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Audio-first VR: New perspectives on musical experiences in virtual environments

Anıl Çamcı[a] and Rob Hamilton[b]

[a]Department of Performing Arts Technology, University of Michigan, Ann Arbor, MI, USA; [b]Department of the Arts, Rensselaer Polytechnic Institute, Troy, NY, USA

ABSTRACT

This special issue of the *Journal of New Music Research* explores VR (Virtual Reality) through the lenses of music, art and technology, each focusing on foregrounded sonic expression – an audio-first VR, wherein sound is treated not only as an integral part of immersive virtual experiences but also as a critical point of departure for creative and technological work in this domain. In this article, we identify emerging challenges and opportunities in audio-first VR, and pose questions pertaining to both theoretical and practical aspects of this concept. We then discuss how each contribution to our special issue addresses these questions through research and artistic projects, giving us a glimpse into the future of audio in VR.

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1. Introduction

Recent breakthroughs in low-persistence display technology and modern spatial tracking techniques have enabled the design of VR (Virtual Reality) systems, setting in motion a new age of immersive experiences. The role of sound in establishing a convincing sense of immersion in such experiences has been acknowledged since the early days of VR. Morton Heilig's 1960 patent for a stereoscopic-television apparatus, which is one of the earliest concept designs for a VR system, describes the use of ear-phones and binaural sound (Heilig, 1960). Ivan Sutherland, who designed what is considered to be the first head-mounted display, wrote in 1965 that despite the availability of excellent audio output devices, computers had not yet been capable of producing meaningful sounds that can be integrated into 'the ultimate display' (Sutherland, 1965). Since then, significant advances in digital computing have facilitated the development of real-time audio rendering techniques. Today's consumer-grade computers are capable of executing complex soundfield synthesis algorithms that are suitable for VR applications.

However, most modern commercial VR systems impart an ancillary role to audio in virtual experiences. As a result, audio remains an afterthought for many VR artists and researchers despite its inherent role in immersion. An opportunity exists for audio and music researchers to elaborate ways in which we can think natively about VR audio, and define the role of sound as a component of the ultimate displays of the future. In this special issue of the *Journal of New Music Research*, we aim to highlight the concept of an audio-first VR as a medium for musical expression, and promote research into multimodal virtual experiences that prioritise the auditory aspects of immersion.

In our call for articles for this issue, we posed the following questions: What is a VR experience that originates from sonic phenomena? How do we act and interact within such experiences? What are the tools and techniques that we have or need to create these experiences? What are the implications of an audio-first VR for the future of musical expression? In response to this call, we received a set of articles from artists and researchers who have tackled these fundamental questions from a range of perspectives. Among these were position articles that analyse existing research into VR audio to identify new paths moving forward, as well as those that flesh out guidelines for harnessing the potential of auditory immersion in VR. Some of these articles discuss VR projects that situate musical expression as a device for scientific research, whereas others describe innovative VR systems for audio-driven applications.

1.1. An interdisciplinary approach

Modern virtual experiences encompass a wide range of domains including casual entertainment, gaming, music, design, communication, engineering, medicine and more. As with any complex software-based sys-

CONTACT Anıl Çamcı acamci@umich.edu University of Michigan, 1100 Baits Dr., Ann Arbor, MI, USA

tem, creators of VR experiences are required to combine practical methodologies from contemporary software development and domain-specific expertise while providing intuitive and robust interfaces for the control of the system. And as today's VR technologies improve in resolution, speed and capacity to create spaces capable of engaging our human perceptual systems at a level nearing that of our physical reality, the task set forward for creators to understand and present percepts in a meaningful and believable way has grown more and more complex. Immersion and presence are not simply technological achievements based on pixel density and frame-rate, but instead require new interdisciplinary directions of research encompassing cognitive psychology, perception, art, design, science and philosophy.

It is this same interdisciplinarity that feeds contemporary artistic research focused on the role of sound and music within virtual spaces. The last decade has seen a dramatic increase in such artistic research – due in no small part to the greater availability, affordability and accessibility of modern VR hardware and software systems – focused on sound's primary role in immersive virtual environments. Throughout this article, we hope to highlight innovative studies and perspectives, including those presented in the contributions to the current issue, that cast a light on the multitude of interdisciplinary paths that lie ahead for artists and researchers in this field.

