz. So every 50 Hz, it will give you some vibration, and the higher the frequency, the faster the frequency."*(P11)

> *"Different vibration patterns for the band type, for example, so low shelf could be one beat. The high shelf could be 2, Low Pass 3, and High Pass 4."*(P13)

For other parameters, participants suggested the use of the amplitude (density) of the vibrations. For instance, P5 highlighted that *"...in Q it would be useful. It could be a sense of density. It is intense, so the Q is too tight. or the opposite, it's loose, so I don't feel the vibration."*. Furthermore, P13 emphasised that: *"The band gain you could add the intensity feature. So, like the increasing intensities, the slider goes up. It decreases as it goes down."*

While describing frequency bands with certain vibration patterns, P16 and P5 suggest that we can use the vibration as a way to complete a task or reach a specific target.

> *"...to get the perfect pitch to like guide you into slotting that note into perfect pitch."* (P5)

> *"If I knew I was aiming roughly for, say, 3 to 4dB of gain reduction, I can twiddle that gain knob while snare drum is playing a part and sort of judging by the feeling on my wrist when I'm roughly in the ballpark and then tune by ear from there. And so again, less speech, more listening, feeling, and then the last little bit is by ear"* (P16).

Navigation: Navigation efficiency comes with speed, and the speed of navigation is succeeded by a functional interface design. The participants suggest that using haptic feedback in the DAW will be beneficial to the navigation and for accessing information, not in the screen reader's focus area. P12 comments that screen readers and Braille displays are not quick enough to convey information, and P9 supports that screen readers cannot inform about events happening in parallel in the software or operating system. For example, during the recording process, screen readers lack the ability to demonstrate that recording is enabled (P9). P13 suggested a way that vibrotactile feedback can express the state of a button in the screen: *"three beeps could mean it's armed, four beeps could mean that it's not, or you could have the beeps in different patterns."* (P13). Vibrotactile feedback has also been suggested for navigating through tracks and receiving information quickly without getting distracted by audio processing. P3 highlighted that when processing and you feel a vibration for the peak of the sound, you want easy access to which track was peaking. This is where another vibration could be useful in symbolically representing the number of the track. In parallel with feeling the track number with haptic feedback, P11 suggests the use of haptic interaction to navigate tracks more effectively: *"so to have a way to change the sound levels and navigate across the channels and maybe is with some taps - three taps is channel three and so on."*.

Spectral: More experienced participants mentioned the lack of accessibility in the spectral analysis plug-ins (P2, P6, P15). Their ideas focus on the haptic representation of frequencies that are peaking or the noise in a sound file.

> *"The noise detection mode. There it could search for signal strength. In or amplitude whatever in the low noise area. It gives some sort of degree of intensity"* (P2)

> *"I also think something to do with spectral displays. You know, people are able to look at a spectral display and see that there is a lot of energy in one area of the frequency spectrum, and I think that it would be useful to know some features to be built into this peak watcher so that we can watch certain areas of the frequency spectrum. And you know, low frequencies are notorious. Taking up a lot of spectral space. And so if instead of just giving me a peak, you know. 0 DB If it could say that frequencies below 100Hz are at 0DB, but everything else is fine. Or whatever. You know, I don't know exactly how it would do it, but so have a way to perceive the peaks or the spectral information"* (P15).

MIDI: Participants highlighted a wider challenge in understanding haptic feedback from MIDI signals. These interactive approaches are narrowed into two main areas, navigation across the edit field (event list or piano roll) and velocity of the notes. P4 and P14 suggested mapping the vibration density to the velocity, whilst P8 suggested the use of vibrotactile feedback to identify switches between edit fields.

Spatial: Two participants suggested different ideas for interacting with spatial information through haptic feedback. P2 suggests the use of two vibration motors representing left and right to assist in understanding the panning of a track. This participant also suggested using a touchscreen device for better interaction in the surround field *"It would be kind of neat though if there was a... like on the iPhone, let's say the iPhone represented the round field. It Would be great if I could move my finger on the screen to where I want that sound and then have to have the haptic feedback."*. P8 is also interested in accessing multichannel mixing and described the need for accessibility in specific tasks as industry standards are moving more and more toward multichannel mixing. In particular, P8 suggested the use of a joystick with integrated vibrations to facilitate navigation and interaction in the aural space.

