TIM SUMMERS (ORGANIZER), WITH JAMES COOK, WILL FAMER, ELISA RAFFAELLA FERRÈ, LUCY HARRISON, RICH HEMMING, ANDRA IVĂNESCU, LUKE REED, FLOSSIE ROBERTS, RICHARD STEVENS, STEPHEN TATLOW AND LARYSSA WHITTAKER

Music and Sound in Virtual/Augmented Realities—Questions, Challenges and Approaches

A Multidisciplinary Roundtable

ABSTRACT The mid-to-late 2010s saw a renewed interest in virtual reality technologies with the release of a wide selection of consumer VR headsets and glasses, and the increased power of smartphones to provide augmented reality experiences. While research on sound and music in these technologies has started to gather pace, practice and research continue to grapple with significant creative and practical questions. In addition, such discussions have tended to be limited within disciplinary or professional silos. The roundtable presented here was an effort to begin conversations across a variety of fields of research and practice. We shared perspectives and exchanged views informed by different disciplinary traditions and experiences. We also sought to identify key questions and issues regarding music and sound in VR/AR. Three main themes are presented here: 1) Spaces and musical performances, 2) Realities and realism, and 3) Movement, orientation, and disorientation. KEYWORDS VR, AR, virtuality, spatiality, diegesis, perception, proprioception, cybersickness

In early summer 2020, just as the scale of the COVID-19 pandemic was becoming apparent, a roundtable on music and sound in VR/AR was hosted (virtually, appropriately enough) by Royal Holloway University of London. The event brought together internal and external researchers working on a variety of topics with the aim of sharing perspectives from different disciplinary traditions and experiences. We also sought to identify key questions and issues regarding music and sound in VR/AR.

The following is based on a transcript of the conversation, reordered and edited to emphasize the key threads of the conversation. I have tried to preserve some of the atmosphere of discussion and exchange. I am very grateful to the participants for their time and thoughtful engagement. I hope readers will find this as interesting and thought-provoking as I did hosting and moderating the discussion. —Tim Summers

PARTICIPANTS

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PART 1. SPACES AND MUSICAL PERFORMANCES: BEYOND THE CONVENTIONAL

An important theme in the discussion was how VR might make use of new possibilities of presenting and documenting musical performances in spaces. In particular, breaking out from inherited processes of performance and audiovisual media is harder than it might appear. Richard Stevens, Luke Reed, Lucy Harrison, and James Cook reported projects that all focused on musical spatialization and, in particular, their ambitions to accentuate or make use of the sonic spatiality of VR and 360-degree video.

What are the new possibilities for composing and listening provided by VR?

Richard Stevens: For the last couple of years my colleague Dave Raybould and I have been working with electroacoustic composer Nikos Stavropoulos on a spatial music

project.[1] We were struck with how spatial aspects are fundamental to the process of electroacoustic composition. Yet many composers are using traditional DAW (digital audio workstation) software packages like Pro Tools, which really don't lend themselves to working with space in an intuitive way. With Nikos, we have been working to develop a toolkit inside the Unreal Engine that allows composers to manipulate audio objects in space. In VR, they can grab hold of an object, move it around, and record its trajectory. We've presented the work as part of European Art Science Technology Network event in Manchester and the Audio Engineering Society's immersive interactive audio conference at York,[2] and people seemed to find it very engaging.

This research also asks whether sound and music have innate spatial qualities, and if that might affect how we interact with those sounds and music. Do certain sounds seem to circle around the listener or imply vertical movement? If we gave users a bank of sounds and asked them to generate a piece or simply just move how they felt, intuitively, using those sounds, and captured the gestures in the software, would we find commonalities? Would particular sonic properties prompt spatial behaviors or gestures from players? That's an idea about embodied cognition, sounds having what Denis Smalley refers to as spatial morphology: that sound itself encompasses some spatial aspects.[3]

Luke Reed: I was part of a group commissioned by the Colston Hall (one of the largest music performance spaces in Bristol, UK) to create a series of artifacts to document the hall and its spaces prior to refurbishment. We agreed to make two 360 video films. One of them was a collaboration with the British Paraorchestra and Friends, which is a well-known UK orchestra that integrates disabled and nondisabled virtuoso performers into a single ensemble. They were performing in the atrium of the Colston Hall, which has a number of glass-sided staircases and bridges over multiple storeys. The orchestra was arranged across these layers, mixing up the sections and performing "The Four Sections" by Steve Reich. It was an interactive performance initially, so audience members were invited to come and move around the space and create their own mix, as it were, as they moved around the atrium of the Colston Hall.

We wanted to capture this spatial aspect of the performance in some way. It struck me that out of all of the 360 recordings of orchestras, they are almost exclusively inside the orchestra and laid out on along a horizontal plane. Productions often missed the power of higher-order ambisonics (full 3D surround audio). The technology for horizontal plane technology has been well established for many years, but it's the sense of height that's afforded by newer formats. The addition of height is only just now filtering in through to the consumer level, through things like Dolby Atmos and various other kind of height-enabled formats. The fact that this was a performance across multiple floors of this space, with performers above you and below you, really lent itself well to that format.

1. See Stavropoulos's profile at "Dr Nikos Stavropoulos," Leeds Beckett University, c.2020, accessed January 31, 2021, https://www.leedsbeckett.ac.uk/staff/dr-nikos-stavropoulos/.

2. AES International Conference on Immersive and Interactive Audio, March 27–29, 2019, York, UK.

3. Denis Smalley, "Spatial Experience in Electro-Acoustic Music," in *L'Espace du Son II*, ed. Francis Dhomont (Ohain, Belgium: Musique et Recherches, 1991), 121–24.

We recorded the performers across the floors, using both close microphones as well as ambisonic microphones. I enlisted the help of a local video 360 video production team, and we shot the final section of "The Four Sections" six times and edited it together and mixed it and delivered it.[4]

James Cook: I've been working on projects to reconstruct lost performance spaces using VR, re-creating the visual and acoustic properties of these spaces, so that we can use it for experimental research on performance practice. We could see and hear what it is like to perform in a fifteenth-century chapel as it was, rather than as these spaces currently are.

