Vessels is a brain-body performance practice that combines flute improvisation with live, sonified brain and body data. This article describes the genesis of this performance practice, which coevolved with the author’s brain-music interfacing and physiological data sonification methods. The author presents these novel interface designs and discusses how the affordances and constraints of these systems reflect onto her brain-body performance technique.

I have experimented with brain-body performance practice for almost 10 years and consider my piece Vessels (2015 to present) to be a culmination of these experiments. Vessels is a long-form musical meditation that layers electroacoustic flute improvisation with sonification of live brain and body rhythms. This practice of performing with sonification started out of scientific curiosity but, driven by expressive need, eventually called for the development of new technology. In this article, I describe the evolution of this brain-body practice and argue the necessity of the sonification approach it inspired. This is the story of my personal experience engaging with brain-body sonification technologies over the course of a decade.

I begin a performance of Vessels seated in a chair on stage, a small table nearby with a volume knob that I slowly turn up. As seen in the performance video available online [1], I wear an electroencephalography (EEG) headset that measures electrical activity from my brain, and my flute and stethoscope are close by. I sit silently, listening carefully to the background drone, an undulating chord of open cello strings ringing sympathetically with the actions of some silent bow.

While it may appear to the audience that I am passively listening to the sound along with them, the tone is in fact driven by my live captured brain rhythms, reflecting a cognitive state driven and influenced by a choreography of attention and breath. The software engineered for this performance streams four channels of electroencephalogram data from the dry-electrode Bluetooth-connected headset to a Max/MSP patch, which translates these neural rhythms into musical ones. In addition, I employ electrocardiogram (ECG) electrodes or an amplified stethoscope to relay electrical or sound signals from my heart and, in the past, have added breathing and skin conductance sensors; in all cases, brain and body signals are treated equally, using the same method that scales automatically to their underlying time scales.

I refer to this specific translation process as a spectral “imprinting,” as the time-varying activity inherent in the brain activity registered by the EEG is imprinted onto a bank of static tones, at first taken from past performances but then updated with flute and voice samples captured from the present performance as it evolves. The spectra of all samples combine to a coherent drone, but one that varies in time to a slow undulation reflecting the underlying rhythms of the brain and body.

I have worked with epileptologist Vijay Thadani on applying this method to EEG recordings of his patients as they experience seizures while undergoing monitoring at the hospital [3]. We found that this technique revealed the spatial and temporal features unique to particular seizure subtypes, suggesting it could be useful as a diagnostic tool. Even in healthy EEG, brain rhythms are far from static. Through a process of experimentation, I developed a choreography of performance behaviors (listening and attention, breathing, singing and playing) that serve both to influence these rhythms and to best reveal and communicate them to my audience.

The choreography begins with me assuming the quiet listening attitude I describe above. Using the volume control, I slowly fade in the sonified EEG and heart signal, and I shift my body, placing my feet firmly on the ground. As my body settles and I attempt to regain a sense of calm, the sound settles along with me. There is a downward shift in the vol-
une of the drone as muscle artifacts fade away, and only my stillness is converted to sound. From there, I am fully focused on listening to the sound quality of the drone and, with this deepening focus, the drone responds in turn. Not only are the brain rhythms being sonified, but the process of listening itself is revealed in sound.

Despite my initial efforts to systematize the techniques I use to manipulate brain activity and categorize the resulting sounds, I now enter this part of each performance comfortable with the reality that each drone sounds different due to the variations in equipment sensitivity and my own varying ability to enter the states of attention necessary to draw out variations in the drone.

If pressed to describe more technically what process is unfolding during this act of listening, I conjecture that I manipulate the energy generated within the brain rhythm frequency banks (delta, theta, alpha, beta, gamma) that scientists and doctors have referred to for decades. This approach drives the choreography in Alvin Lucier’s Music for Solo Performer. The canonical film of the composer performing his piece reveals performative actions that are known to produce large fluctuations in the alpha activity his system selectively sonifies [4]. In particular, Lucier opens and closes his eyes, accentuating the gesture with his hand. Closing his eyes causes a boost in alpha activity (8–13 Hz) in the occipital cortex, triggered when the brain directs resources away from the seat of visual processing. In the case of Solo Performer, this boost in alpha activity causes an increase in the rate and volume of the impulses that pass through a bandpass filter centered at the alpha frequency range, through loudspeaker drivers that are coupled with percussion instruments, creating an expressive crescendo. Lucier’s performance is hardly a passive sonification experience but rather an expert’s expressive practice born out of experimentation interfacing the brain and body with a new system.

I am well equipped to analyze the data I create during performances of Vessels, but I have not done so because I am no longer interested in the features of the EEG data recorded, only in the quality of the resulting sound. I’ve developed this position after early experiences engineering brain-computer music interfaces (BCMIs) with colleagues [5–7]. BCMIs are designed to measure high-level features of a user’s live-captured EEG signal, thus inviting the user to actively manipulate these features in order to be able to influence an algorithmic music composition or other music-generating process [8,9]. While it is technologically possible to build models based on one’s experiences in the studio or lab, apply labels to this experience (e.g. “focus,” “attention,” “relaxation,” “drowsiness”) and subsequently measure the degree to which one is able to match these models, this act of “matching” has little expressive bandwidth and was not satisfying for me as a musician.

