Sounding Human with Data: The Role of Embodied Conceptual Metaphors and Aesthetics in Representing and Exploring Data Sets

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Introduction

Auditory display is the use of sound to present information to a listener. *Sonification* is a particular type of auditory display technique in which data is mapped to non-speech sound to communicate information about its source to a listener. Sonification generally aims to leverage the temporal and frequency resolution of the human ear and is a useful technique for representing data that cannot be represented by visual means alone. Taking this perspective as our point of departure, we believe that sonification may benefit from being informed by aesthetic explorations and academic developments within the wider fields of music technology, electronic music and sonic arts. In this paper, we will seek to explore areas of common ground between sonification and electronic music/sonic arts using unifying frameworks derived from musical aesthetics and embodied cognitive science (Kendall, 2014; Lakoff & Johnson, 1999).

Sonification techniques have been applied across a wide range of contexts including the presentation of information to the visually impaired (Yoshida et al., 2011), process monitoring for business and industry (Vickers, 2011), medical applications (Ballora et al., 2004), human computer interfaces (Brewster, 1994), to supplement or replace visual displays (Fitch & Kramer, 1994), exploratory data analysis (Hermann & Ritter, 1999) and, most importantly for the current milieu, to reveal the invisible data flows of smart cities and the internet of things (Rimland *et al.*, 2013; Lockton et al., 2014). The use of sonification as a broad and inclusive aesthetic practice and cultural medium for sharing, using and enjoying information is discussed by Barrass (2012). As networked smart societies grow in size and becomes increasingly complex the ubiquitous invisible data flows upon which these societies run are becoming hard to monitor and understand by visual means alone. Sonification might provide a means by which these invisible data flows can be monitored and understood.

In order to achieve this type of usage, sonification solutions need to be applicable to and intelligible to an audience of general listeners. This requires a universal shared context by which sonifications can be interpreted. Embodied cognition researchers argue that the shared physical features of the human body, and the capacities and actions which our bodies afford us, define and specify mid-level structures of human cognitive processing, providing shared contexts by which people can interpret meaning in and assign meaning to their worlds (Lakoff and Johnson 1980; 1999; Varela et al., 1991). At present, embodied perspectives on cognition are infrequently explored in auditory display research, which tends to focus on either higher level processing in terms of language and semiotics (Vickers, 2012) or lower level processing in terms of psychoacoustics and Auditory Scene Analysis (Carlile, 2011).

Sonification as Data-Framing: Structural, Narrative, Aesthetic.

Broadly speaking, sonification is useful when representing/investigating data sets which embody significant temporal variation. Sonification gives access to a temporal evolution (and can speed up or slow down temporal processes, depending on the nature of the data sampling). This temporal variation implies narrative and causality; the mapping of data to temporally–evolving sound may reveal significant events through audible significant deviations within the sound. In this way, sonification has been used within the context of data analytics using data from business (Worrall, 2009) or socioeconomic data and may be helpful in searches for patterns within data which may not be as apparent using visual representational strategies. The temporal and frequency sensitivity of the auditory system may tend to make sudden (transient) differences in the formal structure of incoming signals quite obvious, as long as basic sensitivity/just noticeable difference (jnd) ranges are taken into account (or various temporal/frequency scale mappings are investigated).

Fitch and Kramer (1994) provide an example of a rich mapping strategy for an auditory display that is designed to help users monitor and respond to medical complications across eight physiological variables of a digital patient. Two physiological variables are mapped to control sounds to which they resemble. Heart rate was mapped to a rhythmic thudding sound and breathing rate was mapped to a breath like sound. Atrio-ventricular dissociation and fibrillation were mapped to modulate the heart rate sounds in the same way these factors modulate a heartbeat in the real world. These mappings leveraged the users previous knowledge embodied knowledge of human anatomy. Four other mappings, body temperature to a filter applied to the heart beat sound, blood pressure to the pitch of the heart sound, brightness of the heat sound to CO_2 level and pupillary reflex to a high pitched tone, were abstract and so required learning on the part of the listener. Empirical evaluation showed the auditory display system to be more effective than a visual display for helping users monitor and respond to changes in the condition of the digital patient.