We've built two spaces. One is the Chapel of Linlithgow Palace, the pleasure palace of the kings and queens of Scotland. Currently, in reality, it has no ceiling, roof or windows. The walls have partly fallen down. It's not a usable performance space, but it is still a Historic Scotland property that people can visit. In our project, you move between past and present, so you can hear how the acoustic changes and the audiovisual combination also impacts upon the experience of the performance. These kinds of projects also raise the question of applying ideas from audiovisual interaction in screen media to real-life concert performance as well.

We also created St. Cecilia's Hall, the oldest purpose-built concert hall in Scotland. It is a modern performance venue, but you can hear its acoustics both as it currently is and how it was in the first few years of its building. We began with LIDAR scanning, which uses light reflection, for an accurate model of the spaces as they are now. We converted that initial model to one with fewer polygons because the file was too large to work with comfortably, and then we adapted the model based on the archaeological and archival records. We've worked both in Unity and Unreal to build both past and present, so you can move around within it. We've developed it for various types of headsets. A major challenge was working out how to take the incredibly detailed model that also allowed accurate acoustic reproduction in real time with free movement and good specialization, and turn it into something that works on a wireless headset that doesn't require standalone sensors or interference with the historical site.[5]

We played around with lots of different types of acoustic modeling software, including some of our own experiments with acoustic ray tracing.[6] We've had to develop new forms of music production, because we've had to record all the music in anechoic chambers. So we've been recording everything with no natural acoustic. We've released the first

4. Luke Reed, Martyn Harries, Alexandre Hurr, and Mathew Knight, "Applied Multichannel Recording of a Contemporary Symphony Orchestra for Virtual Reality," paper presented at the Conference on Immersive and Interactive Audio, Paper 105 (March 27–29, 2019, York, UK), accessed February 16, 2021, https://www.aes.org/e-lib/browse.cfm?elib=20441.

5. For a project on the reconstruction of Varèse's "Poème électronique," see Vincenzo Lombardo, Andrea Valle, John Fitch, Kees Tazelaar, Stefan Weinzierl, and Wojciech Borczyk, "A Virtual-Reality Reconstruction of Poème Électronique Based on Philological Research," *Computer Music Journal* 33, no. 2 (2009): 24–47. On the preservation of "unteachable" works, see Paul Kaiser, "Not Fade Away: Thoughts on Preserving Cunningham's Loops," in *Transmission in Motion: The Technologizing of Dance*, ed. Maaike Bleeker (Abingdon, UK: Routledge, 2017), 16–31.

6. Rod Selfridge, James Cook, Kenneth B. McAlpine, and Michael Newton, "Creating Historic Spaces in Virtual Reality Using Off-the-Shelf Audio Plugins," paper presented at the Conference on Immersive and Interactive Audio, Paper 50 (March 27–29, 2019, York, UK), accessed February 16, 2021, https://www.aes.org/e-lib/browse.cfm?elib=20419.

classical album recorded and produced in virtual reality, which is using the reconstructed acoustic from the palace.[7]

I'm interested in exploring virtual venues, virtual colocation of live performance in spaces, and modern composers writing operas for virtual reality. At the moment, many projects don't take advantage of the spatial aspects of music, and tend to be, as Luke says, a horizontal plane and seeing the music performed around you, or an opera happening in front of you, which is similar to traditional opera-going. We're yet to explore the new things that the technology can do, dealing with the impossibilities of normal reality, which was part of our aim in reconstructing things you can't reconstruct in reality.

Lucy Harrison: I'm a composer and sound designer and I specialize in interactive audio. I've created immersive and interactive sound installations and work with immersive theatre companies. Just before lockdown, we were hurtling towards a tour that was going to go across four libraries in the UK, and the entire tour was tactile with sound reacting within it. We came to the realization that was absolutely not going to be possible!

We've been working on adapting the project into a virtual reality space. We are seeing a lot of immersive productions going this way. We started with a very literal re-creation of the libraries that we were going to go into, and just placing sound within the space. We were going to build virtual re-creations to walk through and interact with. We were halfway on that and then it started to feel a little uninspiring for us. Instead we've been looking at spaces that don't exist. We've been thinking about how we can use these virtual spaces to create some kind of gallery-type experience, but something that can't exist in the real world.

We'd been thinking about a Möbius strip to walk through. That's a really interesting challenge for sound, because then we're thinking about how it's triggered, beyond simply causing music to sound when the player walks into something, or music that just sounds in particular spaces. We instead want to be strategic with the sound, functionally guiding people with sound, and be a bit more playful with the sound, to allow interactivity in a way that can only exist in a VR environment, like Richard was mentioning. Like James said, a lot of the time what we see with VR are projects that could easily exist in the physical space but have just been transported or adapted to that space. We're trying to "think more 3D" with this.[8] The project launched as "Inside the Living Library" and is available on the Living Library website.[9]

7. Music for the King of Scots: Inside the Pleasure Palace of James IV, The Binchois Consort, Andrew Kirkman, Hyperion, CDA68333, 2021.

8. Jonathan Weinel suggests psychedelic and "altered state of consciousness" connection to VR/AR experiences that may resonate with these comments. Certainly games like *Rez* and *SoundSelf* can seem similar to interactive hallucinations, with a variety of representational and affective qualities. Should we be talking about Virtual Unreality/Augmented Unreality? Jonathan Weinel, "Augmented Unreality: Synesthetic Artworks and Audiovisual Hallucinations," in *The Oxford Handbook of Sound and Imagination, Volume 2*, ed. Mark Grimshaw, Mads Walther-Hansen, and Martin Knakkergaard (New York: Oxford University Press, 2019), 301–20.

9. "Inside the Living Library," The Living Library, 2020, accessed January 31, 2021, https://www.livinglibraries.uk/inside-the-living-library.

What are the conceptual and practical challenges for spatializing music and sound?