> *" I think some kind of joystick would be great. If you didn't wanna integrate vibrations into a control surface, you know you could use the joystick. You could say all the way left is one vibration, and all the way right is one vibration. You kind of know which way you are, but if you're in the middle, say you're 50% left, you might get two vibrations or whatever you can get. You know you could get a lot of interesting information that way"* (P8).

5 Discussion

We conducted interviews with 19 BVI music producers to understand their practices and how they use music hardware equipment in their workflow. Our research revealed some of the challenges that arise with these tools, and how tactile interaction is crucial in making these tools more accessible and user-friendly for BVI users. We align our research with previous studies based on interview methods in a similar sample size (Harrison et al. (2023); Saha and Piper (2020); W. C. Payne et al. (2020)), ensuring our findings are adequate and provide meaningful contributions.

Our study also expands upon this previous work by providing new insights into the plethora of software and hardware tools BVI producers combine to create the most accessible workflow for themselves. Harrison et al. (2023) initiated the discussion on how music hardware devices facilitate a better workflow for BVI users, providing insights into the use of hardware within DAW, their limitations, and the role of voice feedback in making these tools accessible. Our findings identify the rationale behind users' choice of tools, which is influenced by specific technical specifications and the level of software-hardware compatibility.

We summarise the discussion into the following four categories: the advantages and disadvantages of music hardware devices discussed in the interviews and literature, as well as the way to incorporate the findings in future research and design. These insights led us to propose (1) Cost-efficiency, (2) Multimodality, (3) Voice-in-Design, and (4) Haptic feedback.

5.1 Current ways of music hardware use and future opportunities

Participants provided valuable insights on how music hardware devices enhance their workflow. We identify the technical specifications of devices such as faders and knobs that fulfil participants' needs for inclusive workflows. Four main design affordances of the hardware devices were suggested relating to *precision*, *speed*, *tactile Accessibility*, and *portability*.

Faders are a pivotal specification in music hardware, allowing *precise* interaction with sound within the DAW. They also provide an alternative to voice feedback, which is essential for users during various sound manipulation tasks (e.g. volume level). Knobs, on the other hand, facilitate *speed*. Participants have frequently mentioned in the literature that screen readers hinder their ability to interact efficiently with software due to the linearity of information presentation and the speed of speech propagation (Saha & Piper, 2020), and have pointed out the importance of splitting information between touch and hearing to provide equal opportunities for perceiving information in a shorter time. Knobs lower this barrier by providing an alternative way for navigating within the DAW or accessing parameter values. Music hardware *tactile* affordances improve *accessibility* to tools that are not accessible through screen readers. Currently, all visual information must be translated into audio through voice feedback. Translating the information into different types of tactile feedback would allow BVI users to access it more efficiently, especially in cases of screen reader accessibility absence. Lastly, depending on the size of the device, they offer *portability* to a more efficient workstation. Small-size hardware devices such as the Komplete Kontrol M32 and nanoKorg (see Appendix A) can fit in a backpack bag, which gives users the confidence to bring their workstations outside of the house and effectively participate in the broader community of musicians and music producers.

5.2 Music Hardware devices revealed the benefits of multimodal interaction

Multimodal interaction allows users to choose the most suitable way of engaging with a system based on their needs. This flexibility is especially beneficial for BVI users, as there are instances where voice feedback from a screen reader is not the most effective method for interacting with a DAW. For example, users often prefer using motorized faders to write automation in tracks, as these provide a more expressive and tactile way of performing the task (P8, P16). Additionally, when voice feedback delivers information such as numbers that may not be contextually meaningful, interacting through hardware helps reduce the cognitive load imposed by continuous audio feedback (P14, P19). A well-designed multimodal system creates synergies between different modalities, enhancing the overall experience. Participants noted that dividing information between modalities allows them to focus on listening to the audio while receiving complementary data through haptic feedback (P14). In some cases, users may partially listen to the screen reader and complete the missing details through tactile input (P6). This interdependence between voice and haptic feedback showcases their synergistic effect. Furthermore, the modalities also complement each other, contributing to increased speed and efficiency (P13). This two-way complementary approach is evident as knobs can help navigate lists more quickly with voice feedback (P14, P15), while voice cues confirm the information accessed via endless encoders (P16). In scenarios where voice feedback is particularly helpful, haptics provide additional information that is challenging to convey through text alone (P6, P18), such as indicating the range of a parameter (P14).

