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Towards a definition of Autographic Sonifications: Listening as an act of knowledge

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Abstract: In recent years, sonification as a method to analyze, represent and communicate data through sound has grown significantly showing a diversity of purposes, users, and topics. In data journalism, education, art, or data monitoring, sound is used to both support and engage experts, researchers, and the general public with a broad range of scientific and social phenomena. As the field is moving towards shared design and evaluation processes, new practices seem to emerge that put the listener at the center. By analyzing recent cases from the Data Sonification Archive, the paper proposes a definition of autographic sonification as a self-encoding process in which the act of listening becomes central to making sense of complex phenomena.

Keywords: data sonification; autographic design; autographic visualization; human-data interaction.

1. Introduction

Data sonification is a relatively recent field of research. With the first International Conference on Auditory Display dating back to 1992, research on how to represent, explore, analyze and communicate data in the form of sound events has been conducted mainly within academic and research institutions. In the past decade, though, sonification has been gaining momentum: Its reach has increased, with new crowdsourced initiatives such as the *Data Sonification Archive (*Lenzi et al., 2021), multi-disciplinary working groups such as *The Audible Universe* (Pauletto & Misdariis, 2023) and the *AudioVisual Analytics Community* (Enge et al., 2023), and a growing interest by commercial designers to include sound as a means of data representation along with the more traditional data visualization (Maskey and Maroune, 2023; Torban, 2021). As a consequence, the field of sonification has grown to

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show a significant diversity of communication purposes, users, and topics. Authors of recent sonifications are not only researchers and academics, but also data journalists, information designers and artists that use sound to communicate the complexity of phenomena with different intentions (Lindborg et al., 2024), from creating engaging art experiences to increasing awareness and activism on socially relevant issues such as climate change (Linborg et al., 2023) or human rights (Lenzi & Ciuccarelli, 2021).

As a method of representing and communicating data through sound, sonification has been mainly concerned with defining how specific values in a dataset are encoded in the acoustic properties of an auditory stimulus. Traditional definitions of sonification focus on the "mapping of numerically represented relations in some domain under study to relations in an acoustic domain" (Scaletti, 1994) and "the transformation of data relations into perceived relations in an acoustic signal" (Kramer et al., 1999). Successive definitions further required such transformation to be "systematic, objective and reproducible" for a sonification to be used as a scientific method (Hermann, 2008). While some authors have long advocated for sonification to be recognized as a design-driven practice in support of a user's information processing (Jeon et al., 2019; Vickers and Barrass, 2011; Barrass, 1997), similarly to traditional Human-Computer Interaction the creation of a new sonification depends largely on the data-to-sound conceptual model of the designer. The end-users (i.e., the listeners) are then expected to be able to develop an equivalent conceptual model by leveraging the affordances embedded in the sonification. However, the difficulties of listeners in 'reverse engineering' the sonification designer's mapping strategy and consequently correctly decoding the information contained in a sonification, is a known issue in sonification research (Nees, 2019; Neuhoff, 2019; Roddy & Bridges, 2020). Authors have addressed the issue by proposing alternative design strategies, such as leveraging embodied metaphors (Roddy & Bridges 2018; Roddy & Furlong 2014), improving the description of the sonification design rationale (Wirfs - Brock et al., 2021), defining shared design tools (Lenzi & Ciuccarelli, 2024) and evaluation strategies (Pauletto and Misdariis, 2023). However, less attention has been directed to how listeners presented with an unfamiliar sonification are able not only to decode the corresponding data values but also make sense of the phenomenon behind the data, and conversely, how sound relates not to a specific dataset, but to the real-world phenomenon it represents. A notable exception is the influential study by Vickers & Hogg (2006) where the Aesthetic Perspective Space is proposed as a theoretical framework characterized on the one hand by a distinction between sonification (as *Ars Informatica*) and sound art (as *Ars Musica*) and, on the other hand, by an Indexicality axis i.e. a continuum between sound as an index of the phenomenon it represents and sound as an abstract entity. While the focus on sound as a material *index* of a phenomenon resonates with the autographic approach we describe in this paper, Vickers & Hogg's framework is proposed as a tool for the analysis of existing projects, rather than for the understanding of the role of the listener in relating sound to the real-world phenomenon it represents by either causally connecting it to the source that produced it (high indexicality) or decoding the code used by the designer (low indexicality).

The ability to construct meaning from listening to the world is central to human perception. From functional socio-technological environments to natural, urban and virtual contexts, humans decode sound events in order to understand, interact with, and predict the behavior of the world. A recent study investigates how sound can enhance the emotional relation, and conversely facilitate interaction and understanding, between humans and robots (Liu et al., 2023). Experimental research shows how medical staff in orthopedic operating rooms (Özcan et al., 2022) heavily relies on listening as a guide to perform specific, sound-induced actions (e.g., fine tuning the position or speed of surgical instruments, anticipating the request for a specific tool, monitoring the patient's conditions). Reports on the impact of COVID restrictions have proven once more how changes in the soundscape affect the interaction with the world of humans (Lenzi et al., 2021), other species (Duarte et al., 2021), and even plants (Phillips et al., 2021). At cinema, the semantic, causal, and material meaning of sound (Chion, 1994) is widely used to articulate the narrative and direct the public's sense-making. Sonification has long centered the debate on how to design better - more engaging and efficient - sonifications by overcoming the difficulties that arise from translating 'objective' data values into acoustic parameters that are inevitably filtered by human perception. An approach that leverages the act of listening, albeit subjective, to construct a dynamic relation between sound and the phenomenon it represents might provide the paradigm shift needed for sonification to add value to the relationship between humans and complex phenomena. In order to conduct such a shift, it might be helpful to treat sonification projects like a 'datum' per se (i.e., as the acoustic 'autograph' of a phenomenon) that listeners seek to make sense of, rather than a set of messages encoded by the designer. In this paper, we analyze through the lenses of autographic design (Offenhuber, 2023) 16 sonification cases extracted from the Data Sonification Archive (DSA, Lenzi et al., 2020). Expanding on existing sonification methods, we suggest an interpretation that looks at sounds as material traces that a specific phenomenon leaves behind. By listening to these traces, intentionally arranged and presented by the sonification designer, the public gains an understanding of the phenomenon without the mediation of abstract digital data. In Section 2 of this paper, we define Autographic Sonifications as unmediated sonifications where the (audible) qualities of a phenomenon self-inscribe as auditory qualities of the sonification. In Section 3, we look at autographic sonification design to suggest a framework for a listener-focused approach to sonification.