Richard Stevens: One of the key questions for me is "How do we position music in VR?" "How do we put music into VR games?" Is the music, for example, spatialized in the game world, or is it like wearing a pair of 7.1 headphones so that music moves around with you? Furthermore, how will that placement affect sensory immersion? If music is spatialized in the game world, will it start to feel like it's actually in that world, whereas we're more used to music sitting outside, as in the tradition of non-diegetic music? Would that affect our immersion? Would we be asking "what's that violin doing over there *in this room*?"

Will Farmer: I've been working on a game project that plays with this issue. It's a game called *Crazy Cook Off*, set in a kitchen. All the players are cooking and there are three players in the same virtual space wearing virtual reality headsets.

We were trying to make it more interesting. In each player's zone, each separate kitchen, there are six speakers in a 5.1 setup. It's a surround sound system virtually re-created inside the game, so as you walk around and move, you're hearing a different mix. You can also interact with the speakers themselves. So if you pick up a speaker and move it, it will alter the mix you're hearing. We mixed the music and wrote it specifically with this in mind. We implemented aspects in the game so that, for example, if you open a microwave and then put the speaker in and close the door, it applies a high-pass filter solely to that virtual speaker, giving the impression—however unrealistic it may be—that it is coming from inside the microwave.

One of the things that made this interesting musically to write for was we couldn't mix in a conventional way, because we found that one of the fun things was being able to make decisions about the instrumentation by moving the speakers. For example, you might decide that you don't like the piano, and decide to throw that speaker away, removing that instrument, but it meant that we had to mix individual instruments into one speaker so people could get rid of things entirely. The mix sounds fine when you're listening to it, but it's actually very unusual, in order to make the mechanics of the game work and more enjoyable for the player.

The other thing was an issue with having three people in the virtual same space who all have their own surround sound systems. You can throw one of your speakers to another person on the other side of the room and then they get some of your music. So some things are suddenly louder for them and you're missing out things in your own space.

Rich Hemming: I really love this idea of like a dynamic interactive system where you can just throw elements around. The question of having lots of audio emitters in the virtual space brings up the issue of where the music is supposed to sit. Is it external? Is it internal in the world? For me, I tend to find that it would be world-locked, so that it's not head-tracked, because that's very confusing with elements moving around. Here, you've turned the emitters into a bit of a gamification itself. The solution for a lot of sound designers is to mix in quad surround to avoid these problems, or by using a compass-style setting of north, south, east, and west, in order to make sense of musical elements and parts.[10]

10. Winifred Philips and Rob Lawrence have reported wrestling with this question. Winifred Phillips, "Composing for Virtual Reality and Interactive Video Game," *Score It*, April 14, 2017, accessed January 31, 2021,

We're starting to see more virtual events like Travis Scott's concert in *Fortnite*. I think more attention needs to be paid to how we are going to be listening in these events, sharing them like a club situation or live festival, and ways to spatially and sonically and interact. In terms of dynamic mixing, how we going to deal with that?[11] How much control do we give to the user, and how much do we restrict to avoid confusion? I really like the idea of the gamification of that.

Will Farmer: One thing we found quite strange was the idea that we lost all control of the music once it goes in the game. Not just in the conventional way of not knowing when it's played, but having little idea how it might sound by the end of the game, because there is the option for the player, if they don't like the music, to just get rid of absolutely everything entirely and have nothing. It's done on horizontal and vertical planes, so you could move music up and then you get different mixes. There are so many options. It was quite strange to know that although we were satisfied with what we put in the game in the specific way we wanted to hear it, we were accepting that people were going to change the music as they wanted to.

Can musical spatialization in AR/VR help with developing new musical audiences and increase accessibility?

Richard Stevens: We've been working to use this technology to develop new audiences for electroacoustic music. One way is to make the musical processes more tangible. We would like to develop an AR concert, where you go to an electroacoustic composition concert, and you can choose to experience it in a normal typical way, or you can take out your mobile phone and look through the phone to see the movement of these musical sound objects in the space. That might help people to relate to some of the musical processes that are not necessarily immediately obvious if you're unfamiliar with this kind of music.

Rich Hemming: I'm a spatial and procedural audio designer. I was involved in a project called RJDJ, which was an iOS app that took sensory data and motion data to drive a dynamic and interactive music experience.[12] It was a moment for me to start working with nonlinear music experiences and incorporating sensory data in real time.

The biofeedback elements are really interesting because of wearable technology. I have been experimenting with VR implementations, wearing headbands or taking information from an iOS watch, for example, using heart rate and EEG (electroencephalogram brain

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http://magazine.scoreit.org/interview-winifred-phillips-game-composer/; Rob Lawrence, "Producing Music for Immersive Audio Experiences," in *Producing Sound*, ed. Russ Hepworth-Sawyer, Jay Hodgson, and Mark Marrington (New York: Routledge, 2019), 134–55. In the conversation, I also suggested a comparison with music in theme parks as a model for music in VR. See, for instance, Gregory Camp, "Mickey Mouse Muzak: Shaping Experience Musically at Walt Disney World," *Journal of the Society for American Music* 11, no. 1 (2017): 53–69.

11. See also Jean-François Lucas et al. on mixed reality with livestreaming from concerts and the virtual world. Jean-François Lucas, Tracy Cornish, and Todd Margolis, "To a Cultural Perspective of Mixed Reality Events: A Case Study of Event Overflow in Operas and Concerts in Mixed Reality," *New Review of Hypermedia and Multimedia* 18, no. 4 (2012): 277–93.

12. Though RJDJ is no longer available, it has left a long legacy, partly because of its widespread popularity. See Charlie Burton, "Mod Your Sounds with RJDJ," *Wired*, December 16, 2009, accessed January 31, 2021, https://www.wired.co.uk/article/mod-your-sounds-with-rjdj.

activity sensors) to drive not only the mechanics of the game but also sound design and procedural sound design, too.

It's extremely complicated, and it has been problematic trying to use heart rate, for example, to drive aspects of an XR experience, particularly when you're encouraged to move around. Taking any kind of sensory data has been particularly tricky, because you have to parse so much information to make it manageable even to do quite basic functions, and not overload the user in terms of cognitive load.

