TWICE STEPPED IN STILL WATERS: SONIFICATION AND INTERDISCIPLINARITY AS ARTISTIC RESEARCH

Jorge Boehringer

Research Associate,
School of Arts and Cultures,
Newcastle University
Newcastle Upon Tyne, UK
Jorge.boehringer@newcastle.ac.uk

ABSTRACT

Real-time EEG and sensor data sonification have been researched extensively. New implementations of these technologies in the fields of live electronic music performance and sonic art generally focus on instrumentalising brain waves as an interface, or are concerned with controlling brain waves through biofeedback. *Twice Stepped in Still Waters* is instead concerned with using bio and sensor feedback as a focused framework accommodating phenomenological listening for the performer. Furthermore, when presented before an audience, this activity results in circumstances for sound and listening (music). Currently available high-resolution consumer devices and open-source software have now rendered these technologies accessible to a wide pool of researchers from a variety of fields. The present work uses sonified real-time EEG and accelerometer data to situate phenomenological concerns of the performance situation within the field of artistic research. Discussion of the technical development and artistic context for the piece reveals a broad interdisciplinary scope. *Twice Stepped in Still Waters* may be therefore read as a case study offering an implementation and a performance methodology for sonification and focused listening afforded by these sensor technologies. Variations on the approaches described may be applied by other investigators working within or outside of the domain of artistic research.

1. INTRODUCTION

Twice Stepped In Still Waters is a variable length performance for soloist and live electronic sound. The performer sits before or within the audience, becoming as still as possible in mind and body. A bank of electroencephalography (EEG) sensors worn on the head collect data from the performer. The performer also holds a small white box. The box is supported from beneath with the tips of the fingers of both hands (Fig 1). The box contains a device housing three accelerometers, oriented orthogonally in three dimensions. Data from the accelerometers and EEG sensors are transmitted to a computer running Pure Data (Pd) [1] for further processing, sonification, and output to loudspeakers. Currently, the piece is performed in stereo, while a version for flexible output on a variety of spatial sound systems is in development.

Interdisciplinarity is fundamental to both sonification and artistic research [2,3,4,5]. A discussion of the process and technology used to create the sonification performance piece *Twice Stepped in Still Waters* exemplifies interdisciplinary research with the primary output in the field of performance. Interdisciplinarity in this work derives from methodologies and technology developed from research in auditory display, interactive art, music, meditation, neuroscience, gaming, and psychology. *Twice Stepped in Still Waters* serves as a case study for the use of sonification in the field of the performing arts. Key examples of the use of open-source technologies to apprehend and sonify data for cross-disciplinary use feature in the discussion.

Figure 1. Performance position: *Twice Stepped In Still Waters.*

2. BACKGROUND

2.1. Technical and Conceptual Context For this Project

While a great deal of work has been done with real-time EEG sonification in the field of auditory display [6], it has not been undertaken with phenomenological considerations arising in artistic performance settings as primary focus, nor with artistic output as a primary research *event*. The present research is referred to as an 'event' in that this performance requires that it is enacted in real-time before an audience [7]. The sonic output of the piece is experimental in that it is indeterminately derived from brain activity and bodily movements of the performer. The prescribed circumstances for this work to take place require a collision of personal and public space.

As an activity whose primary output is sonic, public, and occurring in real-time, this work is well situated in the field of musical performance [8]. In experimental artwork the composer or artist establishes circumstances in which a range of possible outcomes may be enacted, rather fabricating an explicit set of anticipated compositional outputs [9]. Experimental artistic activity is defined by its purpose or object (which may simply be to create sounds [10]). Artistic research questions evolve as they are being explored. A succinct statement of the notion of 'experiment' as applied to an artistic context is given by composer John Cage in his lecture, *Composition as Process*, where he states that "An experimental action is one the outcome of which is not foreseen" [11]. In the present work, it is foreseen that the performance will create sound, and the bandwidths in which each data stream is sonified are designed, as described in sections III-V of this paper. However, the specific trajectories of the sounds in any given performance are unforeseen. Furthermore, while the linkages between the presence of brain and body movements, sensor data, and the sonification system are demonstrably casual, the results are complex and unpredictable. Making this unpredictability audible for listeners in the center of this situation stands in contrast to many sonification artworks and EEG-driven performances in which the focus is on ready apprehension of quantifiable data, or the practice of control of sounds using brainwaves or sensors [12,13,14].