2. Workshops

Advances in VR technology not only further the commercial appeal of VR as an entertainment medium but also provoke new research questions across disciplines that deal with – or benefit from – simulated experiences. For audio and music researchers, these questions range from those that are concerned with tools and techniques to those that deal with experiential and aesthetic qualities of immersive experiences. Regardless, researchers are faced with many new challenges and opportunities of both technical and artistic nature. To identify some of these challenges and opportunities, we have organised two international workshops in the last two years. The first workshop, titled *Audio-first VR*, was organised as part of the 2018 International Conference on New Interfaces for Musical Expression. This workshop was conceived as an avenue for experts in musical interaction design to identify research trajectories for audio-driven practices in VR. The second workshop held at the 2019 IEEE VR Conference, titled *Future of Audio in VR* (FAVR), was catered towards a broader community of VR researchers and practitioners.

Contributions submitted to both workshops spanned a wide gamut of topics related to VR audio and music, including auditory localisation and perception, VR cinema and installation, virtual instrument design, compositional frameworks and live performance practices, and the pedagogies of VR sound design for gaming and STEAM (Science, Technology, Engineering, Arts and Mathematics) curricula in general. In addition to paper presentations, each workshop consisted of group discussions on topics, seen in Figure 1, that surround the same questions that have motivated the current issue, focusing on the central role of audio in both the creation and consumption of VR experiences. From these workshops, we identified a number of areas that seem to stimulate a growing number of research projects related to audio-first VR.

2.1. Agency

Sense of presence (i.e. being there) is one of the defining qualities of immersive experiences. Slater argues that an immersive environment should not only afford sensorimotor contingencies that conform to the user's expectations, but also consist of reactive elements that are not directly under the user's control. Slater then identifies body as the focal point where these two qualia meet, with the user's representation in the virtual environment functioning as one of the key factors in establishing a place illusion. In *Video Ergo Sum*, Lenggenhager et al. demonstrate that even a displaced virtual representation of the body can induce a sense of self-localisation and, therefore, an illusion of selfhood in VR (Lenggenhager, Tadi, Metzinger, & Blanke, 2007). Accordingly, a major area of research in recent VR studies is agency. More specifically, studies in this area investigate how the user is personified in VR and how their actions affect the virtual environment. This focus on agency in VR is observed in the industry practices as well. For instance, the Oculus Guide for Best Practices in VR emphasises the fundamental role that the virtual avatar plays in grounding the user's experience and evoking aesthetic responses (Oculus n.d.).

In collaborative music performances that involve virtual instruments, agency plays a critical role in articulating a participant's contribution to the output and, as a result, the style and extent of their involvement in the performance (Çamcı, Çakmak, & Forbes, 2019). In *Trois Machins de la Grâce Aimante*, Hamilton leverages technologies and interaction design techniques from both game development and analogue lutherie to give players control over procedurally generated sound with VR string instruments designed for networked ensemble performance. To situate hundreds of