I have a fascination with the mechanics of games and audio. Audiences now expect sonic interactions to be more direct than they used to. If you pick up an object in VR, then it needs to react in a particular way to make it feel authentic and to complete that immersion. Bioadaptive behaviors are possible, but they are tricky to work out how to use them to drive game and audio mechanics.

There is a spectrum between how implicitly or explicitly these aspects are integrated into the game. On one extreme, perhaps players won't even realize these measurements and responses are happening, or the other extreme might be a challenge to keep your heart rate down in order for you to progress in the game. There's a lot of sensory data that can be collected in these systems, and how this might help personalize experiences. That may be for artistic ends, or even medical purposes. There's a really interesting intersection between psychological measurement and personal experience, but also how that can drive the mechanics and procedural design of the game.

I've been working on how AR devices could scan objects and areas and then feed back that acoustic information in real time. That's also led me to consider how that might assist, say, somebody who is visually impaired. For example, if a visually impaired person had a wearable a scanning system, it could use a real-time audio scanner to detect objects and sonify that complicated LIDAR data, as you mentioned, James.

PART 2. REALITIES AND REALISM

It is well-understood that a sense of aesthetic "realism" in films and games (sonic or otherwise) does not strictly come from fidelity to reality but from sonic indications of realism. Does the embodiment and "framelessness" of VR problematize this tension between realism and fidelity? What about AR?

Realism vs. Reality

Flossie Roberts: I've been dealing with realism and the recreation of acoustic spaces in virtual reality. We did recordings of the same speech in the college's chapel, and an outdoor space, and then in an anechoic space. After treating the anechoic sound with the simulated acoustic of the chapel and outdoor space, we asked listeners to try to identify the "real" and "simulated" acoustic. I did a test pilot study. When it came to the recordings in the chapel, at least with the fifteen or so people that piloted it, they thought that the fabricated acoustic was more realistic than the actual recording, because it sounded closer to what they expected the church to sound like. With the outdoor space, the split was more even. But in terms of the chapel, listeners skewed

towards the fake audio, because they thought it sounded more real than the real audio.

Luke Reed: It raises an interesting point that we've touched on: Are we trying to re-create reality or not? When we showed the Paraorchestra film, we had discussions about how "clean" the recorded sound was, how studio-like. It raises the question about what we're actually in this for. Are we trying to create a document of something that happened that was real, or trying to re-create reality, or are we doing something else? In my mind, certainly as a film sound editor, we all know that film sound is a completely unrealistic construct. It's all fake. And we're creating an optimized or perfect version of the world. Should we be doing that for VR, or creating something closer to actual reality?

James Cook: There's definitely something to be said for the public conception of anything, whether that's history, or what a space sounds like, and that matters to an extent more than reality. People have expectations about the sound of a chapel in a game, and if what you're giving them goes against that, even if it's actual reality, it's probably not going be congruent with what they were expecting.

It's that challenging question: Are we trying to make reality? Are we trying to make virtual reality? Are we trying to make something in between? It depends what your priorities are, and it can be tricky when you're constructing these spaces and you can assume you're aiming for one, but your audience might be looking for another.

Andra Ivănescu: Richard, you co-wrote an article about this issue of realism.

Richard Stevens: Yes, this was about the first-person shooter *Battlefield 4*, which had a challenge of what audience expect war to sound like. Most people have only ever experienced war through essentially really bad recordings attached to portable cameras or poor audio equipment that's being distorted. *Battlefield* found better audience response with deliberately distorted sounds because that's how people have learnt what war sounds like.[13] It's the expectations of reality, rather than reality. Reality, as we all know, is deeply disappointing!

Stephen Tatlow: I've been looking particularly at how we conceptualize sound and virtual reality, and how sound actually influences virtual reality. I've been developing a framework that examines virtual reality as an experiential event. Rather than thinking of a virtual world and the sounds within it, I'm looking at the experience of virtuality. This involves, for instance, external sounds bleeding through headphones, mediation of the headset, and so on. And how does that influence the immersion as well? How can we address our sound design to achieve the aims we want? I'm particularly interested in the boundaries and intersections between reality and virtuality.

Richard Stevens: It highlights the issue of off-ear headphones. In the case of off-ear headphones like those of the Valve Index, you're actually in a shared audio space. This kind of approach is different to the enclosed or in-ear headphones where the audio is just your space. As soon as you take it off the ear, firstly, you get that kind of externality that

13. Richard Stevens and Dave Raybould, "The Reality Paradox: Authenticity, Fidelity and the Real in Battlefield 4," *The Soundtrack* 8, no. 1–2 (2015): 57–75. See also Andra Ivănescu, "Torched Song: The Hyperreal and the Music of L.A. Noire," *The Soundtrack* 8, no. 1–2 (2015): 41–56.

you might want in the sound environment, but then also you are in more of that shared audio space. While there are real advantages, if the environment in which you're playing the game doesn't match the environment in the game itself, then there's all sorts of interference and confusion. You might be walking around and having squeaky floorboards in your room, but in the game, you're in a completely different world.

What happens when these intersections between the virtual and "real" world are part of the experience, as in AR projects?

Andra Ivănescu: I'm coming to this from a theoretical perspective. My interest started with one of my colleagues, Mariza Dima, who worked on a project called Sutton House Stories. This was a heritage project that used Microsoft HoloLens create an AR storytelling experience in a Tudor house in East London.[14] What struck me was how important sound was to the experience, not only in terms of practical navigation, but also to the storytelling.

It reminded me of earlier research on the Walkman and the iPod, such as Michael Bull's work on the Walkman, and William Gibson's comment that the Sony Walkman has done more to change human perception that any virtual reality gadget.[15] Sound transforms landscapes and architecture in these two scenarios.