Sonification practices are prevalent throughout science and the arts. This mixed appeal has led to its use as a public outreach tool for popularising scientific research (Supper, 2014). The search for the Higgs Boson at CERN's Large Hadron Collider installation in Geneva is embracing sonification as a means of public outreach[1]. Researchers at NASA have are also making extensive use of sonification as a public outreach tool[2]. They have also made new discoveries using sonification, which would not have been possible through visual media alone[3]. Researchers at the

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[1] http://tedxtalks.ted.com/video/Listening-to-data-from-the-Larg

[2] https://www.youtube.com/watch?v=kcqiLvHiACQ

[3] http://www.economist.com/news/science-and-technology/21694992-scientific-data-might-be-filled-important-things-waiting-be-discovered

Climate Change Research Center used sonification techniques to create The Climate Change Symphony in order to communicate climate change data to the public[4].

Sonification is emerging as a critical technique for understanding and communicating large complex data flows in the context of increasingly networked and data-driven societies (Rimland et al, 2015; Hermann and Hunt, 2005). This has resulted in increased interest in sonification as a tool for observing network activity patterns and monitoring network security, as evidenced by a number of notable contemporary projects (see Worrall, 2015; Wolf and Fiebrink, 2013; Fairfax et al, 2014). A number of artists have used sonification techniques to reveal the hidden data flows of smart cities and the IoT. Kasper Fangal Skov's Sonic Particles 2.0 project sonifies data provided by smart sensors placed in major cities for Data Canvas' Sense Your City competition[5]. Stanza, a UK based sound artist, makes extensive use of environmental sensor data in his artistic sonification practices[6]. The Social City Detector project and the Citigram project (Park et al, 2013) used sonification to integrate the digital and physical layers of the city by making social data visible through sound[7]. The Phantom Terrains project used a repurposed hearing aid to reveal the electromagnetic signals of the wireless networks, which pervade the contemporary built environment.[8] Composers Natasha Barret and Andrea Polli make extensive use of the sonification of environmental data in their compositional practices, often with the activist intent of raising awareness about important environmental issues (see Barret and Mair, 2014; Polli 2012).

Beyond the arts, technology researchers are also examining the use of sonification practices to help reveal, analyse and understand the rich data flows of the IoT. Eva Sjuve's (2015) Metopia is a research project that explores sonification as a medium for representing data in the context of the IoT and Big Data. The Sound of Things project aims to add sound to the IoT. It also reveals the invisible IoT networks of smart cities through novel applications including agogic maps[9], geo located tweet sonificaiton[10]. A number of hardware applications that generate live sonified sound streams when physically attached to IoT devices have also emerged in recent years (Barrass and Barrass, 2013; Lockton et al., 2014).

Barrass (2012) discusses how the current aesthetic turn in the field is driving the adoption of sonification as a mass cultural medium by making sonification more appealing to the listener. Rimland et al (Rimland et al, 2015) discusses how as societies become increasingly networked and the IoT grows in size and complexity sonification will be needed as a means of making sense of the complex data flows that can no longer be effectively understood by visual means alone. Listeners will turn to sonification for enjoyment, aesthetic appreciation and to learn about the data sources

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[4] http://www.scidev.net/global/data/multimedia/climate-symphony-data-sound.html

[5] http://www.kasperskov-audiodesign.dk/projects_SonicParticles2.html

[6] http://www.stanza.co.uk/emergentcity/?tag=sonification

[7] http://thecreatorsproject.vice.com/the-makers-series/the-makers-series-social-city-detector

[8] http://phantomterrains.com/

[9] http://www.soundofthings.org/Proj/AgogicMaps.html

[10] http://www.soundofthings.org/Proj/SonifyTweet.html

represented therein. In the coming years sonification will become a popular method by which the invisible data flows of smart cities and smart environments are revealed and by which the digital environment is manifest in the physical environment.

What some of these applications illustrate is that sonification may bring with it a consideration of aesthetics; how data may be rendered in sound such that its structure is not only accessible, but 'attractive'/'engaging', perhaps even 'beautiful'…certainly, sufficiently engaging to hold interest over longer time-spans spent interrogating data sets in this way. More broadly, the sense of narrative causality and dynamism within sonification makes it an emotive technique; data may become more 'impactful', less 'neutral', when perceptualised. The temporal evolution and frequency variation of sonification may be seen as corresponding to a basic model of emotion (arousal/valence), which has previously been identified as one underpinning music's emotional efficacy (Huron, 2006). Technology artist Luke Dubois[11] has made the point that music is an 'emotional technology', a data–art…the similarity relationship between sound–data–art (sonification) and music may also run in the opposite direction! As such, both (a) basic structural framing (accessible to auditory parsing processes), and (b) narrative/affective qualities, may be relevant considerations when exploring sonification strategies and may be unified within an aesthetic domain.