2. Autographic sonifications: Towards a definition

The DSA is a curated database of crowdsourced sonification projects. Each new submission is heuristically classified by the curatorial team by using a combination of top-down and bottom-up strategies that iteratively define the emergent taxonomy of the Archive. Currently, sonification projects are classified by intended purpose (e.g., research, data analysis, public engagement, art, accessibility), targeted users (e.g., researchers, domain experts, general public), subject matter (e.g., physical, social, or life sciences), combination of media (e.g., only sound, sound and visuals), and sonification method (e.g. traditionally,

audification, parameter mapping, and model sonification). Within the *Methods* category, projects are categorized according to well-established techniques such as *Parameter Mapping*, *Model Sonification*, and *Audification* (Hermann et al., 2011). Recently, other practices seem to emerge that the curators have defined as *Autographic* (Linborg et al., 2024). In these projects, by engaging with the sounds emitted by a specific phenomenon - not only by listening through one's ears but also by sensing vibrations with one's whole body or seeing the sound waves' ripples on water surfaces - the audience makes sense of it (e.g. by decoding the intensity of a rainfall through the sound it produces, or the behavior of a computer processor by the sound of its electrical circuits) without the mediation of numerical values attributed to specific acoustic parameters, In this case, the designer is rather a facilitator that collects and displays sound in a way that helps listeners in the sense-making process, and a central role is taken by the way the sonic experience is *presented* to the audience (e.g. as an installation in a physical space, a digital experience, a live performance) rather than by how data are (semantically) *represented* through sound. Paraphrasing Offenhuber (2019) *Autographic* sonifications stand as an emerging counter-model where "the materiality of sound as a raw manifestation of the phenomenon is used to engage the public through a more direct experience of the phenomenon to which sound is a causal manifestation". Sixteen projects of the 455 currently in the DSA are classified by the curators as *Autographic* and are further analyzed in this paper. As mentioned, the curatorial classification is based on heuristic strategies developed by the curators that rely on closely listening to the sonification project and analyzing available documentation (scientific publications, blog posts, authors' interviews, project descriptions, etc.). As such, the decision mainly relies on tacit knowledge (Friedman, 2008), i.e. based on "ideas and information on which we draw without necessarily realizing that we do so" and is therefore inevitably subject to the individual interpretation of the curators although grounded in "the larger body of distributed knowledge embedded in social memory and collective work practice" (Friedman, 2008). However, the recent systematic analysis of the DSA corpus by automatic means (LDA and Sonic Information Retrieval, see Lindborg et al., 2024) showed strong correlations between human and machine classifications. A predictive model to automatically categorize the DSA cases is currently under study by the co-authors. The newly introduced *Autographic* category identifies projects where, by means of sound events that are collected from real-world phenomena with varying degrees of 'fidelity' (e.g. extracted from recorded material as in **First wave** and **Wildfire,** see below, or reconstructed from 'acoustic memories' as in **Saydnaya**) or are listened to in the ephemerality of the real-time auditory experience (e.g., **Sound ranging**), sonification designers intentionally act as facilitators - rather than creators - of an act of knowing-through-listening. In this paper, we analyze the 16 projects with the goal of further detailing the characteristics of autographic sonification and identifying potential design guidelines. The projects were produced between the year 1914 and 2023 as art experiences (three cases), tools for data analysis (three), data exploration (five) and citizen science (one), and to engage the public with socially relevant phenomena (four). While most of these projects use only sound to represent and communicate information to their audiences, five projects combine

sonification and visualization. A variety of subjects is covered from health sciences and epidemiology to ecology, sociology, and urban studies. A closer look at the projects reveals a predominance of socially relevant topics such as the COVID pandemic and its consequences on the urban environment, public and individual health, and society; violations of human rights; gender inequality; and climate change. The complete list of cases including metadata and links to the sonification can be found here. Below we will analyze the 16 cases in detail by focusing on 1) the choice of sound material 2) the mapping strategy and 3) the listening mode (cfr Chion, 1994) that the authors of the sonification expect to elicit in the audience.

Voices of the pandemic

The COVID - 19 pandemic has affected human society greatly. For the work **deathIncrease** (Seznec, 2020), Seznec built an instrument that collects data on the number of people who died of COVID in the United States on a daily basis and uses it to control the number and frequency over time of sound 'fragments' which are extracted from spoken prayer requests uploaded to YouTube by people. Similarly, in **First wave** (Perera, 2021) Perera collected recorded soundscapes from before, during and after the pandemic, and interviews with people on the frontline (healthcare professionals and near-death survivors). This sonic material is used to sonify the deaths in the UK during the first 154 days of the pandemic. In open contradiction with the most accepted definition of sonification, which actively excludes the use of speech (Kramer et al., 1999), Seznec and Pereira are using fragments of recorded human voices to communicate the individual yet collective tragedy of the loss of thousands of lives during the pandemic. Rather than for the semantic meaning conveyed by language - which is, in these two projects, often unintelligible - or for its prosody (Hermann, 2008) the human voice is used as raw sonic matter to engage listeners at a visceral level, suggesting a causal, pre-semantic connection between utterances and the real people who produced it. The fragments of human voices transmit the urgency, drama, hopes and fears in the form of perceptual characteristics of sound events (i.e., pitch, loudness, timbre, morphology of each individual voice) that go beyond (or come before) the understanding of semantic codes.

In these two cases, the authors chose 1) a *sound material* that expands on the definition of sonification by using speech, and uses only 'found sounds' i.e. recorded sound material connected to the real-world phenomenon that the sonification represents 2) a *data-to-sound mapping* reduced to the minimum, with speech-based sound events appearing as minimally manipulated in their acoustic characteristics. Finally, the authors seem to focus on eliciting 3) *causal listening* (Chion, 1994) i.e. they expect the audience to connect the sounds they hear with the sources that produced them and eventually, with the phenomenon behind, rather than with the dataset used in the sonification.

Recording of urban and natural soundscapes during the lockdown periods that characterized the pandemic are the material of projects such as **Amsterdam in and out of lockdown** (van Cruchten and Kloos, 2020) and **Soundscapes in times of change** (Lenzi, 2021). In the first case, the authors created a series of what they call 'sounddrawings' (Figure 1) based on audio recordings and visual illustrations of iconic locations in Amsterdam just before, during

and after lockdown. While visuals provide a contextual representation of the places where the recordings were taken, the recordings act as unmediated auditory fingerprints of the phenomenon (i.e., the COVID pandemic). Specific characteristics of the sonic matter - for instance, the resonance and decay time of individual sound events in the vast, empty halls of Amsterdam train station where sound waves are not anymore absorbed by any physical obstacle (e.g., human bodies and objects) - reveal to the listener the impact of the pandemic on the urban and social space of the city.