5.3 Limitation of music hardware devices and participants needs that haven't been met

Based on participants' adverse feedback on music hardware devices, we concluded that the design of *software-hardware compatibility* is the primary factor preventing existing technology from providing an optimal solution for DAW accessibility.

Faders and knobs, which provide beneficial tactile feedback, are also limited in their usefulness if they cannot synchronize with digital information. For example, the nanoKorg controller (see AppendixA)(P14) can only be used momentarily; the knobs and faders are not motorised or endless encoders and cannot recall any values from the DAWs. Motorized faders can bridge the gap between software and hardware by effectively recalling information, but their high cost poses a barrier for many potential BVI users. Endless encoders can address this issue by not requiring motorization to access and represent software values. However, users report that not all DAW functions can be effectively represented by endless encoders. For instance, panning is a function that demands limited-range encoders, which clearly represent left and right positions with their tactile affordance.

5.4 Designing inclusive music hardware

Each of the 19 participants in this study contributed their unique approaches to DAW accessibility, shaping an overview of the advantages and limitations of using music hardware technology in their workflows. These results focus on the technological aspects of hardware devices. We identified three main areas considered most important by the majority of participants. However, it is crucial to consider the individuality of each user and provide flexibility by creating tools that can be easily tailored to their needs. The main areas identified are: (1) *Cost-Efficiency*, (2) *Voice-in-Design*, and (3) *Haptic Feedback*. Although we consider these areas equally important, we acknowledge that they have different timeframes for implementation. Cost-efficiency represents a long-term solution, relying not only on technological and design decisions but also on socio-economic and socio-political progress. For instance, the development of awareness about available, accessible technology and the state's provision of accessibility technology to individuals who require it. In contrast, incorporating voice feedback into the design is considered an intermediate-level solution. While it currently exists, improvements are needed, along with frequent re-evaluation of user needs. Finally, the use of haptic feedback in design is an immediate solution. New technologies can be effectively implemented in new designs, providing an advanced accessibility method for new devices but also with the opportunity to retrofit in non-haptic enable devices.

Cost-Efficiency: Financial barriers are a crucial factor to consider when designing a new accessibility tool. Data shows that the relationship between participants' age and environmental context influences the choice of DAW and hardware devices (Table1). While this is not a ground-breaking observation, research had consistently highlighted the enduring nature of this barrier over the years. Various factors, including age, profession, location, educational background, gender, and ethnicity, collectively contribute to shaping this ongoing challenge (Borg et al. (2011); Longoria et al. (2022); Cote (2021)). Developing software applications for smartwatches and smartphones and utilizing their haptic technology can suggest a more cost-effective solution. Such an example is the *TouchEq* by Pesek and De Man (2021), which uses the textural information made by vibrotactile feedback in a tablet to provide an alternative non-visual interaction with EQ. Research by De Pra et al. (2021) (HapticKnob) demonstrates the incorporation of haptic feedback that can imitate the sensation of the limited-range encoder by using resistive force feedback technology to create four different haptic feedback effects. Vibrotactile feedback is also integrated within hardware such as smartphones and computers' trackpads to imitate the sense of a "click" (Boréas Technologies, 2022). Similar technology could be used alongside DAWs specifically for knobs and faders in the future.

Voice-in-Design: Proper design decisions can render voice feedback an indispensable and valuable element of hardware devices and users' workflows. Utilizing voice feedback to indicate the functionality of encoders or sliders and hardware capabilities can be expanded, resulting in cost reduction as the same equipment can be mapped to multiple parameters. Apart from the functionality, voice feedback becomes crucial in situations when there is no tactile indication about the level of a specific parameter being accessed. In such cases, it serves as a vital means for users to gain essential information and interact with the hardware effectively. However, while voice feedback can be beneficial for providing initial indications, caution should be exercised when using it within scenarios that lack meaningful interpretation, as numerical representations may not hold significance for the user. Voice feedback should be easily tailored to the user's preference or dynamically and intelligently adapt to their specific needs. Optimizing its utility, voice feedback should emulate the role of a sighted human assistant and intervene in the users' workflow only when necessary (e.g., providing alerts when sound peaks or other thresholds are exceeded).