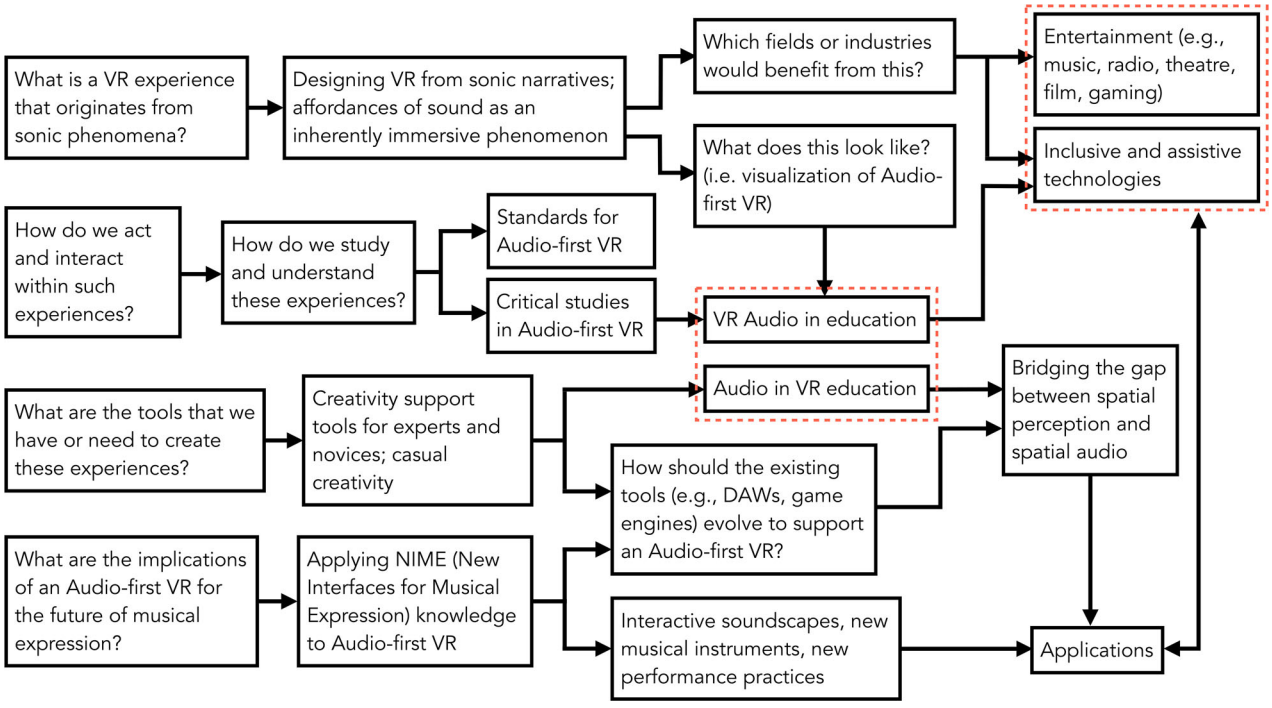

Figure 1. Questions and practices around the concept of an audio-first VR.

years of historical performance tradition in a decidedly twenty-first-century musical practice, Hamilton borrows from the affordances of traditional bowed-string instruments (Hamilton, 2019a). Virtual avatars of the performers and their instruments are displayed to one another to facilitate communicative visual gestures that are essential to ensemble performances (Hamilton, 2019b). In another project focusing on VR instruments, titled *Hyperreal Instruments*, the virtual presence of the performer is augmented with haptic feedback by pairing the digital model of the virtual instrument with a physical artefact that is fabricated from the same model (Çamcı & Granzow, 2019). The sensory mappings across the visual, auditory and haptic modalities anchor the performer's virtual experience in the physical domain and give the performer a sense of scale and agency.

In their contribution to the *Audio-first VR Workshop*, Chace Mitchusson and Edgar Berdahl demonstrated the *Enhanced Virtual Reality* system, where VR is used to augment the musician's presence in a performance. The system tracks the musician's movements and mirror these in a virtual character to situate the performance in a narrative multimedia experience. Other examples of intersections between music performance and virtual narratives were highlighted in Rachel Rome's contribution, where she formulated a view of VR as a means to put Donna Haraway's concepts of situated knowledge and cyborg feminism into sonic practice. Focusing on artistic projects from the past decade, such as the *Avatar Orchestra Metaverse* and the Hyphen-Labs' *NeuroSpeculative AfroFeminism*, Rome has contrasted the traditional forms of performance that gives the artist a 'God's view' with VR performances where the audience can occupy the same hierarchical space as that of the performer's. Indeed, VR opens up interesting possibilities for transferring creative agency to the audience. While participatory systems are not entirely novel in the context of musical interaction design, VR allows the artist to grant the user poietic duties that can be dynamically constructed and displaced in ways that defeat constraints of physical reality.

2.2. Education

Education is considered to be among the foremost areas to be transformed by VR technology (Velev & Zlateva, 2017). Although 2D and 3D virtual environments have long been used for medical and military training purposes, modern VR systems are finding educational applications in an increasing number of fields ranging from manufacturing (Salah et al., 2019) to mathematics (Lai, McMahan, Kitagawa, & Connolly, 2016).

Several projects have already shown that VR can be used for music and audio education. For instance, Bissonnette et al. demonstrate the use of VR exposure training to reduce music performance anxiety. The authors suggest that music institutions can benefit from instating virtual systems where musicians can

train themselves in a variety of concert scenarios to improve their anxiety management skills and, as a result, the quality of their performance (Bissonnette, Dubé, Provencher, & Moreno Sala, 2015). Similarly, Serafin et al. propose that VR can be used to teach students in primary and secondary education music-related concepts such as rhythm and acoustics (Serafin, Adjorlu, Nilsson, Thomsen, & Nordahl, 2017).