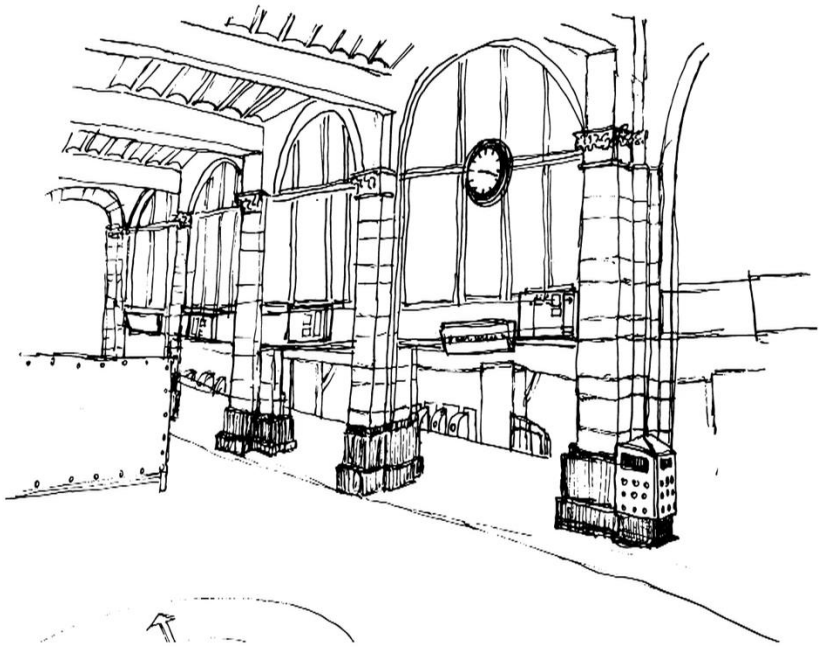

Figure 1. The 'sounddrawing' of an empty Amsterdam train station van Cruchten and Kloos.

The acoustic traces contained in the recordings help the listener quantify the impact of the restrictions e.g., by comparing resonance, decay, and reverberation of sounds when people are/are not present. In **Soundscapes in times of change** Lenzi (2021) published five minutes of recordings taken at the same location and time during the 100 days of lockdown in Spain. By identifying and causally connecting the presence, appearance and disappearance of different sound sources (e.g., airplanes, cars and other vehicles, children, animals, interaction with objects in public spaces such as bars and restaurants) listeners can follow the evolution of the pandemic. Again, other architectural acoustic features that characterize the relationship between sound and space - such as the time a sound takes to fade away (decay time) or the types of frequencies that are amplified (resonance) by specific characteristics of a space (such as materials, shapes, and sizes) - reveal the impact of the restrictions on human society and the environment, without the mediation of a numerical dataset.

Similarly to the previous cases, here, too, the choice of sound material is limited to field recordings with minimal editing (e.g. duration trimming) and there are no univocal mapping rules: the sound material is presented as a footprint of the phenomenon, without the

mediation of a numerical dataset that determines the behavior of sound over time. The sound material is, to some extent, "autonomous and not under the control of the designer" (Dombois and Eckel, 2011), influenced, instead, by the contextual conditions of the space and the events that happen in the space at the time of recording. Lastly, the listener is expected to understand the causes (i.e. the sources) of the sound events and, through them, relate to the phenomenon that produced that specific soundscape (causal listening). While soundscape studies (i.e., the study of the acoustic environment as it is perceived by humans in context ISO 12913-1:2014) collect similar material (i.e. soundscape recordings), this is usually used to generate new datasets, often in the form of visualizations (e.g., spectrograms, frequency diagrams, etc..). This material is then used by researchers and scholars to, for instance, identify and classify sound sources, evaluate perceptual characteristics (Axelsson, 2010) and generate specific indices to measure and assess the acoustic environment (Aletta et al., 2016). Within an autographic approach, the designer collects raw fragments of a soundscape and plays them to a lay audience as indexes causally connected to real-world events. As such, they are traces of the dynamic - yet ephemeral - relationship between sound waves, space, and the ear. In this sense autographic sonifications of the soundscape are closer to the practice of soundwalk (Velasco Pufleau, 2023) that invites participants to listen and decode the information conveyed, unmediated, by the sounds that occur in a specific space at a given time. In these two projects, van Cruchten and Lenzi are asking the audience to pay attention to the sonic matter of the environment, treating it as a sonification of underlying processes. The act of listening becomes an act of decoding and understanding a living phenomenon and its evolution over time.

Sonification as an (auditory) fingerprint of the environment

Wildfire (Bellona, 2019) and **The Great Animal Orchestra** (United Visual Artist and Fondation Cartier, 2016) use a combination of sound synthesis, recorded sounds, sound spatialisation, visualization techniques, and data-to-sound mapping strategies to engage the public in a reflection on the consequences of climate change. According to its author, Wildfire is a sound art installation that "strives to have viewers embody the devastating spread of wildfires through an auditory experience" (Bellona, 2019, p.2). Interestingly, he claims to build on ecoacoustics (Farina, 2018), an emerging field that, moving beyond bioacoustics and the study of non-human communication (e.g., animal calls) aims to understand sound as a manifestation (both a cause and a product) of the network of relations between humans and the broader ecosystem (Haskell, 2022). By listening to Wildfire, the public is able to better understand (and causally connect) how environmental conditions and climate change enable destructive fires that lead to national emergencies and cause the loss of human and non-human lives. The artwork uses sound samples of real fires whose speed rate has been modeled according to simulated and real data of forest fires in California during 2018. Through sound spatialization techniques waves of 'fire sounds' at realistic speed move through the space at realistic speed. Similarly to what happens during

soundwalks (cfr. above), a narrator guides the audience through different fire events to help them compare how different geographic conditions (type of wood, topography, weather) reflect in acoustic differences (e.g., the granularity, loudness, and directionality of the fire sound) and ultimately in differences in the behavior and disruptive force of the fire. The Fondation Cartier invited United Visual Artists to collaborate for The Great Animal Orchestra, the 2016 exhibition that celebrates the work of musician, bioacoustician and scientist Bernie Krause. Soundscapes excerpts from Krause's personal collection of nearly 5,000 hours of recordings of more than 15,000 animal species in different ecosystems are projected in the exhibition space together with their visual counterpart, the spectrograms extracted from the recordings (Figure 2).