By contrast *Twice Stepped In Still Waters* is focused on experiences of listening to listening, for both performer and audience. The performer listens, and the primary sound in the performance space is the sound produced by the performance of the performer listening. The audience also listens to this, sharing the space with the performer. Although activity is reduced to a minimum in the directions for the work [7], stillness remains ideal and unattainable. In sonifying data from the mind and body of a performer who attempts stillness, a complex sonic result arises from a simple and direct process of sonification. This is detailed in the following sections.

2.2. Interdisciplinary Use of Data Sonification as Artistic Research

By definition, interdisciplinary research draws upon multiple fields of technical specialisation. From this intersection, many affordances of working across disciplines arise, along with problems. Some common problems have to do with terminology, for expectations arise in specific disciplines when technical vocabulary is employed that may differ in a transdisciplinary context. For example, some may argue that the output of this project is not musical according to some definitions [15,16,17]. Others might claim that what is involved in this project does not constitute sonification [18]. Such complaints stem from restrictive definitions, biconditional exclusions, and imply expectations perhaps valid in one domain, but not for all. Argument over domain-specific ownership of terms where analogous technologies and methodologies are used to different purposes is at least a counter-productive interruption to communication across disciplines if not an a priori fallacy.

Where communication is ruled out by inability to share vocabulary, continued development of the underlying fields is at stake. It is not uncommon that technical terms are observed to mean different things in different fields. The term 'scales', for example, would certainly connotate different immediate meanings to a herpetologist and a musicologist. In another sense, 'harmonic series' is used in both related and contrasting ways in music and physics. A similar situation has arisen around the nature of 'sonification', which has not developed within the sole provenance of any one discipline but is better seen as part of a larger human project of perceptualising information [19,20]. If a project is truly interdisciplinary, outputs in any of the fields upon which it draws may be expected, and by-products may be found of benefit to these and further fields.

An artistic research project in which the output is primarily an experience of sound, such as is the case of *Twice Stepped in Still Waters*, may draw on techniques, methodology, and processes of sonification while not prioritising conveyance or rational understanding of data. While by some definitions this work does not constitute sonification, it is better to avoid entanglements of terminology, especially when definitions do not agree on all points among themselves [21,22,23,24]. Rather than impede interdisciplinary experimental work, terminology can be suspended, and concepts treated as less than fixed. This project therefore approaches 'sonification' with an operative definition akin to what composer David Behrman suggests for the performance of his live electronic music: "Whatever you do with a surfboard in the surf remains a part of surfboarding" [25].

This paper and project are not about defining sonification. The focus is not on what it is but what it does. The primary field of output for this work is music, and the focus is on listening rather than on teaching listeners about data, controlling sound, or measuring a phenomenon in any usual sense of these terms. Many sonification projects primarily result in a better understanding of data or of a phenomenon from which data has been collected, and primarily serve a scientific role in an interdisciplinary project. The present project serves to suggest an extension of some ways of creating and structuring sounds using sonification, and serves the field of music. As in cases where scientific aims of a project do not rule out musical enjoyment, an artistic output given prominence over communication or cognition of data does not negate technical contributions.

2.3. Sonification of real-time EEG data

As previously noted, a wide corpus of research on EEG sonification exists. Several fundamental examples of this research can be found within the proceedings of ICAD [6]. Real-time sonification for EEG monitoring forms a significant portion of this research, exemplifying a diversity of approaches [26,27,28]. Research related to EEG sonifications intersects with novel platforms for human computer interaction (HCI) and interface design [29], data analysis [30,31], multi-channel and spatial audio [32,33], and has served as a field for presenting new methodical approaches to sonification [34,35,36,37], along with already noted examples of EEG sonification in the context of musical and installation work.

The present paper adds to this research by presenting real-time sonification of EEG and sensor data in a performance context in which the aim is neither control of the sound materials, nor the brain. Instead, as described in the sections to follow, the aim is to utilise bio and sensor feedback to fabricate a sound situation for listening. Following

establishment of context for this work within the field of artistic performance, technical approaches are detailed which reveal how the present research serves to demonstrate low-cost, creative means of accessing this once highly specialised technology. As evidenced in the present work, the availability of open-source bridges between sensors and sound offers the creative coder the opportunity to work with EEG in a variety of research contexts.

2.4. Real-time EEG data/neurological signals in live electronic music performance

EEG and neurological signal usage has an established basis in live electronic music, with a great deal of foundational work created between 1965 to 1977. The performance methodology of Alvin Lucier's *Music for Solo Performer* (1965) [38] was influential in developing the present work. In Lucier's piece, as in my own, the performer seeks a state of stillness in body and mind. In Lucier's piece, the object was to generate Alpha waves which were transduced into vibrations made audible by placing speaker drivers directly onto or under percussion instruments [39]. Alpha waves are brain waves in the 8-12 Hertz range that are commonly linked to a state of relaxation [40]. Theta waves (4-8 Hz), along with Alpha, are often monitored with EEG in research studying changes in people's bodies when meditating [41,42]. My piece is not explicitly concerned with the type of waves registered in the EEG data, nor with attempting control of either brain waves or sound, but rather with perceptualising these through sonification as material for a temporal listening experience.