In Dima's work, sound was related to storytelling, not only through actors' voices but in a lovely moment where a minuet played while some ballet shoes moved, because the house used to be a girls' school. So this was a beautiful storytelling moment.[16]

I want to come from a theoretical perspective where I draw on early work on the Walkman like the writing of Iain Chambers, Stuart Hall, Paul du Gay, and other cultural studies.[17] There are several aspects that the recontextualization of this work reveals:

- AR blurs the boundaries between the public and private.
- Spaces are partly visible but also transformed, because of the sound.
- It is both a collective *and* individual experience because players or visitors follow the same path, but they draw on what they've heard and seen before, their experience with sound, to make it a personal and intimate experience on a number of levels.

Personal stereo use and sound in AR can tell us a lot about how we experience sound in virtual worlds and in virtual reality by looking at how we experience space and the

14. For Dima's commentary on this project, see Mariza Dima, "Sutton House Stories," c.2020, accessed January 31, 2021, https://www.marizadima.space/sutton-house-stories.

15. See, amongst others, Michael Bull's *Sounding Out the City: Personal Stereos and the Management of Everyday Life* (New York: Berg, 2000); William Gibson, "The Walkman," *Time Out*, October 6, 1993, 49.

16. Giles Hooper suggests that VR might prompt more use of audio for storytelling through found objects in the diegetic world (e.g., audio diaries or other sound-producing artefacts). Giles Hooper, "Sounding the Story: Videogame Cutscenes," in *Emotion in Video Game Soundtracking*, ed. Duncan Williams and Newton Lee (Cham, Switzerland: Springer, 2018), 115–42.

17. Iain Chambers, "A Miniature History of the Walkman," *New Formations* 11 (1990): 1–4; Paul de Gay, Stuart Hall, Linda Janes, Anders Koed Madsen, Hugh Mackay, and Keith Negus, *Doing Cultural Studies: The Story of the Sony Walkman,* 2nd ed. (London: Sage, 2013).

relationship between things like psychogeography, musical immersion, and augmented reality spaces.

This raises questions about how music and sound in our environments may influence the movement of players through space in AR, making it seem more "balletic" and dictating a sense of space. That seems slightly different from complete virtual reality. These all relate to how sound and music affect storytelling as well as our understanding and perception of physical space.

Richard Stevens: That blurring of the private and public is really interesting, particularly in the shared or blurred audio spaces of headsets with off-ear headphones.

Rich Hemming: That analogy with the Walkman is very interesting because there's a chapter by Iain Chambers called "The Aural Walk," which describes walking around with headphones in the world, and as we do so, we create our own remix of the world and our own soundscape.[18] But what you're predominately doing with putting headphones on is shutting out the external world and listening to music. So applying that "shutting out" to VR is quite a difficult problem because it comes back to what Richard was alluding to earlier: How do we actually mix that? Is it an externalized music, or is the music in the world with you?

The Walkman analogy is really interesting, in comparison with the RJDJ project I worked on. We used the Apple headphone microphone to pick up environmental sounds and then incorporate those, transformed, into the musical soundscape you were listening to. So if you were walking down the street and a bus went past you, it would suck in the bus sound as a sample and then play it back to you quantized and distorted or even with musical effects.

The new Apple earbuds actually have transparency mode where they allow some sounds to come through the mix. They are being described as headphones with microphones on the outside. And I think there's some really creative and interesting areas that we can get into with that. But it could be completely disruptive if people started talking to you and end up breaking your immersion.

In this discussion about on-ear or off-ear headphones for VR, I'm wondering whether we're getting to a point where we could perhaps use AR audio in a performance space, where a VR system could dynamically mix between outer surround sound system and a close system like headphones. That could allow very close and distant sound to happen, almost like an augmented version of the audio.

Technologically, the advancements of the diffusion techniques of audio and splitting of sounds inside and outside the worlds, plus spatialization, and music is going to get really interesting. VR is very immersive and closed, but what happens if we start using bigger performance spaces?

Sharing Virtual Spaces

Lucy Harrison: I'm wondering if this issue of being "closed off" is key to VR becoming more mainstream. I've always thought it is so niche because you can't actually share the

18. Iain Chambers, *Migrancy, Culture, Identity* (London: Routledge, 1994), 49–53.

experience with other people. The reason why the Nintendo Wii was such a successful console was because everybody could play it and have some kind of shared experience. If there is something that bridges between the players and observers, and makes it sellable to a family, then you suddenly have something that you can actually profit off, because at the moment the VR emphasis is on these tiny, closed experiences, sonically and visually. Everything is just marking you off from the world.

There are experiences that are empathy-generating, like those that simulate sensory overload, but anything that would kind of make a bridge to bring in some of the outside sounds would be interesting to widen that audience.

In the AR realm, there are two apps I used with my students. Fields AR, which allows you to build your own AR soundscapes, and it localizes the audio so you can literally place it within a room.[19] I use it to give them a sense of the physicality of a space. The other is Anna Meredith's AR single, where you can do your own mix around a space.[20]

James Cook: For our project on Linlithgow Palace, we were aware that one of the nice things about going to a historical space is you actually see the real thing. And what we were asking them to do is stick on a VR headset and not see "the real thing." We experimented with AR glasses, where you can see the real world, but you can drop in a Unity file with all the sound spatialization. People can walk around the chapel wearing them and it sounds like the singers are where we place them in the game engine, so they still get the acoustics and they still get specialization, but it doesn't knock out other sounds. So you can still talk to your family. That works quite nicely. I suppose you could have a Magic Leap when you can see things but you have AR overlaid. That might be one way to tackle this bridging question, which gives you the ability to still interact with people, the ability to still to get something out of going to a place in the real world, but also offers something else which is fun.[21]

Laryssa Whittaker: I've been working on a longitudinal project with university-age students and their receptiveness to VR for home use. This question of the desire to either isolate or multitask is something that I get very different perspectives on from our participants. Sometimes the thing they love about VR is sonically and visually escaping from the real world, as opposed to some students where that aspect really irritates them.

This question of framing virtual reality as a family experience is interesting. I really didn't expect to get that from university-aged students. But whenever they are asked about buying one, they say, "Yes, it'd be great if my parents would buy one; I would use it at home with my siblings and my family."

I think that's really quite interesting, in terms of the market and the experiences that are being developed. For young adults, it maybe says something about their stage of life,

19. "Fields," Planeta, 2018, accessed January 31, 2021, https://fields.planeta.cc/.