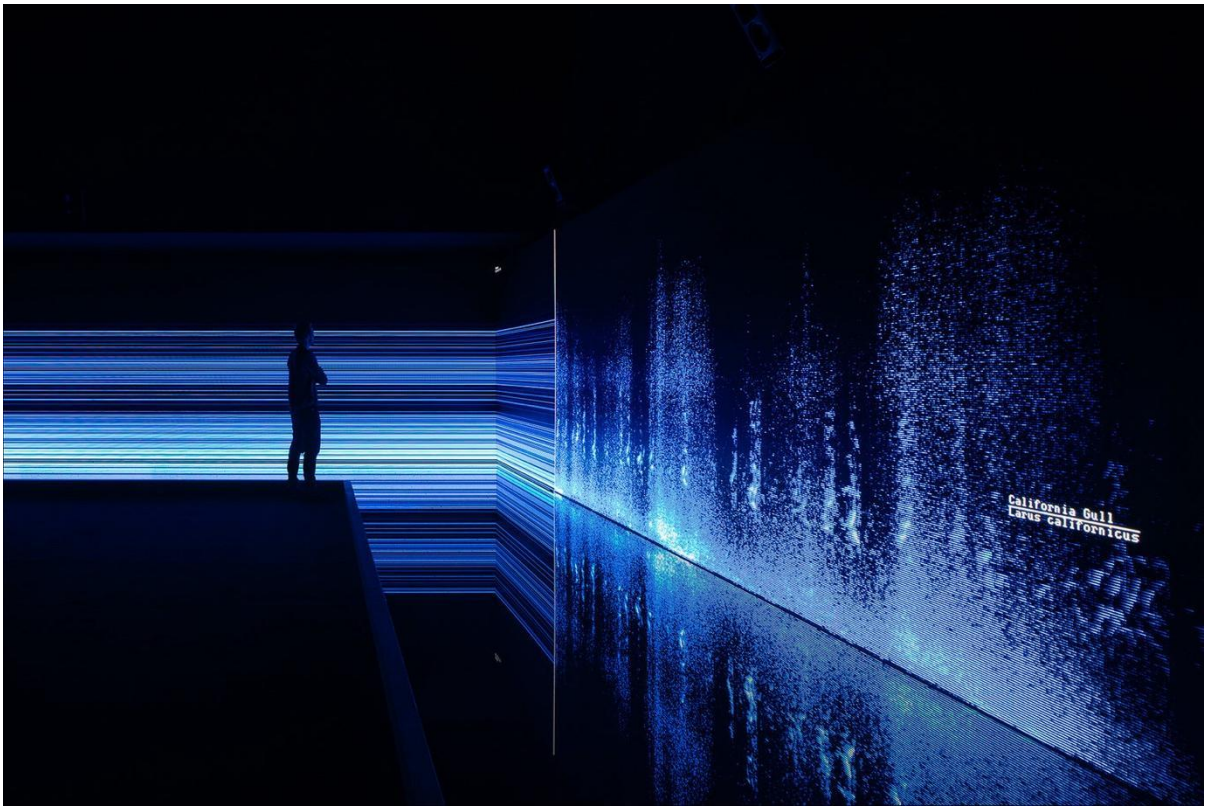

Figure 2. The Great Animal Orchestra Exhibition (© United Visual Artists © James Medcraft).

The goal of the authors is to engage the public in a reflection on the loss of biodiversity over the years by listening to a decreasing quantity and quality in the soundscape in terms of diversity of timbre, pitch and loudness is causally connected to the loss of ecosystems populations (animal and plant species). Note that this effect (i.e. the decrease in quality and quantity of sound events) is not artificially obtained by manipulating the sound recordings (i.e. by applying filters or equalization), but it is a direct consequence of real-world phenomena that are self-inscribed in the different sound recordings collected over the years in the same location. In **Eclipse Soundscapes** (Severino & Winter, 2020), NASA acknowledges how traces of astronomical phenomena (in this case, two eclipses that take place in October 2023 and April 2024) are inscribed in the earth soundscape and can be collected, recognized

and decoded by recording and listening to the sound. The goal of the project is to collect non-expert multi-sensory observations including recorded sound data from the 2023 and 2024 solar eclipses to understand the impact of the two astronomical events on the U.S. ecosystems. The project mimics a study from 1935 (Wheeler et al., 1935) that engaged scientists, professionals (e.g., gardeners), and the general public in the observation of the 1932 solar eclipse. Wheeler and colleagues were able to prove through the observations that indeed the eclipse had affected animal and insect behavior and provoked changes in the soundscape. One of the goals of the current NASA project is to expand these findings and standardize the use of a multi-sensory approach to scientific observation and data collection to include subjective observations by non-expert.

These three projects show how, as design research and practices are progressively shifting from a human-centered approach towards an interspecies discourse that takes into account the needs and features of non-humans (Giaccardi & Redström, 2020; Forlano, 2017), data representation methods also need to move away from conventional language and symbols. Future data sonification methods should enable audiences (including those with no expertise in data conventions) to listen to (and understand) natural phenomena such as climate change or astronomical events and communicate with other beings (including artificial intelligences). This can be achieved by the means of sounds that have not been manipulated by the designer to follow a data-to-sound univocal mapping strategy, but rather are listened to as a causal manifestation and material traces of the complexity of the phenomenon they represent, based on the understanding that communication is always possible beyond shared conventions.

Acoustic traces as autographs of human rights violations

In digital forensics, the material qualities of data play a crucial role in collecting evidence of crimes and uncovering disinformation practices. Methods have been developed that leverage the "unintentional traces generated during the production of a data set rather than its explicit content." (Offenhuber, 2023, p.19). The research group Forensic Architecture (FA) uses sound, and its specific material characteristics, to reconstruct violations of human rights, increase the awareness of the general public on socially and politically relevant issues, and ultimately trace and attribute legal responsibilities. In **The killing of Nadeem Nawara and Mohammed Abu Daher** (2014), FA combines the analysis of video footage with the digital reconstruction of the 'sound signature' of two gunshots by the Israeli police that caused the death of two Palestinian teenagers during the demonstration of 2014. The acoustic traces of the gunshots were first analyzed individually to investigate, and determine, the exact cause of the sound (live ammunition vs non-lethal rubber bullets). Secondly, the two sound signatures were compared to further identify a pattern of behavior (i.e., Israeli police systematically firing lethal ammunition through a weapon designed for rubber bullets) and consequently, disclose and attribute political and legal responsibilities. The *materializing indexes* (i.e., "those sound details that cause us to feel the material conditions of the sound source and refer to the concrete process of the sound's production"