Composer Richard Teitelbaum was concerned with applications of biofeedback in the arts, specifically for use in performance and music [43]. For *In Tune* (1966-74) synthesizer designer Robert Moog "built a very good low pass filter at the end of the high-gain amplifier to further emphasize the Alpha waves being amplified live from the brain" [44]. Amplified brain waves were thus transduced as Control Voltage (CV) signals, and audified with Teitelbaum's synthesizer, along with breath and heartbeat signals. In *Spacecraft*, a collaborative composition by Musica Electronica Viva (MEV), Teitelbaum experimented with musical biofeedback using his colleagues, as well as his own bio-signals [45]. Combining biofeedback and telephonic performance approaches, he transmitted his brainwaves by telephone signal from California to New York City for *Alpha Bean Lima Brain* (1971) [45]. Teitelbaum's approaches, like my own, tend to view the body and sounding environment holistically, with biofeedback being one element of interaction between elements in a shared environment. As such, a freer treatment of signals and mappings can be adopted in a musical context than would be the case in a neurological experiment. More recent research extends and updates many approaches that are prefigured in Teitelbaum's work [46,47], combining similar conceptual approaches with new technological solutions.

David Rosenboom created some of the first works utilising neurofeedback in musical performance and sound installation, and continues to develop neurofeedback works alongside new approaches human-computer interaction in music [48,49]. In *On Being Invisible* (1976-77), Rosenboom's brainwaves are analysed and processed by software which compares this data against the sound produced by live performance on several instruments [50]. This data is fed to an evolving algorithm resulting in "correlative musical materials" [51]. Rosenboom describes this as "a self-organizing, dynamical system, rather than a fixed musical composition" where "it is an essential characteristic of all parts of this piece that the performer constantly rides a borderline between being, on the one hand, an initiator of action and, on the other, submerging him/herself in processes larger than him/herself" [52].

2.5. Contingency, Continuity and Modes of Consciousness As Performance Practice

Aspects of the performance practice adopted for *Twice Stepped In Still Waters* require further context. While the present work calls for the performer to attempt a state of stillness similar to Lucier's *Music for Solo Performer*, discussed previously, the sonification methodology and sounding result depart sharply from Lucier's transduced percussion instruments.

While in-depth contextualisation of feedback in contemporary sound work outstrips the allowed space, work with feedback and specifically biofeedback makes explicit connections between performer and environmental circumstances that most other Western performance practices actively isolate from both performer and audience. One result of this is that feedback performances require degrees of improvisational adaptability, what composer Scott McLaughlin refers to as "responsiveness to contingency" [53]. Such responsiveness takes another form in Agostino di Scipio's piece *Modes of Interference 2* [54]. In these works, the performer is in a precarious, self-amplifying situation, in which not only sound and listening, but overall body movements must be attended to [55].

Composer Eliane Radigue's early work exemplifies an intersection between feedback and music of gradual change. She describes her work with feedback as a process of maintaining a nearly still activity [56], and her music is often characterised by continuity of tone. Tone continua in Western music are becoming more common, while still not as common as in many musical traditions from across the world [57]. Composer Pauline Oliveros has worked with feedback and continuity with the stated intention of phenomenological investigation. Oliveros formalised a practice of phenomenologically engaged active listening called Deep Listening [58], a term later used for a teaching and arts foundation [59] and a musical ensemble [60]. Speaking of her methodologies for music making and in relation to early work with sound continua, Oliveros states "I haven't been working with musical ideas for a while. I've been working on my mode of consciousness. And the result of the mode is the music. So I have a task to do…I have to give up my intentions as far as the sounds are concerned….To reach that mode of consciousness is intentional, so my intention is directed toward the task." [61]. Sound continua entangled with a mode of consciousness approaching stillness characterises both this work and *Twice Stepped In Still Waters*.