Care must be taken when considering aesthetics in a sonification context and to this end it is useful to draw a sharp distinction between aesthetic (for structural ends) and cosmetic sonification practices. Cosmetic sonification practices simply aim to produce an attractive and easily listenable sonic result while aesthetic sonification practices aims to frame and shape the qualities of the listeners' sonic experience as a means of communicating information about a data source. While it is important that a sonification should sound pleasing and be easy to listen to, especially if a listener is expected to attend to it repeatedly or for an extended period of time, aesthetic considerations reach far beyond this concern to the framing and shaping of the listeners very experience of the sonification, and so their understanding of the original data. It has been argued that the aesthetic dimensions of sound are those best suited to the communication of data in a sonification context (Roddy & Furlong 2014; Roddy, 2015).

Even if some sort of narrative of dynamic change is obvious via the audible changes within a sonification 'signal', does that render the sonification inherently meaningful? How might abstract data be converted to sound such that the structure of the data is accessible to interpretation? There is no uniform consensus in terms of strategies; sonification designers must currently answer questions of *mapping* (transposing from data structures to sound parameters) during the design phase (Flowers, 2005). Successful sonification is not simply a straightforward case of mapping data to isomorphic sound parameters (an approach which is basically formalist; one which found favour in early explorations of auditory display techniques). Listeners may not always be able to easily interpret sounds in the absence of consideration of certain perceptual–conceptual predispositions. For example, certain dimensions within a sonification, whilst isomorphic in terms of a dataset, may appear 'counter–intuitive'; for example, an increase in a dimension could be represented by a similar change in magnitude of the frequency of a tone, but if the

[11] https://www.ted.com/talks/r_luke_dubois_insightful_human_portraits_made_from_data?language=en

resulting parametric change were a *decrease* in frequency (albeit with similar magnitude), the polarity of the sonification might appear to be reversed. This phenomena is explored in depth by Walker (2000) and Roddy (2015)

The Mapping Problem and the Dimensions of Sound

The mapping problem represents a significant open problem within the field of auditory display (Worrall 2009). It was first introduced by Flowers (2005) who criticised the central claim of auditory display research: that submitting the contents of complex data sets to sonification will necessarily lead to the emergence of meaningful relationships in the data. In reality, this is rarely the case. It has been argued that the dominant conceptualisation of sound in the West is tailored to describing the physical acoustic waveform and its perceptual correlates but that it cannot adequately account for how sound communicates information to a listener (Truax, 1984). An analogous argument has been made about Western art music, which reduces the rich multi-dimensional spectra of musical and sonic possibilities to just three primary dimensions (pitch, duration and timbre) which can be easily represented on a written score. Worrall (2010) argues that this reductive approach to music is informed by the computationalist theory of mind and auditory display researchers often impose these same limits upon their own work by using the music and sound synthesis software developed for these paradigms, failing to account for the role of the embodied performer and the perceptual and cognitive configuration of the embodied listener. The mapping problem may be seen as the result of a tendency amongst auditory display researchers to adopt the acoustic/psychoacoustic and Western art music paradigm when specifying sound, thus imposing a set limits on how sound can be conceptualised, parameterised and used to communicate data to a listener. This *psychoacoustic paradigm* can result in auditory display solutions that are not designed to exploit the full range of communicative dimensions provided by sound and music and which do not account for the perceptual and cognitive faculties of the listener.