Chion, 1994, p. 114) contained in the two sound events tell the 'audio investigator' a different story from the official one i.e. that they are caused by different sources. In the following steps of the investigation (in a similar manner to soundscape studies, see above), the recorded sounds are translated into visual information (e.g., spectrogram) for a deeper analysis of the acoustics characteristics with the goal of supporting legal action (see Figure 3)
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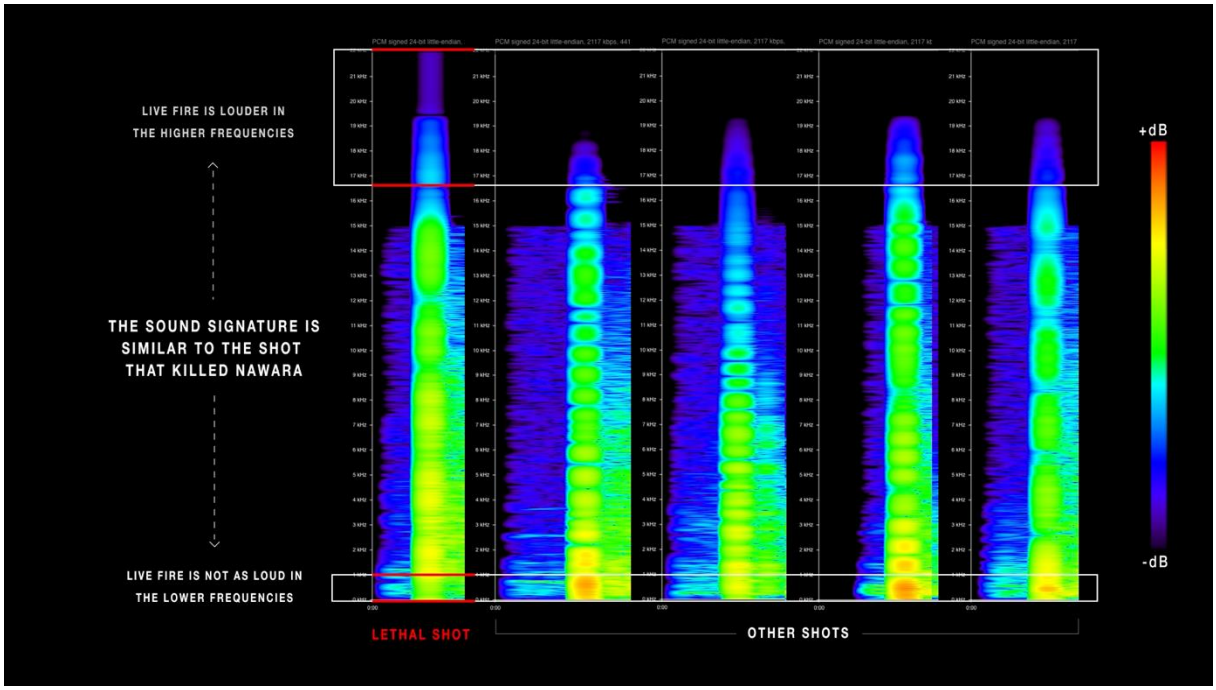

Figure 3. Audio analysis of the sonic signature of live ammunition fired through a 'rubber bullet' extension (Forensic Architecture and Lawrence Abu Hamdan).

In **Saydnaya - Inside a Syrian Torture Prison** (Forensic Architecture, 2016), the analysis of the sound signatures of events is brought to an extreme by the impossibility to collect tangible acoustic traces in the form of audio recordings. The architectural space, the logistics and organizational mechanisms of human rights violations by the Syrian regime, and ultimately the political and legal responsibilities are reconstructed in detail through the acoustic memories of former prisoners. Using a methodology developed by FA, architectural and acoustic modeling are employed to help witnesses reconstruct the architecture of the prison and their experiences of detention. During the investigation, participants were asked to match sound events of different sound pressure levels (SPL, measured in dB) to the sound level perceived inside the prison. An echo profiling of different sounds was used to determine the dimension and shape of individual cells and common spaces (stairs, corridors). Sound probes such as sounds of doors, locks, footsteps were used to stimulate further acoustic memories. Similarly to the previous case, by collecting and modeling the material *sonic indexes,* self-inscribed in the acoustic memories of the prisoners, the investigators reconstructed a 3D model of the Saydnaya prison. The 3D model was publicly released as a web experience to increase awareness on the responsibilities of the Syrian regime and support a public call-to-action.

Sound events as material indices

In **Reimagine the Game** (The Economist and Siemens, 2018) “for the first time…through the fans' voices we can judge the quality of each game. By responding to every change of possession, questionable decision or missed chance, the fans give us the perfect lens through which to reimagine the game”. The supporters' voices recorded at each location of the German Bundesliga football matches over the course of one year are used to create an immersive web-based audiovisual experience. Visitors can select and play the recordings by clicking on a visual map of the stadium. By listening to changes in the material features of sound events (e.g. loudness, pitch, timbre, localization) and causally connecting such changes with different fans’ behavior, listeners gather knowledge on which players are the most supported and which sectors of the stadium are the most vocal. The information materially encoded in the chants of the supporters help overcome the abstraction of visualization conventions, reconnecting the observer with the phenomenon behind the numerical data. As the previous cases analyzed in this paper, minimally manipulated field recordings are presented to the audience without the mediation of their symbolic (numerical) value (e.g. SPLas it is measured during the football match). A data-to-sound mapping strategy is replaced by the direct, 'before-data' experience of the phenomenon as it is autographically inscribed in the sonic matter.

Sound ranging (Imperial War Museum, 2019) was developed by the Allies during World War I to locate the enemy artillery and estimate its caliber. Sound ranging used multiple low-frequency microphones connected to analog galvanometers to record on photographic paper the traces emitted by artillery firing from the enemy lines. Similarly to a seismograph, the ‘sound ranging’ machine records sound events in the form of visual information, thus translating the acoustic, material traces of the phenomenon to visual data. In the document ‘The End of the War’ (Figure 4) we can see the sound ranging transcription of the minute before and minute after the announcement of the cessation of hostilities, on November 11th, 1918.

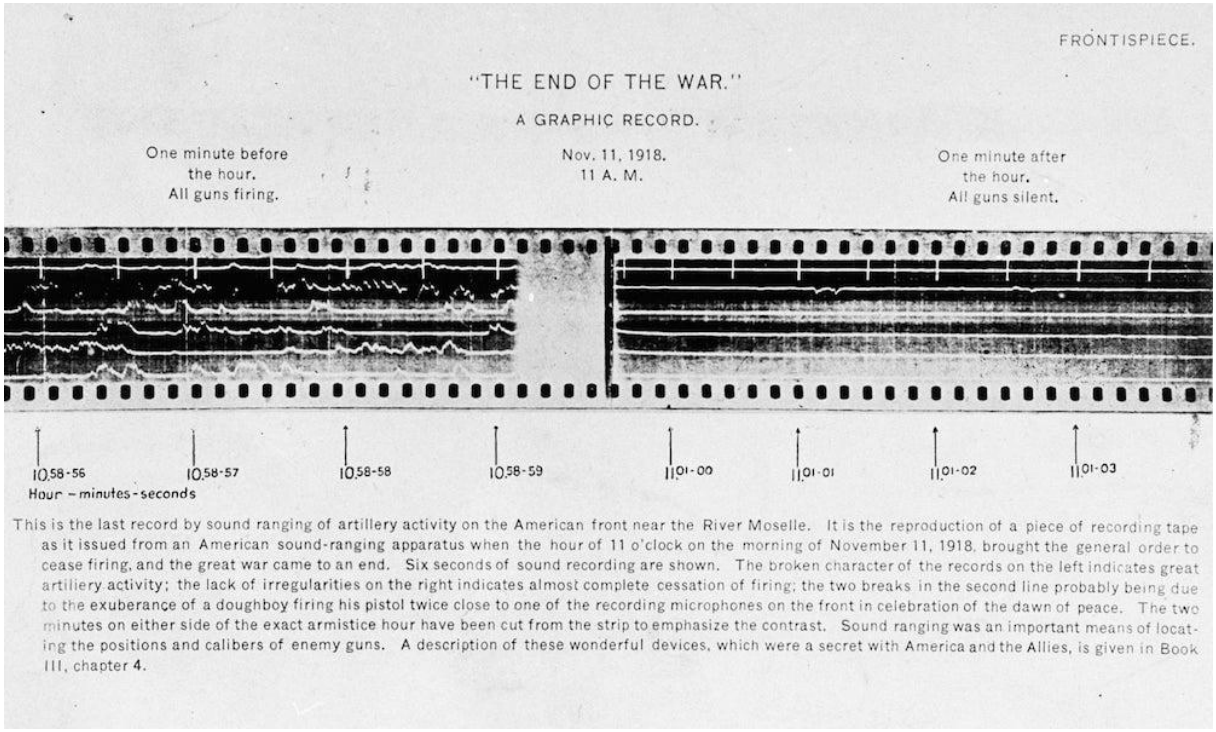

Figure 4. 'The End of the War', a graphic recording on photographic paper of the minute before and minute after the cessation of hostilities that ended the First World War at 11am on 11 November 1918 (Imperial War Museum Collection).