In *Twice Stepped In Still Waters*, the organisation of the sounds arise from an interaction between environmental, neurological, and perceptual factors focused through a relatively simple system, to produce music. In much Western music, events arise out of tension between a frame of reference and movement toward or away from this (e.g. 'key' in Western tonal music). Here the situation is not dissimilar, except that the frame of reference, both for performer and listeners, is implied rather than explicitly stated. The

performer approaches stillness, an ideal state impossible in practice to attain. Yet this impossibility is appropriate as a goal for performance, as the ongoing task of maintaining stillness conditions the necessary mode of consciousness for performing the piece. Meanwhile, for audience members, consciousness functions as a frame of reference for relative change, underscoring the phenomenological basis of the piece.

3. EEG SYSTEM

The EEG system used for this work is a Muse 2 "brain sensing headband" manufactured by InteraXon Inc [62]. The Muse system is marketed for consumer use as a "meditation assistant" along with the Muse smartphone/tablet application. In parallel it is also marketed to neuroscience, psychotherapy, music cognition researchers [62]. Muse has been validated in independent clinical research [64], and research using Muse has been published in a variety of specialist fields [65]. Comparison studies demonstrate that Muse performs comparably to industry standard medical and research EEG systems like g.Tec g.USBamp, and Brain Vision's actiCHamp system [63].

For the purpose of *Twice Stepped In Still Waters*, Muse 2 was chosen over other consumer EEG devices [66] due to connectivity and flexibility of data extraction. The Muse 2 was selected over open-source hardware [67] for reasons of cost and build expertise, however future developments indicate utilisation of this approach. The procedure used in the present work establishes a direct connection between the Muse 2 and my computer via Bluetooth. Petal Metrics, an open-source middleware [68], is used to package and transport data as OSC messages across internal ports to Pd for sonification. The format of the data is five bands of OSC messages that contain raw data from each EEG sensor, not separated by spectral bandwidth.

The five EEG channels collect data via one 'reference' sensor and four dry channel electrodes. The names of the EEG sensors are analogous to the International Standards, Modified Combinatorial Nomenclature (MCN) [69]. The reference sensor, Channel 5 (Fpz) resides vertically in the centre of the forehead. Two channel electrodes, Channels 1 (Tp9) and 4 (Tp10) are located just above and behind each ear. Two further electrodes (AF7 and AF8) are placed on left and right temples [62].

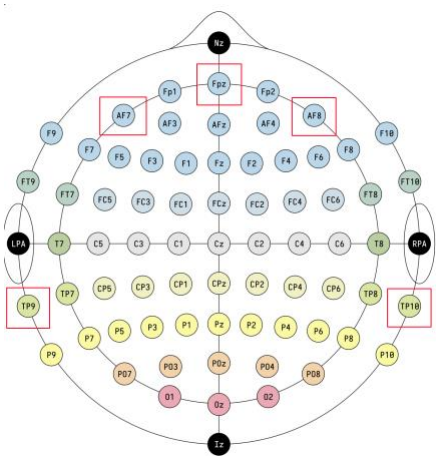

Figure 2. Muse 2 sensors (boxed) in context of MCN [70]

4. ACCELEROMETERS

Research with the accelerometers used in this piece began from two directions. The first device used in my experiments sonifying accelerometer data was a headtracking apparatus [72,73] with Pd implementation by Kronlachner for use with binaural playback of Ambisonic audio [74]. The sensor I used was noisy, even when the device is at rest. Sonifying this noisy data produced interesting results and encouraged further research in this direction.

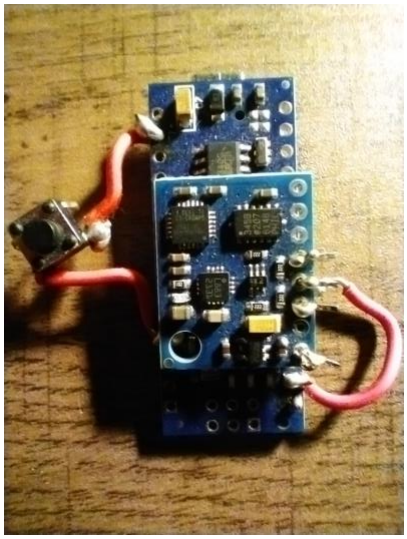

Figure 3: DIY open-source headtracker [72,73] using Arduino with Pd implementation.

Meanwhile, I was exploring Nintendo Wii remotes [76] as interfaces for teaching people to work with sound and gesture. I devised a sonification for listening to Wiimote accelerometers. Impressed with the sensitivity of the device, along with its shape, I began experimenting with situations in which it could maintain a precarious state of near-rest subject to environmental perturbations. This led to a solution for my performance in which the curved lower surface of the Wiimote is placed downwards in a box held loosely by the performer. The device rocks back and forth in response to external movement, amplifying small deviations from rest.