In fields that benefit from computer-aided forms of expression and exploration, creativity support tools can impact the ways in which users gather information and make discoveries (Shneiderman, 2007). These tools should be easy for novices to pick up while at the same time offering a range of features that will appeal to specialists. In VR audio, the existing selection of creativity support tools can be prohibitively geared towards expert users (Çamcı, Lee, Roberts, & Forbes, 2017). We therefore need more accessible tools that will facilitate new learning experiences for inexperienced users who wish to utilise immersive audio as a medium for artistic expression. Current VR authoring models, where the design and review stages are often separated, can be of particular hindrance to the learning process (Çamcı, 2019b). We therefore see an increasing number of tools, including those for VR audio design, that enable content creation within VR, effectively coupling the learning, design and exploration processes with one another.

At the *Audio-first VR Workshop*, Melissa Clarke and Margeret Schedel presented examples from their immersive media installations that lie at the intersection of arts and sciences, emphasising the role of sonic immersion in STEAM education. In doing so, the authors contextualised VR audio as a medium for data sonification fundamental to the design of a game system, and argued that it should be made an integral part of VR curricula. In a similar vein, Corness et al.'s contribution to the *FAVR Workshop* explored the use of 3D audio in game design education. By designing audio-only VR games, the students in their game design course identified the strengths and weaknesses of modern 3D audio implementations in game engines.

2.3. Auditory perception

Although the recent VR systems have brought us closer to a mass-adoption of VR as a consumer-facing entertainment medium, there are still technical bottlenecks to be overcome. In VR audio, one of the primary challenges lies in the use of standardised head-related transfer functions (HRTFs) for 3D audio spatialisation. Unlike individualised HRTFs, which are derived from the unique physiological properties of a user, standardised HRTFs are based on an averaging of such properties across the population. While these alleviate the need for extracting individual HRTFs for each user, they are also prone to inaccurate spatial imaging due to the deviations between the standardised model and the individual attributes of the user's auditory apparatus (Wenzel, Arruda, Kistler, & Wightman, 1993).

In their contribution to the *FAVR Workshop*, Luke Reed and Philip Phelps discussed the current challenges in audio production for VR Cinema exhibitions. In addition to highlighting a need for modern 3D audio formats to be supported in exhibition spaces such as museums and galleries, the authors proposed the implementation of an onboarding method for visitors to select from a range of standardised HRTFs to determine the model that will yield the most accurate audio spatialisation for them (Reed & Phelps, 2019).

At the same workshop, Tray Minh Voong and Michael Oehler presented their work into developing one such HRTF selection system with a particular focus on the use of bone-conduction headphones. Using a tournament-style elimination method, the authors tasked users with the selection of the best-fitting HRTF out of 8 standardised profiles. The users' performance in a following localisation task was found to be directly correlated with their selection of an HRTF profile (Voong & Oehler, 2019).

Approaching the same problem from a different perspective, Song Hui Chon and Sungyoung Kim presented their work on training users with standardised HRTFs to improve their localisation performance over time. Using a single standardised HRTF, the authors trained users over the course of four weeks and administered follow-up localisation tests. Their preliminary results have shown that not only the user performance has improved as a result of the training but also the localisation skills were retained after a 10-week break (Chon & Kim, 2018).

2.4. Theoretical perspectives

We are arguably in the early days of establishing a theory for VR akin to those of film and music. Many VR experiences today offer a juxtaposition of transformative qualities with ones that are adopted from traditional art forms. For instance, while many of the narrative devices common to filmmaking are applicable to VR film, the inherently first-person disposition of the user's gaze into VR brings about new considerations in terms of storytelling (Çamcı, 2019a). Similar distinctions come into play with VR research as well. Parallel to the development of new tools and techniques for VR, the research and artistic communities in this area will need to identify existing theories and standards that can be applied to VR, while formulating new ones idiomatic to the immersive domain.