20. Anna Meredith and Arthur Carabott, "MoonMoons AR," 2019, accessed January 31, 2021, http://www.annameredith.com/moonmoons

21. See also, on the combination of physical objects with virtual instruments to make "hyperreal instruments," Anil Çamci and John Granzow, "Hyperreal Instruments: Bridging VR and Digital Fabrication to Facilitate New Forms of Musical Expression," *Leonardo Music Journal* 29 (2019): 14–18.

but also it says something about sort of the socio-technical imaginaries,[22] about where we think virtual reality fits within our life experience. For a lot of these young people, it's fitting in in their family homes.

PART 3. MOVEMENT, ORIENTATION, AND DISORIENTATION

Clearly, orientation in a virtual world is an important topic. How might music and sound play into these questions of how we engage successfully with these worlds?[23]

How we could use music for ludic functions? Can it be useful in terms of drawing our attention?

Richard Stevens: The problem with sound VR in games is a directorial one: you need to draw the players' attention to certain objects in the game to direct players to interact with them. Could we use music to do that? This could be literally spatial representation, perhaps attaching an instrument or musical fragment to a particular object, so it draws our attention in the 3D space. Perhaps, though, sounds have symbolic relations with space. To pick a basic example, we associate birds with height. If we have sound or musical elements that are evocative of birdsong, might we be more likely to look upwards?

Binaural panning in VR, despite the amount of attention, doesn't always work very effectively, because filtering of sounds as they happen around us is very personalized and depends on the width of our head, and the shape of our ears, and so on. The models currently in use are based on HRTFs (head-related transfer functions), which aim to model how sound is transformed by the physical properties of our heads. These functions, though, are based on average values, which means that they don't fit the individual experience, which can be quite different. For instance, in my case, across the numerous examples I've tried, I never get any sense of sonic movement in the central c.35 degrees directly in front of me.[24] It is possible to have personally tailored HRTFs created, but for a mass market, is it practical to have a those created for everyone, especially when it currently involves scanning or photographing their heads?

Rich Hemming: Richard, that talk of personalized HRTFs, since we are seeing LIDAR scanners built into phones and tablets now, perhaps there's a scenario where an app could scan your head very quickly and then feed the metrics into the experience and then try and tighten that experience for you.

22. See Sheila Jasanoff and Sang-Hyun Kim, eds., *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power* (Chicago: Chicago University Press, 2015).

23. For more on sound and presence theory, which informs the following discussion, see Rolf Nordahl and Niels Christian Nilsson, "The Sound of Being There: Presence and Interactive Audio in Immersive Virtual Reality," in *The Oxford Handbook of Interactive Audio,* ed. Karen Collins, Bill Kapralos, and Holly Tessler (New York: Oxford University Press, 2014), 213–33.

24. Rob Lawrence, "Producing Music," notes that our detection of locating lower frequencies in space is less precise than for higher frequencies, so the question of localization also differs across the frequency range.

Luke Reed: Genelec have started promoting an "Aural ID" which scans and creates personalized HRTFs derived from a 360 video of your head and shoulder region from a phone.[25]

Richard Stevens: Another mass-market approach is to prompt users to choose from a selection of HRTFs and find the one that's the best fit for them.[26]

Luke Reed: I recently wrote a paper on audio reproduction in VR cinemas, and it presents suggestions of what the playback software needs to do.[27] And it does exactly what you're talking about, which is to create an onboarding/calibration process for users through localization games.

If bespoke HRTFs are impractically expensive, does it make a significant difference to the average user? Do they notice? Are they aware that this is something that they need to have? And does it really affect their experiences of doing it?

One recommendation is a selection from a wider range of HRTFs that are out there, which are predominantly male, North American models. Yamaha, for example, have done a lot of work on creating libraries of Asian morphologies and have their own version of the KEMAR head, which is a dummy head and torso model used for simulating and testing audio. Their version is more representative of the entire global population rather than just white North American, male, and European.

Another important observation is that the longer we use an HRTF, the better our localization becomes. Studies have reported that when a modification is made to impede the sound reaching the ear, our localization slowly improves over time, and then when the impediment is removed, localization isn't affected, but the modifications can be added and removed while localization stays relatively constant.[28] This suggests that actually the longer we use these HRTFs, the better we become.

And I've noticed that in my own practice, that there are certain spatializers I've used more of, and I know how they sound. It's a little like your reference monitors: we all have speakers and monitors that we like and that we trust and we know how they translate audio. And I think that HRTFs are likely a similar thing.

W. Owen Brimijoin of Facebook Reality Labs has recently been speaking about research where there is a compression of the spatial field of our perception around the sides of our heads, where sounds at the sides of our heads have to move twice as much to be perceived as moving the same distance, as if they were in front of us.[29] And that this could be measured and applied to mixes as the head moves.

25. "Aural ID," Genelec, c.2020, accessed January 31, 2021, https://www.genelec.com/aural-id.

26. This conversation took place before the release of the new PlayStation 5 console—which actually does exactly this! (Richard Stevens)

27. Luke Reed and Philip Phelps, "Audio Reproduction in Virtual Reality Cinemas—Position Paper," 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 2019, 1513–16, accessed February 16, 2021, https://doi.org/10.1109/VR.2019.8797904.

28. Catarina Mendonça, "A Review on Auditory Space Adaptations to Altered Head-Related Cues," *Frontiers in Neuroscience* 8 (2014): 219, accessed January 31, 2021, https://doi.org/10.3389/fnins.2014.00219.

29. W. Owen Brimijoin, "Angle-Dependent Distortions in the Perceptual Topology of Acoustic Space," *Trends in Hearing* 22 (2018), accessed January 31, 2021, https://doi.org/10.1177/2331216518775568.

Luke Reed: In our Paraorchestra project, the version was linear, rendered as a 360 video, which switched from different perspectives. We have all of the raw files, so it would be possible to make something that was navigable in something like Unity by using those materials as in-game objects. But this output was linear. We spent a lot of time discussing how to switch perspectives in the edit. Some of the things we noticed were about musical congruence in the edit.