Haptic Feedback: Haptic feedback could be beneficial in nine areas of the DAW interface. These areas include *peak meter, editing, automation, effects, navigation, spectral, MIDI, spatial, and metronome* manipulations (Figure 4). Observing the participants' examples of design haptic feedback for DAW accessibility, we can identify three types of information that apply to different DAW functionalities: (1) *event notifications*, such as sound peaks or button states; (2) *graphical information*, such as waveforms or MIDI data; and (3) *ranges of numerical values*, such as automation lines or effect parameters. These types of information reflect on the evolution of music interaction from analogue-tangible to digital-visual (Tanaka, 2019), and we can understand how the barriers in the accessibility for BVI were created (see section 2.2). DAWs adopted the graphical interfaces that visually represent faders and knobs found on analogue consoles in recording studios (Macchiusi, 2017). This is similar to how a computer's interface visually represents folders, files, and trash bins that exist in an actual office environment. BVI users are relying on music hardware technology, such as surface controllers, to replace the functions that were previously utilised in early music production processes within an analogue studio (e.g., audio effects, menu navigation, and automation). However, elements such as editing waveforms and midi arrangements were never physical, thus new opportunities were presented to create novel ways of conveying these graphical elements effectively to BVI users with the use of haptic feedback. Moreover, we should reconsider the design of DAW interfaces and provide alternative representations and interaction methods that do not rely solely on visual interaction.

6 Study Limitations

This research's main method of data collection was through the online interview process. While online interviews offer the advantage of reaching a broader range of participants across diverse locations, extending the scope of findings beyond local boundaries, they also present technical challenges. Achieving deep engagement with participants proved to be a significant barrier in this format. Technical limitations posed the main challenges; for example, the ability to gather demonstration data was restricted due to difficulties in screen sharing for demonstrating music content. Another issue revealed during the analysis of the interviews was the voice feedback captured in the recordings of the video calls, often resulting in overlapping voices and complicating the transcription process.

7 Conclusion

This paper contributes to understanding the role of tactile feedback in the workflow of BVI music producers. It specifically examines the impact of music hardware technology on their workflow, highlighting the crucial role of tangible interaction.

We presented findings from interviews with 19 participants who were blind and low-vision users of DAW at various levels of experience in music production. Their insights were centred around their DAW workflow while utilising external hardware devices such as Native Instruments Komplete Kontrol, Behringer X Touch, and Softube Consol 1. Through rigorous thematic analysis of the interviews, we present three main thematic groups that express the key elements affecting the use of hardware technology and the future design of haptic technology to support DAW accessibility. The first thematic group is related to the technical specifications, encompassing aspects such as the design of the current hardware devices and a comparison between newer offerings, such as Komplete Kontrol, and older analogue equipment, all examined through the lens of their tactile affordances and usability in the workflows. The second group revolves around usability issues, including the configuration of hardware with other systems and the economic affordability of these devices. The third thematic group addresses the participants' needs but also presents ideas for future tools and alternatives to voice feedback within the DAW environment. This included the use of vibrotactile feedback for receiving notifications like in peak meter, accessing graphical information like automation lines, and enhancing interaction with numerical ranges (e.g., FX parameters).

We highlight four ways in which hardware advancements benefit the efficiency of workflow: (1) precision, (2) speed, (3) tactile accessibility, and (4) portability. We emphasise the primary limitation, which revolves around software and hardware compatibility. We finally propose three key points that should be considered for future development for BVI users: (1) cost efficiency, (2) voice-in-design, and (3) haptic feedback. These insights aim to benefit both music technology companies and researchers in creating more inclusive and accessible solutions.

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Disclosure Statement

The authors report that there are no potential conflicts of interest.

Institutional Review Board Statement

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Informed Consent Statement

All participants in the study provided their informed consent prior to involvement.

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