However, it was the human operator that had to isolate the sound of firing on the resulting visual map and distinguish it from other sounds - the sonic booms, shells exploding in the ground, and general background noise. In a similar manner, modern-day geologists use recording of the sounds and vibrations emitted by earthquakes (Dombois, 2001) to identify and predict seismic activity. By combining the visual trace left by sound events with the act of listening seismologists develop an extremely sophisticated knowledge that enables them to distinguish the geologic activity from other low-frequency producing machinery (e.g., trucks, trains) based on the audible differences of sound events (their `materializing sonic indexes` of Chion, see above) thus showing that the artificial distinction between mapped data and real-world phenomena and between reduced (i.e. a listening practice that focuses on distinguishing the physical characteristics of a sound event regardless of its source or semantic meaning, Chion 1994) and causal listening is sometimes blurry. Paraphrasing Offenhuber (2020), analog sound recordings are often at the same time physical traces. and this ambiguity blurs the boundary between data sonification (in this case, audification) and autographic sonification. Unlike audification, that translates into audible sound waves any type of wave emitted by real-world phenomena for further manipulation or analysis, an autographic approach to sonification interprets any type of sound events as a physical trace resulting from the acoustic manifestation of a phenomenon - the sound emitted by a telescope monitoring the night sky, the noise produced by the ventilation of a data factory, or the voices of participants to a virtual event. By minimally manipulating these 'found sounds' and presenting them, unmediated by univocal mapping rules, to an audience that is

expected to causally listen to the sounds to engage with the sources that produced them, the sonification designer becomes a 'facilitator' of an autographic approach to sonification.

3. Discussion: Towards a definition of autographic sonification

According to Dombois and Eckel (2011), "Often, sound recordings themselves have already been named 'audification' if they have been shifted in pitch. Therefore, we want to include with our definition above all data sets that can be listened to, i.e., also all sound recordings themselves." (p.302). In this paper, we argue that *autographic sonification* is an emerging method that extends the definition of audification in that autography considers the sounds produced and emitted by a phenomenon a 'datum' per se, without the mediation of mapping strategies (e.g. pitch shift), with minimal or no manipulation of the sound material. A second aspect of autography is the inscription of the sound into the space and the body of the listener - whether a presentation emphasizes the physical effects of sound on listener and environment, not only its informational value. By engaging with the sound events and causally connecting with their sources, the audience gains new knowledge and awareness on the phenomenon and its characteristics, and can, in some cases, predict its evolution over time (for instance in the The Great Animal Orchestra or Wildfire). The analysis conducted in this paper shows how autographic sonifications can be defined by:

1) Choice of material. Typically, an autographic approach to sonification relies on sound material that is minimally manipulated before it is presented to the audience.
2) Absence of a univocal data-to-sound mapping strategy. The audience is presented with sounds as they are produced by a specific phenomenon, understanding the underlying 'mapping rules' is understanding the phenomenon itself.
3) Causal listening. Listeners are guided by the designer to identify the characteristics of sound events that provide information on the phenomena that produced it. Such characteristics are 'materializing sonic indexes' that highlight the relationship between a sound and its source and include both how the spectro-morphology of sound is shaped by the material attributes of the phenomenon (e.g., produced by metal, wood, living beings), how its propagation is influenced by the spatial characteristics of space (e.g., reverberation, decay) and the medium of transmission (e.g. water or air which impacts the speed and distance of propagation). While these characteristics include acoustic and psychoacoustic features, these are not the focus of the design strategy which aims, instead, to engage the listener with 'relational' attributes of sound with the source and the context in which it occurs.
4) A focus on how the sonification is presented (rather than represented), so that it preserves and emphasizes the physicality and the effects of sound (on listener, space, materials), not only its abstract informational value.

Table 1, inspired by Offenhuber (2023), recaps on the main differences between traditional data sonification and autographic sonification as it emerges from the analysis conducted in this paper.

Table 1 A comparison between Data Sonification and Autographic Sonification.

	Data Sonification	**Autographic Sonification**
Sound features	Acoustics & psychoacoustics	(Materializing) Sonic Indexes (e.g. reverberation, morphology, texture).
Sound matter	Non-speech audio	Any sound wave generated by a phenomenon and transmitted through a medium.
Relation to the phenomenon	Relations in a dataset are transformed into perceived relations in acoustic signals.	Sound is a tangible albeit ephemeral trace generated by a phenomenon, unmediated by abstract (numerical) data.
Relation with the listener	Semantic: The listener needs to know the code. Causal: The listener identifies the source of the sound. Reduced: The listener focuses on the material properties of the sound.	Causal: The listener identifies the source of the sound.
Role of design	The designer defines the rules that transform data values into acoustic values. The transformation must be systematic, objective, and reproducible.	The designer facilitates a listening experience that interprets sound events as traces of a phenomenon.

Traditional sonification methods tend to design *after-the-data* by defining rules that determine the acoustic properties of sound events based on the properties of a predefined dataset. Emerging autographic practices propose a *before-the-data* approach, where design is used to guide and orientate the unmediated sonic experience of the listener. These two

definitions might eventually expand to include a *design-in-between* approach, where the experience is partially data-driven - as in Wildfires, where the sonic material is extracted from real recording but modeled based on a pre-collected dataset - but where the listener is at the center, invited to explore the sonification as if it was the ephemeral trace of a real-world phenomenon.

4. Conclusions

In this paper, we analyze sonification cases from the Data Sonification Archive through the lenses of autographic design, an approach that considers sound as the 'datum', a material a trace of real-world phenomena that we can listen to, decode, and understand without the mediation of abstract representation. Broadening the current definitions of sonification, an autographic approach takes into account any type of sound events that is directly produced by a phenomenon (i.e., it does not exclude speech). Similarly, the ephemeral nature of sound is embraced as part of the material process that generates the acoustic traces of the phenomenon. How sound events behave in time and space is an informative aspect that the listener should take into account when trying to understand a phenomenon through its sonic manifestation.