This issue is exemplified in one of the complications resulting form the mapping problem: *dimensional entanglement*. This is the intermingling of auditory dimensions traditionally assumed to be separable within the computationalist framework. For example, in *PMSon* pitch, loudness, duration and timbre are often mapped to unique data (see Grond and Berger, 2011). However, these dimensions are not perceived independently of one another but are perceived as individual aspects of larger sonic wholes. They are integrated and changes in one dimension can cause changes in another making it confusing for the listener to interpret a *PMSon* sonification during listening (Peres and Lane, 2005; Worrall, 2010; Peres, 2012). Ideas of discrete sonic dimensions such as timbre, pitch and amplitude have little to do with the listeners' everyday experience of sound. From the perspective of embodied cognition and the ecologically–grounded theories of perception which have influenced it, these are not meaningful dimensions along which to sonify data. Mapping data to such parameters is not *sonification* but *acoustification*, the straightforward mapping of data to acoustic features. This results in mapping strategies that seeks to communicate data to a listener by means of acoustic symbols that are seen to be made meaningful through the application of some internal set of syntactical rules in the mind (cognitive grammars). Ryle (1949) and Searle (1980) and Harnad (1991) have variously shown that meaning cannot be generated for a listener in this way because, as Dreyfuss (1965) and Polyani (1966) point out, objects of meaning require a background context against which their meaning can be assigned, and the act of processing information provides no such context.

However, contemporary sonification research and practices seek to solve the mapping problem whilst preserving the structure of the data during encoding so that it can be accurately represented to a listener. Much contemporary sonification takes place in a context which recognises *ecological* perspectives on the problem; that the very act of encoding data into sound may also allow for aspects of its structure to be revealed via a listener's engagement (Walker & Kramer, 2004). Ecological, in this sense, situates the problems of perception within its inter-dependent relationship with the sensory environment. In this context, the *perceptualization* (Hermann, Hunt, Neuhoff, 2011) of data is important because different sensory modalities may be useful for revealing different aspects of data structures. The heuristic processes of parsing environmental sound and music (Bregman, 1990) may therefore be particularly helpful in a search for meaningful patterns within data sets.

From this contemporary perspective, sonification may be seen as a structural investigation *at both the encoding and decoding stages*. Whilst much attention has previously been focused on strategies for *encoding* (also referred to here as *mapping*), we believe that considering these alongside frameworks for *decoding*, based on contemporary theories of embodied auditory perception and cognition may be of great significance for improving the efficacy of sonification. While ecological approaches to sonification have been explored by a number of researchers in the field, the current paper is concerned with approaches informed by embodied cognitive science and musical aesthetics.

An additional problem with formalist auditory display/sonification approach is its treatment of complexity. The discretized treatment of these materials also conforms to a computational–formalist information processing paradigm (the Shannon–Weaver model of communication (Shannon & Weaver, 1949) which considers (discrete) channels/dimensions with particular bandwidths, influenced by external sources of noise (via signal interference, or, from some broader perspectives, a lack of contextualization allowing reconstruction of an ambiguous communication). A formalist mapping approach based on the assumption of discrete dimensions may be viewed as encompassing such a set of discrete channels, with the idea of additional noise/ambiguity which that entails. An early commentary on the channel capacity/mapping problem is to be found in George Miller's[12] commentary on human information–processing and recognition abilities via working memory, 'The Magical Number Seven, Plus or Minus Two' (Miller, 1956). Miller's work was informed by an analysis of Pollack's (1952) early auditory display studies which showed a communicative potential of c. 2.5 bits (6 elements/values channel capacity) for

[12] Godøy *et al.* (2010) argues that coarticulation, the fusing together of smaller units into larger wholes, is critical to Miller's theory of information chunking. While the miller limit might define the mechanical limits of perception, at the level of musical/sonic experience the information in the chunks is co-articulated so that the listener can
experience rich musical imagery and gestures.

unidimensional, i.e. single-modality, stimuli. Miller analyses the experimental results of various contemporaries who were investigating auditory perception as an information processing task to conclude that, for *unidimensional judgments,* working memory, the kind of memory responsible for the short-term holding and processing of information, has a capacity of 7 ± 2 chunks, or discrete objects, of information. He argues that a listener can identify and remember roughly 7 ± 2 distinct pitches, amplitudes, rates of interruption, on-time fraction, durations, and spatial locations when presented as domains for representing data. Miller also noted that information capacity could be increased through additional parsing known as *chunking*; items to be remembered could be associated with one another, freeing capacity in formal, working memory.

This case is reserved for high–level cognition of precise rank-ordering relationships, etc. Although it may be tempting to take this as a hard–and–fast rule (within its own somewhat imprecise boundaries), it should be noted that Miller states clearly that this only holds true for unidimensional stimulus cases and cannot describe the parsing of multidimensional stimuli e.g. facial recognition, or, indeed, more complex musical cases. For example, even in more 'unnatural' formalist multidimensional cases, such as integrated frequency and amplitude displays (Pollack, 1953), Miller comments that capacity has increased beyond the 7+-/-2, albeit not in an obvious pattern noting the complexity of music[13]. Our own perspective is that such a comparably unpredictable increase in capacity is due to ecological concerns.