At the *Audio-first VR Workshop*, Davide Mauro prompted a discussion of standards for audio-centric practices in VR, arguing that the recent influx of VR content is indicative of an exploratory phase which raises questions of reproducibility for research and artistic practices. According to Mauro, an audio-first VR would require technical standards that, while posing functional limitations, could serve as a framework for sustainable practices, similar to how MIDI served to standardise interface design for keyboard manufacturers.

On a more conceptual level, Zach Buckley and Kristin Carlson's contribution to the *FAVR Workshop* stressed the need for a compositional framework for designing music-driven VR experiences. The authors argued that composers should utilise a combination of predetermined and interactive elements to make the musical affordances of a VR soundscape discoverable to the listener. Adopting the concepts of hi-fi and lo-fi soundscapes from acoustic ecology, the authors suggested, for instance, that the composer can guide the listener through their embodied experience of an immersive audio environment by manipulating the density of sound elements in the virtual soundscape (Buckley & Carlson, 2019).

3. This issue

In this special issue focused on contemporary and future-looking approaches towards audio-first virtual realities, we present a collection of papers that exhibit the interdisciplinarity and cross-modal understandings required to fully explore today's technological, artistic, cognitive and social qualities of VR. As such we can identify three main threads trending across these contributions: Position statements that analyse past and ongoing research projects, and formulate guidelines and trajectories for VR practitioners; reports on artistic projects that exploit the unique affordances of VR for musical experiences; and systems papers that challenge and reimagine the means of content creation for VR.

In 'Modular reality: Analogues of patching in immersive space' Palumbo and Wakefield introduce a performance system for VR that aims to capture the embodied nature of performing with a modular synthesiser in VR, while exhausting the distinct opportunities available in this medium for creative expression. Through a series of technical contributions that enable such a system, the authors also lay the groundwork for a collaborative tool that would allow its users the improvize realities.

In 'Reflections from five years of Sonic Interactions in Virtual Environments (SIVE) workshops' Serafin et al. give a comprehensive overview of recent research on sonic interaction design for virtual environments. Drawing from their experiences organising international workshops on this topic, the authors identify and expand upon critical areas of research in VR audio, such as physics-based models that could streamline the relationship between user interaction and sound generation in VR and auralisation methods for modelling sound propagation.

In 'Doing vs. being: A philosophy of design for artful VR' Atherton and Wang construct a comprehensive framework for designing VR experiences with a particular focus on musical or audio-driven applications. The authors offer a critical analysis of VR projects, including those of their own, to delineate a set of design principles for creating accessible VR experiences that justify the use of immersive technologies, and strike a balance between intentional actions and introspective observations on the user's part.

With '3D user interfaces for musical expression', Berthaut offers a detailed review of 3D interaction techniques for musical control and proposes new directions for research into musical interaction design in VR contexts. Providing examples from a series of tools and platforms that he has developed over the years, the author identifies critical areas of investigation, such as dedicated input systems, haptics and visual feedback mechanisms for musical applications in virtual environments.

In 'Points further North: An acoustemological cartography of non-place' Trommer and Wakefield investigates the role of auditory immersion and mnemonic sound within the VR documentary filmmaking process. Adapting theories of acoustic ecology to immersive media production, the authors investigate the phenomenological relationship between a sonic territory and its inhabitants.

Research and artistic practice cross disciplinary boundaries as Snook et al. investigate the musical sonification of astronomical data and the interactive control of XR (Extended Reality) instruments in 'Kepler Concordia: A musical XR instrument for playing the solar system'. Inspired by Keppler's use of music as a means to reveal the underlying principles of planetary motion, the authors employ a game-like audio-first VR, where the solar system becomes a playable instrument that reveals patterns in scientific data.

And in 'Virtual 3D environments as composition and performance spaces' Ciciliani explores spatial movement and its use in analogue and digital environments as a tool for both composition and interactive performance. Comparing the structure of one of his VR pieces to that of Nine Bells by Tom Johnson, Cicilliani offers an analysis of how music composition techniques can be mapped onto gamified virtual environments.