Aware that autographic displays ``do not present conclusions but invite curiosity and causal reasoning, engaging the audience differently`` (Offenhuber, 2023), we propose an autographic approach to sonification as an effort to 'return to things' in a neo-phenomenological perspective (Anceschi, 1998) and put the listener at the center of a relationship with the world, through its sonic matter. Autographic sonifications encourage the audience to actively listen and interpret the (materializing) sonic indexes that are revealing of the relationship between a sound source and the environment. For instance, psychoacoustic and spectro-morphological, and architectural acoustic features (e.g., how sound waves are influenced by a physical space). A designer of autographic sonifications will focus on interpreting or shaping these characteristics so that the traces of the phenomenon, self-inscribed in the sound matter, can emerge. To do that, designers will need to learn and teach specific ways of listening to autographic sonifications, that are more than reverse-engineering the designers' encodings. Listening practices such as soundwalks, purposely guided to point towards a process of listening-as-knowing, could provide a method for preliminary training. Sonification design tools such as the Sonification Canvas (Lenzi & Ciuccarelli, 2024) that explicitly ask designers to reflect on their audience listening attitude (e.g., semantic, causal or reduced) might support an autographic sonification design process.

5. References

Aletta, F, Kang, J, Axelsson, Ö (2016). 'Soundscape descriptors and a conceptual framework for developing predictive soundscape models.' *Landscape and Urban Planning*, Volume 149, Pages 65-74. https://doi.org/10.1016/j.landurbplan.2016.02.001.

Anceschi, L. (1998) Che cos'è la poesia? Bologna: CLUEB.

Axelsson, Ö, Nilsson, M. E., and Berglund, B. (2010). A principal components model of soundscape perception. *J. Acoust. Soc. Am.* 128, 2836–2846. doi: 10.1121/1.3493436.

Barrass, S (1997). *Auditory Information Design*. PhD Thesis, Australian National University, Canberra.

Bellona, J. (2019). Wildfire. *Center for Environmental Futures, Andrew W. Mellon 2019 Summer Faculty Research Award*.

Chion, M. (1994). *The Audiovision: Sound on Screen*. New York, U.S.: Columbia University Press.

Dombois, F. (1999). Earthquake sounds. Webpage: https://shorturl.at/CORX4. Last accessed: October 30th, 2023.

Dombois, F. (2001). Using audification in planetary seismology. In Proceedings of the International Conference on Auditory Display (ICAD 2001). Espoo, Finland: July 29 - August 1, 2001. http://hdl.handle.net/1853/50660.

Dombois, F & Eckel, G. (2011). Audification. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, *The Sonification Handbook*, Chapter 12, pp. 301 – 323. Logos Publishing House, Berlin, Germany.

Duarte, CM, Chapuis, L, Collin, SP, Costa, DP, Devassy, RP, Eguiluz, VM, Erbe, C, Gordon, TAC, Halpern, BS, Harding, HR, Havlik, MN, Meekan, M, Merchant, ND, Miksis-Olds, JL, Parsons, M, Predragovic, M, Radford, AN, Radford, CA, Simpson, SD, Slabbekoorn,H, Staaterman, E, Van Opzeeland, IC, Winderen, J, Zhang, X and Juanes, F. (2021). The soundscape of the Anthropocene Ocean. *Science*: 371, eaba4658.

Economist, The & Siemens (2018). Reimagine the Game. Webpage. Last accessed: October 30th, 2023.

Enge, K, Rind, A, Iber, M, Höldrich, R, Aigner, W. (2023). Towards a unified terminology for sonification and visualization. P*ers. Ubiquitous Comput*. 27(5): 1949-1963.

Farina, A. (2018). Perspectives in ecoacoustics: A contribution to defining a discipline. Journal of ecoacoustics. *Journal of Ecoacoustics*.

Friedman, K. (2008). Research into, by and for Design. J. Vis. Art Pract. 2008, 7, 153–160, doi:10.1386/jvap.7.2.153_1.

Forensic Architecture (2014). The killing of Nadeem Nawara and Mohammed Abu Daher. Webpage: https://shorturl.at/aefJ7. Last accessed: October 30th, 2023.

Forensic Architecture (2016). Saydnaya - Inside a Syrian Torture Prison. Webpage: https://shorturl.at/aisN9. Last accessed: October 30th, 2023.

Forlano, L. (2017). Posthumanism and Design. *She Ji: The Journal of Design, Economics, and Innovation*, Volume 3, Issue 1, Pages 16-29, https://doi.org/10.1016/j.sheji.2017.08.001.

Giaccardi, E. & Redström, J. (2020). Technology and More-Than-Human Design. Design Issues 2020; 36 (4): 33–44. doi: https://doi.org/10.1162/desi_a_00612.

Haskell, D. (2022). Sounds Wild and Broken. Sonic marvels, evolution's creativity, and the crisis of sensory extinction. London: Penguin Random House.

Hermann, T.; Hunt, A.; Neuhoff, J.G. (2011). The Sonification Handbook; Logos Verlag Berlin, 2011; Vol. 1.

Hermann, T. (2008). Taxonomy and Definitions for Sonification and Auditory Display. In *Proceedings of the 14th International Conference on Auditory Display*. Paris, France.

Jeon M, Walker BN, Barrass S. (2019). Introduction to the Special Issue on Sonic Information Design: Theory, Methods, and Practice, Part 2. *Ergonomics in Design*. 2019;27(1):4 - 4

Kramer, G., Walker, B., Bonebright, T., Cook, P., Flowers, J., Miner, N., Neuhoff, J., Bargar, R., Barrass, S., Berger, J., Evreinov, G., Fitch, W., Grohn, M., Handel, S., Kaper, H., Leivkowitz, H., Lodha, S., Shinn - Cunningham, B., Simoni, M. and Tipei, S. (1999). The sonification report: Status of the field and research agenda. *Report of National Science Foundation*.

Imperial War Museum (2019). Sound Ranging Explained. Webpage: https://shorturl.at/fvC57. Last accessed: October 30th, 2023.

ISO 12913-1:2014 (2014). Acoustics Soundscape Part 1: Definition and conceptual framework.

Lenzi, S. & Ciuccarelli, P. (2024). Designing tools for designers: The Data Sonification Canvas'. Design Research Society Conference 2024. Design Research Society Conference: Boston2024. Northeastern University, Boston: June 25-30, 2024.

Lenzi, S., Ciuccarelli, P., Liu H., Hua Y. (2021). The Data Sonification Archive. Webpage: http://sonification.design. Last accessed October 27th, 2023.

Lenzi, S. & Ciuccarelli, P. (2021). Intentionality and design in the data sonification of social issues. Big Data & Society, 7(2). doi: 10.1177/2053951720944603.

Lenzi, S. (2021). Soundscapes in times of change. Webpage: t.ly/2nNSM. Last accessed: October 30th, 2023.