Although the psychoacoustic paradigm expanded to encompass ecological psychoacoustics in auditory display research (Walker and Kramer, 2004), the methods employed in this framework draw heavily from the *operationalist* framework developed by Stanley S. Stevens, the founder of psychoacoustics. Operationalism is a form of positivism which holds that a concept that cannot be reduced to a measurement is meaningless. Stevens developed his cross-modal matching and magnitude estimation techniques in order to reduce psychophysical information, e.g. heard sounds, to simple measurements. However as Dreyfus (1965), Searle (1980), Johnson (1987) and Polyani (1966) point out a large spectrum of human experience and human knowledge cannot be reduced to simple measurements, an issue which Miller's (1956) account of memory and information processing grapples with even as it seeks ways to quantify its capacity.

It is in these contexts that we argue that one crucial avenue to consider in the development of sonification is an ecologically–considered model of auditory dimensions which is meaningful to a listener as it aligns with the perception and interpretation strategies which we use within our everyday environmental experience. For more richly perceptualised sonification, as opposed to the narrower discretised signals of auditory display, we are not concerned with chunking, per se, but with pattern and correlation recognition, an entirely different problem within a perceptual, rather than formalist, context. Leveraging our (integrative) cognitive–perceptual parsing systems may help us identify meaningful patterns within multiparametric data

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[13] Pollack (1954) saw 6 different acoustic variables of 5 different values each, yielding 7.2 bits (c.150 values), a value which may be seen closer to real-world cases of cognitive–perceptual recognition abilities and closer to what might be viewed as reasonable 'channel capacities' for music (note how close this figure is to the 7-bit range of the MIDI (Musical Instrument Digital Interface) standard.

(if degree of change is relatively constrained). It is in this context that we contend that an ecological perspective on the mapping problem is crucial in certain contexts: those where the data is mapped for clear communication; for example, for didactic purposes. In this context, our interpretative framing of multiparametric data may be aided by a consideration of models (schemas) derived from common perceptual experience cases. These may, in part, be explained as the 'environmental regularities' which underpin heuristic principles within our perceptual processes. But these regularities are more basic structural framing principles rather than necessarily supporting *interpretative framing*. To consider how interpretative framing beyond the basics happens, we may need to consider how our experience of the environment impacts upon our conceptual systems.

Sense-making in Sound from Perception to Cognition

To restate our perspective on sonification, it is our contention that sonification is not just rendering, but also the act of framing data as it is 'filtered' through our perceptual transduction and expectancy schemas; our 'sense-making' apparatus. This *perceptualization* (Hermann, Hunt, Neuhoff, 2011) is thus more than just a mapping from one domain to another, but also entails an act of structural framing which derives from our perceptual systems. As such, approaching sonification simply from the perspective of formalism as opposed to being *perceptually and cognitively informed* may impede its ability to meaningfully represent data (Worrall has compared with serial music 'problem', see also (Lerdahl, 1988, McAdams, 1987).

Perceptualization involves not only leveraging familiar environmental contexts but also leveraging from embodied contexts in ways that are compatible with the faculties and processes of embodied cognition. Patterns within complex data may be revealed by rich mappings which are engaging enough to support careful listening and communicative enough to furnish the listener with the required information. But, beyond even these concerns, there is the question of how conceptual framings arise out of the basic perceptual–structural framings through which we approach sonification. Theories of embodied cognition place the emergent patterns of experience that arise in the interaction between structural regularities of the environment and the structural regularities of the human body at the center of the 'problem' of conceptualisation.

Electroacoustic Music Theory, Embodied Cognition and Sonification

Embodied cognitive science examines the relationship between the body and mind with a specific focus on how the physical and perceptual dimensions of the human body shape and define the cognitive processes and conceptual systems of the human mind. It emerged in the late 20th century as researchers began to study emotion, culture and aesthetic experience. It has shaped the development of a number of important disciplines related to sonification research and practice, e.g. computer science, artificial intelligence and human computer interaction (Brooks, 2003; Dourish, 2004; Imaz and Benyon, 2007), computer music (Leman, 2008; Klemmer *et al.*, 2006), cognitive sciences (Varela *et al.*, 1991), visual perception (Noë, 2009), aesthetics (Johnson, 2013), music (Godøy, 2006;, 2005; Brower, 2000; Larson, 2010; Cox, 2001), linguistics and philosophy (Lakoff and Johnson, 1999).