Figure 4: Form of underside of Wii remote, please note curved lower surface [75].

The Wiimote used does not contain gyroscopes, but rather three accelerometers that measure acceleration along fixed axes. Although the accelerometers cannot distinguish between

rotational and linear motion, the device measures the direction of gravity, and renders angles of pitch and roll from this. A Wiimote thus provides five channels of raw data: X, Y, and Z (orthogonal accelerometer measurements), and angular values between -90 and 90 degrees for (horizontal) roll and (vertical) pitch [76]. Open-source middleware called DarwiinRemoteOSC [77] packages the raw data into OSC messages. As with the EEG data, I unpacked the data in Pd and performed my sonification and sound output there.

5. MAPPINGS AND CROSS MAPPINGS: COMPUTERISED SOUND PRODUCTION

5.1 Accelerometer sound mappings

Different sonification strategies are implemented to allow for relative separation or interaction between signals of the Wiimote's accelerometers (X, Y, and Z). Data from the X and Y coordinates are sonified discretely in the Left and Right channels whereas the Z coordinate is broadcast in stereo. X and Y are also sonified with no pitch rescaling, using a mixture of sine and square waveforms. The Z channel is sonified with a sawtooth waveform rescaled to a set of frequencies between 105 and 220 hz.

Pitch and roll coordinates of the Wiimote are both scaled to 45 to 120 hz and sonified with sine waves. These are broadcast monophonically but as dual mono, out of both channels. Small changes in pitch and roll measurements create detailed variations in which movement is of a small scale but more active in terms of rate of change than accelerometer data (provided the performer does not drop the box). In contrast, since pitch and roll are sonified to the same range, spatial position, and utilise sine waves, they tend towards blending. This conflict between blending and resistance in sound increases the perceptual notability of the small differences that occur.

Harmonic effects are heightened by the approximate correspondence between the ranges of the pitch, roll, and Z component of the Wiimote data. At rest, relationships of the ranges of roll and pitch data to Z data have centroids which approximate a musical fifth (2:3 ratio). However, approximation of such consonant intervals are perceived as extremely dissonant when not exact. As with near unisons in the pitch and roll values, deviation produces audible harmonic beating. As the Wiimote is never really at rest, there is a constant tension created by these relationships, with moments of consonant intersection within a ground of more active vibration.

5.2. EEG sound mappings

EEG data is received on discrete channels representing each sensor. Channels 1 and 2 are scaled to a range of 160 to 170 hz. Channels 3 and 5 are scaled from 325 to 335 hz. Channel 4 is scaled to 400 to 500 hz. The ranges chosen, spatial position and waveforms by which the data is sonified, contribute to a balance of expected perceptual fusion and separation. This varies given the state of the brain, a performer's movements and attention, and spatial acoustic conditions. Channel 1 is sonified by a mixture of sine and sawtooth waves. Channel 2 uses sine and square waves. Channels 3, 4, and 5 are used to filter individual pink noise sources, by controlling the centre frequency and resonance of a Moog-like, "ladder-style" filters [78]. There is some cross modulation in this portion of the sonification process.

The mappings given here and in the previous section are in a state of continuous development and revision, but the rationale expressed here remains consistent as refinements are made. Initial decisions for the technical and temporal aspects of the piece began with a direct relation of sound and data. However, designed decisions as to clarity and sonic fusion have been undertaken in favour of a contingent intersection of sound and listening in performance. From simple relationships of signals arise great phenomenal complexity.

6. CONCLUSION

Twice Stepped In Still Waters evidences a listener-focused approach to sonification in the context of artistic research. Unlike a great deal of previous work with real-time EEG and sensor sonification in musical performance, this work does not seek to instrumentalise the data collection, sonification, or biofeedback processes for the purposes of controlling minds or sounds. Instead, this work demonstrates a means of sound creation in live, public performance that encourages phenomenological investigation of listening experiences for the performer and audience members. Consideration of this work within the performance practice of other works cited in this paper suggests a budding interdisciplinary tradition that links techniques of sonification to phenomenological artistic research. *Twice Stepped In Still Waters* exemplifies interdisciplinarity by drawing upon a great body of research into real-time EEG sonification, while extending this by demonstrating open-source and accessible methodologies that may be used by a wide body of researchers. In the context of artistic research, sonification is not only a means of communicating data, but is also suggestive of new approaches for performance and new modes of listening.

7. ACKNOWLEDGMENT

The author has undertaken this work as a member of Project RADICAL: A New Interdisciplinary Space for Sonification. RADICAL is funded by a Leverhulme Trust Research Project Grant (number RPG-2020-113).

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