4. Future(s) of audio in VR

Any discussion of the future of VR is generally undertaken with regards to existing areas of artistic and technological research, focusing on issues surrounding hardware, software, and human perception. No one of these focus areas alone can encapsulate the nature of how VR will evolve. Instead, it is through the combination of each that new digital possibilities are being opened to us all as consumers of interactive content, as researchers exploring new paradigms of data representation and manipulation, and as artists pushing through boundaries that separate our physical existences from novel virtual ones. When this discussion is further focused on the role of sound within VR, we are prompted to question not only the technical concerns for representing sonic characteristics of a rendered environment but also the philosophical implications of how sound itself shapes our understanding of space and our roles within that space. There is no one singular future of audio in VR; instead, there are numerous divergent and often contradictory paths that can shape what comes next, drawing simultaneously from the fields of game development, interaction design, narrative storytelling, musical composition, networked communication, audio engineering, auditory perception and software development.

For this special issue of the *Journal of New Music Research*, we have proposed four fundamental questions and focal areas (see Figure 1) that our contributing researchers have leveraged during their explorations into the role of sound within virtual spaces. In response to the first question put forth, 'What is a virtual reality experience that originates from sonic phenomena?', Trommer offers a version of audio-first VR framed through the evolving lenses of documentary filmmaking, using immersive audio and spatialisation to enhance the viewer's sense of space and place, and in the process highlighting the unique sonic identity of location. Snook et al. turn their gaze towards the heavens, sonifying patterns of celestial periodic motion using musical systems and relationships to scale these immense spatial relationships to levels at which our human perspective can comprehend the essentially incomprehensible. And in a nod towards the very human musical intimacies explored and exploited by composers throughout history, Cicilliani presents human action and motion as the drivers for interactive systems designed primarily for the presentation of sound and music. All three experiences shape our understanding of three unique perspectives and scales of attention through the presentation of carefully constructed and referential sonic elements.

Our abilities to perceive virtual spaces are intrinsically shaped by our abilities to act and interact, the target of our second framing question, 'How do we act and interact within such audio-forward experiences?'. For researchers like Berthaut, who are interested in the means by which we can shape sonic structures and musical relationships in immersive contexts, the focus turns to the act of control itself, dissecting forms and functions of musical control systems designed to be operated in virtual rendered spaces. It is the models of sonic interaction and production themselves, as well as the means by which communities of researchers have pushed forward audio-first interaction design in the recent past that is discussed in Serafin et al., providing an overview of the field's recent history and its near future. Pushing even further forward, the roles of actions and interactions in virtual spaces and their codification into an actionable framework for designing 'artful' sonic immersive experiences is presented by Atherton and Wang, combining analytical and philosophical justifications for choices made in their own pursuit of the next stage in audio-first VR.

The role of audio in virtual spaces is intimately tied to the tools and techniques used to craft representative and artistic sounds, leading to the third question 'What are the tools and techniques that we have or need to create these experiences?'. For virtual realities that seek to reference our very physical 'real' world, from the sound of footsteps to the articulation of musical instruments built upon first principles, Serafin et al. discuss physics-based models for sound generation and control. The ability to share virtual sonic spaces and collaborate by sharing a virtual presence is addressed by Palumbo and Wakefield's virtualisation of modular synthesisers and their control systems. Similarly, Atherton's discussions regarding a means by which audio programming processes can be not only controlled but also coded within a VR environment seeks to establish a VR-centric paradigm for audio programming and musical construction. These two projects also highlight a growing trend we observe in VR studies, where the ultimate platform to create content for VR is deemed to be VR itself. Alleviating the need for switching between a desktop device to create content and a VR headset to experience it, VR-based creativity support tools can exploit the immediate action-perception feedback loops that have been available to electronic music composers since the 1950s.

Our fourth and final question brings us to consider how these new reserch directions will shape our artistic practices by asking 'What are the implications of an audio-first VR for the future of musical expression?'. Musicians' ability to explore new means and interfaces for musical expression have always made them eager explorers of future-facing technologies, from the fortepiano to

the mobile phone, to virtual and augmented reality systems. Fittingly, the role of music-driven discussion and musician-led creative research is prevalent across each paper presented in this issue. And it is the promise of novel, enhanced and expanded forms of musical expression that makes audio-first futures for VR so compelling and simultaneously complex for researchers.

As editors of this special issue, we see a fascinating and promising future for the technological innovations that will enable the future of audio-first VR as well as the musical methodologies and performance practices that are already changing our understanding of how sonic space and immersive realities inform one another. We hope this issue gives the readers of the *Journal of New Music Research* new insights into how artists and technologists alike are embarking on these bold and innovative new directions.

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No potential conflict of interest was reported by the authors.

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