Embodied cognition researchers have presented a number of theoretical models which describe how the embodied mind perceives meaning in and applies meaning to it's world. Image schemas were first introduced by Lakoff and Johnson (1987) and can be thought of as 'gestures of thought' in that they are basic gestural patterns derived from sensorimotor experience which we draw upon to structure our thinking and conceptual systems. The process by which these basic patterns of experience are imported into cognition is referred to as conceptual metaphor (Lakoff and Johnson 1980). The process by which multiple mental spaces are integrated to create new mental content s referred to as conceptual blending (Fauconnier and Turner 2002). A number of researchers have described musical listening and composition in terms of embodied schemata, conceptual metaphors and conceptual blends: Kendall (2014), Cox (2000), Brower (2000); Adlington (2003) Godøy (2003; 2006) Wilkie et. al. (2010). These thinkers make the argument that the embodied components of cognition represented in these theoretical models play a key role in the listener's experience of music. In electroacoustic music theory, Spectromorphology is a descriptive framework for electroacoustic music consisting of detailed categorisation schemes deriving from basic gestural shapes called primal gestures that are extended to add a meaningful low-level organisational structure to musical domains (Smalley, 1997).

Sound(ing) Schemas and Embodied Functions in Electronic/Electroacoustic Music

Previous work by one of the authors (Graham and Bridges 2014a; 2014b) has investigated points of compatibility between Smalley's spectromorphology and the embodied image schema theory of Lakoff and Johnson. They argue (*ibid.*) that Smalley's gestural surrogacy and the dimensions of his gestures are compatible with image schema theory and its extension by Johnson (2007) in terms of *qualitative dimensions of movement* (essentially, gestural details of more regular or chaotic behaviour which alter some of the contours within image schemas).

Particular points of comparison between Smalley (1997) and Lakoff and Johnson's work, especially its extension by Johnson (2007):

- **General:** environmental models/embodied–ecological models of causality, ideas of musical 'forces' based on environmental analogues
- **General:** idea of 'embodied functional associations' of particular movements
- **Specific:** image schema structures (cycles, verticality, source–path–goal, container) identifiable within spectromorphologies
- **Specific:** dimensions of Smalley's sound gestures are similar to Johnson's qualitative dimensions of movement

The similarity between the dimensions of Smalley's sound gestures (termed *energy–motion* profiles) and Johnson's *qualitative dimensions of movement* can be seen below (Bridges and Graham, 2014a).

Johnson (2007)	Embodied Association	Smalley (1997)
Tension	Rate–effort=>overcoming inertia	*Motion rootedness*
Projection	Sudden rate-change / transient movement	*Motion launching*
Linearity	Coherence of path	*Contour energy/inflection*

Table 1.1 *Embodiment and Spectromorphology*

Not only are these dimensions of movement similar in terms of the division of embodied associations, but they also relate closely to the basic schematic forms of verticality and source–path goal. Smalley's logic of environmental causality sees certain sound gestures as embodying more rootedness or dynamism (projection/motion launching). We believe that these ideas of certain timbres as providing temporal structural dynamics may help us to develop more convincing 'sonic narratives' using data if theories such as spectromorphology and exploratory practices within electronic music can help to move us in the direction of embodied theories of musical timbre.

This emphasis on physicality within novel musical structures is also to be found beyond the world of electronic and electroacoustic music. Whilst common practice tonal music could be said to be based on structures explicable via the metaphor *Music–as–Moving–Force* (Johnson, 2007), Adlington (2003) explores image schema theory and contemporary music from the perspective that salient metaphors may relate more to ideas of changes of material and changes of physical state. The key developmental aspect which this highlights for our present purposes is that sonic 'image' schemas may be best viewed as temporally dynamic and morphologically/structurally plastic.