Lenzi, S, Sádaba J, Lindborg P. (2021). Soundscape in Times of Change: Case Study of a City Neighborhood During the COVID-19 Lockdown. *Front Psychol.* 12:570741. doi: 10.3389/fpsyg.2021.570741.

Lindborg, PM, Caiola, V, Chen, M, Ciuccarelli, P, Lenzi, S. (2024). Re(de)fining Sonification: Project Classification Strategies in the Data Sonification Archive. *Journal of the Acoustical Society of America*. In review.

Lindborg P, Lenzi, S, Chen M. (2023). Climate data sonification and visualization: An analysis of topics, aesthetics, and characteristics in 32 recent projects. *Front Psychol*. Jan 25;13:1020102. doi: 10.3389/fpsyg.2022.1020102.

Liu, X, Dong, J and Jeon, M. (2023). Robots' "Woohoo" and "Argh" can Enhance Users' Emotional and Social Perceptions: An Exploratory Study on Non-Lexical Vocalizations and Non-Linguistic Sounds. *J. Hum.-Robot Interact.* https://doi.org/10.1145/3626185.

Maskey, M & Maroune, A. (2023). From Data to Melody: Data Sonification and Its Role in Open Science. IMPACT Unofficial IMPACT Unofficial. Webpage: https://impactunofficial.medium.com/from-data-to-melody-data-sonification-and-its-role-in-open-science-6a7c955167cc. Last accessed: October 27th, 2023.

Nees, M. (2019). Eight components of a design theory of sonification. In *Proceedings of 25th International Conference on Auditory Display* (ICAD 20 19) 23 - 27 June 2019, Northumbria University, Newcastle upon Tyne, UK.

Neuhoff, J. G. (2019). Is sonification doomed to fail? In *Proceedings of 25th International Conference on Auditory Display* (ICAD 20 19) 23 - 27 June 2019, Northumbria University, Newcastle upon Tyne, UK.

Offenhuber, D. (2023). *Autographic Design: The Matter of Data in a Self-Inscribing World*. Introduction. Boston, Massachusetts: MIT Press.

Offenhuber, D. (2020). Data by Proxy - Material Traces as Autographic Visualizations. *IEEE Trans Vis Comput Graph*. Jan;26(1):98-108. doi: 10.1109/TVCG.2019.2934788.

Özcan E, Broekmeulen CLH, Luck ZA, van Velzen M, Stappers PJ, Edworthy JR. (2022). Acoustic Biotopes, Listeners and Sound-Induced Action: A Case Study of Operating Rooms. *International Journal of Environmental Research and Public Health*. 19(24):16674. https://doi.org/10.3390/ijerph192416674.

Pauletto, S. & Misdariis, N. (2023). The Audible Universe Workshop: An Interdisciplinary Approach to the Design and Evaluation of Tools for Astronomical Data Sonification. In *Proceedings of the International Conference on Auditory Display.* Norrkoping, Sweden: June 25th- July 1st.

Perera, J. (2021). First Wave: A sonification of deaths from Coronavirus in the UK over 154 days, from 2nd March to 2nd August 2020. Webpage: https://www.jamieperera.com/coronavirus-sonifications. Last accessed: October 30th, 2023.

Phillips, JN, Termondt, SE and Clinton, FD. (2021). Long-term noise pollution affects seedling recruitment and community composition, with negative effects persisting after removal. In *Proc. R. Soc.* http://doi.org/10.1098/rspb.2020.2906.

Roddy, S. & Bridges, B. (2020). Mapping for meaning: the embodied sonification listening model and its implications for the mapping problem in sonic information design. *J Multimodal User Interfaces* 14, 143–151. https://doi.org/10.1007/s12193-020-00318-y.

Roddy, S., Bridges, B. (2018). Sound, Ecological Affordances and Embodied Mappings in Auditory Display. In: Filimowicz, M., Tzankova, V. (eds) *New Directions in Third Wave Human-Computer Interaction: Volume 2 - Methodologie*s. Human–Computer Interaction Series. Springer, Cham. https://doi.org/10.1007/978-3-319-73374-6_12.

Roddy, S. & Furlong, D. (2014). Embodied Aesthetics in Auditory Display. *Organised Sound.* 19 (Special Issue 1. Sonification):7-77.

Scaletti, C. (1994). Sound Synthesis Algorithms for Auditory Data Representations. In *Auditory Display. Sonification, Audification, and Auditory Interfaces*, edited by G. Kramer. Reading: Addison - Wesley Publishing Company, 223 – 251.

Severino, M K & Winter, H T. (2020). Eclipse Soundscape. Webpage: https://eclipsesoundscapes.org/. Last accessed: October 30th, 2023.

Seznec, Y. (2020). deathIncrease. https://www.yannseznec.com/works/deathincrease/. Webpage: Last accessed: October 30th, 2023.

Smalley, D. (1986). Spectro-morphology and Structuring Processes. In: Emmerson, S. (eds) The Language of Electroacoustic Music. Palgrave Macmillan, London. https://doi.org/10.1007/978-1-349-18492-7_5.

Torban, Am (2021). Episode 66: How to Turn Data into Music. Featuring Duncan Geere and Miriam Quick. Data Viz Today. Webpage: https://dataviztoday.com/shownotes/66. Last accessed: October 27th, 2023.

United Visual Artist and Fondation Cartier (2016). Webpage: https://vimeo.com/364836175. Last accessed: October 30th, 2023.

van Cruchten, M & Kloos, F. (2020). Amsterdam in and out of lockdown. Webpage: t.ly/fvyxR. Last accessed: October 30th, 2023.

Velasco Pufleau, L. (2023). Listening is Action: A Soundwalk with Hildegard Westerkamp. *Performance Philosoph*y, 8(1), pp. 86-100. 10.21476/PP.2023.81430.

Vickers, P. and Barrass, S. (2011). Sonification design and aesthetics. In Hermann, T., Hunt, A., Neuhoff, J. G., editors, *The Sonification Handbook*, Chapter 7, pp. 145 – 171. Logos Publishing House, Berlin, Germany.

Vickers, P. & Hogg, B. (2006). Sonification abstraite/sonification concrète: An “æsthetic perspective space” for classifying auditory displays in the ars musica domain. In Proceedings of the 12th International Conference on Auditory Display; Georgia Institute of Technology: London, UK, June 2006; pp. 210–216.

Wheeler, W. M., MacCoy, C. V., Griscom, L., Allen, G. M., & Coolidge, H. J. (1935). Observations on the Behavior of Animals during the Total Solar Eclipse of August 31, 1932. *Proceedings of the American Academy of Arts and Sciences*, 70(2), 33–70. https://doi.org/10.2307/20023118.

Wirfs-Brock, J, Fam, A, Devendorf, L and Keegan, B. (2021). Examining Narrative Sonification: Using First-Person Retrospection Methods to Translate Radio Production to Interaction Design. *ACM*

Trans. Comput.-Hum. Interact. 28, 6, Article 41 (December 2021), 34 pages.
https://doi.org/10.1145/3461762.

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