Whether the cuts happened in time with the music has a significant effect upon orientation and disorientation. We noticed that when you cut when there was a predominant solo instrument nearby, that helps you to anchor yourself within the mix again.

Richard Stevens: I think that's an important observation because of "cuts" and how we move around virtual worlds in VR. For example, in *Half-Life: Alyx*, while one can walk around, the main method of movement, as in many of these games, is through teleporting from one spot to another, to help with motion sickness. The idea that music might play a part in that is interesting. If you're trying to direct somebody's experience in a VR game, for example, you wanted them to move from one position to another, that if you make it congruent with some sort of musical gesture, it might make it less disturbing to the player. I think that's really interesting.

Spatiality, Motion, and Sickness

Elisa Raffaella Ferrè: Our research focuses on the vestibular system, which is an organ in the inner ear that detects the movement of our head in space and provides the brain information about linear acceleration (translational movement, including gravity) and angular acceleration (rotational movement). We are interested in the vestibular system because it's a perfect model of multisensory integration—how our brain collects and combines sensory information to create a coherent representation of the external world. My lab is working on virtual reality because it can provide a useful site for studying sensory experience and embodiment.

We know that multisensory interactions are fundamental in providing a feeling of immersion and embodiment in virtual reality. We are interested in how the vestibular system can contribute to embodiment, the sense of presence. But perhaps more importantly we are investigating whether vestibular signals might be involved when virtual reality doesn't work "well," such as when users experience cybersickness. Despite the improvement in technology, up to 80 percent of VR users report to symptoms of nausea, disorientation, and discomfort during VR exposure.

My research focuses on the neurocognitive mechanisms of cybersickness, but also what can be done to reduce it.[30] What is cybersickness? Let's imagine you are in a VR roller coaster. Our brain is receiving visual information about movement, the so-called vection, but because you are not physically on the roller coaster, there's no real movement associated with that vision. There is a conflict between visual and vestibular information.

30. See, for example, Maria Gallagher and Elisa Raffaella Ferrè, "Cybersickness: A Multisensory Integration Perspective," *Multisensory Research* 31, no. 7 (2018): 645–74; and Maria Gallagher, Reno Choi, and Elisa Raffaella Ferrè, "Multisensory Interactions in Virtual Reality: Optic Flow Reduces Vestibular Sensitivity, but Only for Congruent Planes of Motion," *Multisensory Research* 33, no. 6 (2020): 625–44.

Visually, the brain detects movement, but the vestibular system does not transmit any information about acceleration. We have been funded by the British Academy to investigate the mechanisms underlying cybersickness, and we have observed a significant alteration in vestibular processing while people are exposed to virtual reality, which supports the idea of a sensory conflict.

We are interested in VR aftereffects and brain plasticity. We found that after a few minutes VR exposure, the brain seems to adjust to vection-induced motion, reducing the importance of vestibular cues. Accordingly, VR aftereffects have been described, such as tilted vision for hours after been exposed to long VR simulator training. This is very important, and more attention should be done to guidelines and standards for VR experience.

Some of our current projects focus on reducing the saliency of the vestibular input in order to improve VR immersion and possibly cybersickness. We are also interested in sensory augmentation. Can we provide artificial vestibular information during virtual reality? Although this seemed very promising, it is much more difficult than we were expecting, and further research needs to be done.

Sound is also very relevant for providing a feeling of immersion and embodiment. The multimodality experience is essential for VR. So not only visual, vestibular, tactile, and proprioceptive information, but also sound and possibly music may be crucial to shape the feeling of immersion in VR.

Interestingly, research has shown that sensory information is distorted in VR. So it would be interesting to investigate how sounds are perceived in VR. Sound localization in VR might be distorted, as we have been discussing today, and it's not clear how we can provide a full 360 sound experience in a reliable way.

I'm very interested in questions related to sounds and head movement, and how they can be integrated with vision. Every time that you move your head, there is obviously information about vestibular, visual, and sound. More in general, how can sound be integrated with the stream of sensory information?

In some VR scenarios we aim to create sort of "realistic" experience, in which all the sensory information is neatly combined and people can feel to be in a different place, with a certain degree of realism. However, research might also focus on how the brain reacts to nonrealistic environments in which the usual perceptual and physical laws are no longer there. How quickly can we adjust to and interact with this new reality?

James Cook: One thing that I've noticed from very anecdotal evidence, from our user testing, is that when we had more accurate acoustic models and more accurate specialization, people seemed to report less motion sickness in our experience.

Elisa Raffaella Ferrè: Is that something you've measured?

James Cook: No, it's just something that came up a lot in our discussions. We gave them different acoustic models for the room. Some that matched the space, some that didn't. And we have better or worse localization. We discussed with them how they felt about the experience, not really expecting anything to come up about motion sickness at all. And people did say that they felt better in the one with more accurate acoustic models—"I normally struggle with motion sickness; I didn't this time."

Elisa Raffaella Ferrè: Similar phenomena have been described in the visual domain. Initially, creators assumed that the main problem was visual resolution, or in other words people were getting sick because the technology was not good enough. However, despite the improvement in VR tech, cybersickness is still there. Indeed, some people report that as vection is getting better, motion sickness is getting worse.

James Cook: That's definitely my experience.

Elisa Raffaella Ferrè: It doesn't necessarily mean that if you improve one sensory modality, the others are going to adjust quickly, too. Actually, you can increase the conflict because the gap between sensory cues is even higher. If I have super-accurate vection, and I'm not moving, the vestibular system reports that you are not moving, and these do not match. It has been shown that you can use VR like a sort of training: you use it daily for a few minutes, you can get better, even if you are very sick at the beginning. Can we make that process faster, and is it safe to do so?

It's also important to keep in mind what measure one is looking at. I would strongly suggest to use both implicit and explicit measures. It's very good to ask people about their perception during the VR experience, while also using physiological measures. Humans are very good in telling you what you want to hear. But it's difficult to cheat if there is a physiological change. If motion sickness is increasing, heart rate increases, people are sweating, oxygenation is different because when you're sick, all these physiological changes are happening. I suggest researchers take a multidisciplinary approach using both explicit measures but also physiological measures.