There is much still to explore in terms of how the specific domains of sound and music can be addressed via image schema theory. The common auditory–perceptual affordances of stream segregation and integration (Bregman, 1990) and the material metaphors of *glitch/rupture*, stretching and *bouncing/inertial effects* which are observable in a variety of contemporary electronic musical processes have the potential to be useful in sonification mappings (indeed, where these configurations occur unintentionally within existing sonifications, they may already act as clues to significant elements within the data). Sound's perceptual–ecological *interpretative frames* (contextual framing) occurs within commonplace perceptual experience due to the alignment of perceptual–heuristic processes with 'environmental regularities' (Bregman, 1993). Combining these inbuilt dynamics with more attention to potential embodied timbral/textural mappings could lead to a much more sophisticated integrating approach which avoids the obscuring of meaningful sonic dimensions behind inappropriate formal models. Exploratory creative processes which investigate embodied mapping strategies may help to suggest further avenues for the development of accessible sonic mappings.

A Consideration of *The Human Cost*: A Data-driven Composition Using Embodied Sonifiction Techniques

The Human Cost is a piece of data driven music composed by one of the authors (see Roddy, 2015), in which principles from embodied cognitive science are applied to organise mapping strategies from data to sound in a sonification context. Some of the embodied dimensions of this piece are considered in this section. The piece is intended to communicate a sense of the human cost of Ireland's economic recession.

The Human Cost was motivated by Smalley's statement that "In electroacoustic music the voice always announces a human presence" (Smalley, 1996). It was thought that as result the human voice might prove effective for representing data which measured the lives and behaviors of people. As such it was decided to sonify socioeconomic data sets from the period of Ireland's economic crash and recession. Deprivation, unemployment, emigration and GNP rates in Ireland from 2007 to 2012 were chosen as data sets for sonification. Rich multi-layered mapping strategies were employed to sonify this data. GNP is mapped to control a parameterised sounding object intending to reflect the sound of a heartbeat as GNP falls the heartbeat slows and as it rises the heartbeat increases. The choice of the heartbeat sound to represent GNP data was informed by White (2003) who argues that the economy is often conceptualised as a living organism. Deprivation, unemployment and emigration are mapped to control the prosodic features of three synthesised vocal simulations. The simulation to which the emigration rate was mapped acts as a "lead line" and the pitch and prosodic content of the vocal gesture are modulated to imitate the kinds of structure found in the old Irish laments, a type of song sang at a wake, a kind of funeral celebration which was often held to honour either a deceased relative, or a relative who was emigrating with no prospect of return.

Laments represent a cultural connection with the historical (and contemporary) experience of the emigration of the Irish Diaspora, cultural forms in which the singer's personal experiences of the passing or emigration of a loved one are expressed and communicated through vocal gesture. This transduction of human experience to physical, sound-producing gestures represented a useful physical-emotive mapping of relevance to the data sonified. The data is mapped so that the lead voice takes the foreground while the other two voices present a form of backing and the heartbeat performs a grounding percussive role in the piece. Deprivation rate and unemployment are mapped to these backing voices. Data is mapped to control the vowel shape in each vocal simulation so that as the economy worsens the open vowel sounds shift to closed vowel sounds to communicate a sense of tension. It is also mapped to spatial parameters so that both vocal simulations move through space and as the data increases and decreases the speed at which they move through space also increases and decreases creating a sense of frenzy in the piece as the economy crashes!

Conclusion

There is more to sound and music than pitches, durations, timbres and amplitudes. Sound is a powerful medium for the representation of data precisely because of its communicative dimensions; some of which are unaccounted for in standard sonic models based on discrete dimensions and parameterisation.

We have argued that a new conceptual model and specification of sound which recognises the embodied and aesthetic dimensions of sound is crucial to the development of effective data to sound mapping strategies. If sonification involves the mapping of data to sound for the purposes of communicating information about a data-source, this necessarily re-frames the information in the data in terms of the embodied and aesthetic and dimensions (and dimensional integrating effects) of the chosen sound materials. Such a process of reframing has the potential to integrate insights from a diverse range of sonic practices and theories, from embodied cognitive science and ecological psychology to electronic/electroacoustic music composition and production.

Framing of this nature can be used to ensure that sonification mapping strategies are a good fit for the listener's cognitive meaning-making faculties, thus supporting the efficient communication of the data. They can also be used to explore emotional and affective dimensions to a sonification, thus presenting a richer representation of the data than would otherwise be possible. The development of sonification within this context is best seen as an integration of the arts and sciences as their interests intersect within the spheres of sound, perception and meaning–making.

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