Richard Stevens: Some game developers have put heart rate monitors and skin capacitance on the hand controllers to monitor when people start reacting, so it can be adjusted in real time. I certainly can attest to the VR aftereffects, which can be very strange, particularly the spatial dimensions.

In *Half-Life: Alyx*, which had a huge investment in development, I found only limited sickness, usually only during elevator sequences. It's worth noting that during movement the sound localization in the game seems to blur—because you're teleported from one place to another very quickly and you can also rotate as you teleport. If that sound localization was to be very accurate, you'd have sound moving quickly around you. Here, there seems to be some interpolation happening over time. Many sound sources are also from a nebulous large area. They aren't the pinpoint sources you might find in other games.

Concerning proprioception, there was a lot of investment in Foley sound. If I turn my wrists, I get a little bit of clothing rustle as I move my arm, I'm hearing sounds coming from the different parts of my body that might be those kind of clothing movements. As a consequence, I've never felt the sense of proprioception as much as I do in this game. Part of that is down to the Foley that is really representing my body movements more than any game has before.

Voice Spatialization

Will Farmer: One thing we struggled with was the frequent displacement between the real-world position of players wearing headsets altogether in one room, to their relative location in the shared virtual space.

When we were talking to each other, you'd be looking straight ahead and see the representation of their character, but the voice of them actually speaking would perhaps come from behind you. In that way, it was incredibly disorientating and took you out of the VR experience to be sharing a space, because it didn't match up exactly with what you were being told by the headset you had on. That's an issue that has to be overcome, especially if transporting is done, if you want to be talking to somebody who's actually with you in a room playing the game as well.

Stephen Tatlow: Voice is a big issue here, and I wonder if voice is still spatialized in games. Perhaps people are so used to externalized voice programs like Discord, Skype, Mumble, and so on, maybe we don't use that as a way of identifying where people are within the space.

Luke Reed: I think that actually comes from a cinematic convention. Most Foley and voices are mono centered, coming through the centered channel if you're watching with surround. It's part of our screen literacy that voice is not specialized, and I think that's extended to games, where it was experimented with a little, and then VR, which is interesting.

I've worked on some VR 360 documentaries, and there is sometimes a point of friction between the sound editors and the director about whether a voiceover should be specialized or not. We propose for the voiceover to be in a fixed position, locked to the viewer's head and centered all the time. But some directors want to have the spatialization off to one side, to direct attention within the 360 image.

Richard Stevens: I think in terms of games, it very much depends on the nature of the game itself. There are certain conventions at play, including some from cinema. In the games I play, voice has been spatialized up to a certain distance. Then it hits the ludic necessity of understanding, hearing that information. Beyond a certain distance, it becomes non-spatialized and non-attenuated because we need that information. But I'd actually argue that other media can learn from games. For instance, online video conferencing can easily become a cacophony of noise. Spatialization might help.

Rich Hemming: Luke, I agree that this is likely a hangover of the ventriloquist effect from cinema, in terms of the central mixing where spatialization isn't particularly necessary, but in line with Richard, we need more accuracy, in order to enable the cocktail party effect, the dynamics of conversation need to be able to move spatially—the dynamics of spatialization is part of the conversation construction.[31] We are really supersensitive to that spatial aspect of listening, and it's very difficult to do that in a flat, two-dimensional scenario.

CODA: PRACTICE/RESEARCH

We concluded our discussion considering working methods, particularly the role of practice as research and the creative dimension.

31. The "cocktail party effect" refers to our ability to interpret and follow one audio source (typically a conversation with someone) by ignoring other concurrent conversations or audio. E. Colin Cherry, "Some Experiments on the Recognition of Speech, with One and with Two Ears," *Journal of the Acoustical Society of America* 25, no. 5 (1953): 975–79.

Richard Stevens: The work I've been doing with Nikos Stavropoulos has had practice-based research built into the design. It's part of an iterative process through collaboration.
Lucy Harrison: Everything I do comes from a practice angle. I think in these cases there are a number of ways that we can experiment creatively. Using VR for more abstract or realistic constructs is an important question. The challenge for practice-based research is access to equipment: with a practice-based research approach you're limiting your audience to people who can afford VR, which means that you're already skewed to people who love VR enough to buy it. I think I'm in the middle of this question, trying to move something from the real world to the virtual.
Luke Reed: One of the issues with practice-based research is that it's very difficult often for one or two people to make something that has the reach to fulfill REF (Research Excellence Framework, a UK research evaluation exercise) requirements in the way our institutions wants us to be working. In particular, the emphasis on international recognition as an important metric can be difficult to meet. With more festivals come more stages and awards to demonstrate international recognition, the opportunities are increasing. I'm a big advocate for practice-based research, but the impact metrics are limiting. Within the university, with experimental noncommercial work, it's harder to get those high impact outcomes. Opening out this discussion beyond universities for collaboration may be a valid way of going forward.
Elisa Raffaella Ferrè: My work is very lab-based, rather than applied. I'm not familiar with "practice-based research methods" as such, but it is useful to have an integration of different methods working in parallel. Practice and applied research and lab research may complement each other. Lab research is helpful for collecting controlled measures, but of course it is a sort of simplified model with limited variables. It might be interesting to combine different methods, and perhaps including creative elements.

CONCLUSIONS

This discussion was an exercise in opening up conversations between different disciplinary perspectives on the same subject. It was rewarding to see the same issues recurring across areas of expertise and practice. The themes of 1) the artistic possibilities of VR/AR, 2) the nature and construct of virtualities, and 3) spatiality kept recurring in our conversation. The fact that these topics are crucial to virtual reality experiences in general illustrates the significance (or at least potential significance) of sound in these realities. It is difficult to believe that the challenges identified in this discussion will be answered by one approach, piece of technology, or solution. Instead, researchers and technicians should consider these factors and how they may be addressed, mitigated, researched, or articulated in their projects. ■

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