I first performed EEG music with fellow student Tim Mullen in 2011 at a concert at the University of California at San Diego (UCSD). Over the previous year, we had engineered a sound installation that allowed listeners to manipulate a live music mix using their brain rhythms [10], as measured through single-channel NeuroSky headsets and analyzed for band power ratios developed to correspond to focus and meditation measurements. Mullen had developed an arsenal of biofeedback techniques from his past engineering experiences, and we trained and applied these techniques together. For instance, imagining our heads as fish tanks, slowly releasing water (to increase the “meditation” index, driven primarily by alpha band power) or as balls of fire, levitating higher with increased mental effort (increasing “focus” as revealed in beta band power). David Rosenboom describes in Biofeedback and the Arts his experiments, which demonstrate the minimal training required to learn interface control via biofeedback [11]. A transformation took place when, with training, our system changed from being a reliable measurement of our “meditation” or “focus” to being simply another control mechanism by which to move a cursor on the screen.

I took a similar approach in two live performances with Maxwell Citron in 2014 [12]. I adapted the raw stream from the Muse headset and measured the power of each EEG band relative to the others, using the measurement of each band to control parameters of a chain of effects in Ableton Live. The performance cited here is indicative of the early challenges faced in performing this music, and some of the techniques created in response to these challenges persist in my recent performances. I had begun to limit the amount of movement I use on stage, directing outward expression inward. This is partly a practical measure to increase the quality of the EEG data that reached the analysis stage by reducing the number of muscle artifacts in the data. But this inward movement was also necessary at times to achieve the attention states needed to produce a range of EEG data manipulations and thus audible changes in the resulting sound. In the latter of the 2014 performances, I experienced my first case of stage fright in more than a decade and found myself unable to relax enough to match the calibrations I had set in the lab during a state of lower physiological arousal. I was unable to match on stage a model I had built based on a different version of myself, and the result was a more constrained, less successful performance. I was eventually able to change some code mid-performance to adapt to my current state and regain the full range of mappings I had rehearsed. However, this experience revealed a fundamental flaw in the aesthetic act I was pursuing on stage.

The image of a “brain performance” advertised a direct translation of experience to sound, but even my most successful performance with this system was still only an imitation of a disembodied memory of conscious experience, coded into software during the engineering process. A successful performance with this system hinged on my ability to recall another self with no relation to the expressive needs of the musician on stage. The most exacting and correct uses of this system were, in fact, the least expressive and compelling. I was thus led to explore alternative systems that would capture my experience on stage and communicate this experience to my audience.

In an effort to uncover a new way to create sound with the EEG signal, I applied the entire arsenal of audio processing techniques at my disposal. Eventually, I experimented with a cross-synthesis technique I had learned from Tom Erbe at UCSD and previously employed in my compositions [13].
This technique uses discrete convolution by applying a finite impulse response (FIR) filter (determined by a recorded music sample) to an input signal (the incoming EEG) in order to create a new signal that is equivalent to the multiplication of the Fourier transforms of the two source signals. The EEG thus acts as an “actuator” for a musical filter, akin to running a finger along the rim of a wine glass, creating an increasing resonance (see Fig. 1). This metaphor allowed me to retain the feeling of using the brain signal as a control stream but also allowed me to passively actuate a complex sound, skipping the analysis stage.

My first experiments with this system revealed an unruly and vastly expanded range of sonic possibilities, as if I had picked up a violin without having heard or played one before and willed it into creating sound without understanding the mechanism by which I was expected to play it. Still, the feeling of resistance was familiar to me as a trained classical musician. My job henceforth in the studio was not to build a new instrument around my brain, body and experience but rather to learn to mold myself to the inherent possibilities it contained in its design, just as I had decades before when feeling of resistance was familiar to me as a trained classical musician. My job henceforth in the studio was not to build a new instrument around my brain, body and experience but rather to learn to mold myself to the inherent possibilities it contained in its design, just as I had decades before when learning the flute. I no longer gave any thought to the cognitive strategies employed in manipulating brain activity or how to label what I was doing or experiencing when playing this instrument. My attention was pointed entirely on the sound quality of the sonified signal. A photo taken prior to my first public performance using this system, at the Institute for Provocation in Beijing, China, is seen in Fig. 2.

This learning process naturally aligned with Gibson’s concept of affordances [14], a theory often cited in cognitive science and design fields that refers to the user behavior that emerges naturally from both the affordances of systems (the handle of a teapot enabling the hand to grasp and lift) and their constraints (the heaviness preventing extraneous movement). My early experiments made it clear to me that this new raw sonification system afforded me greater depth of expressive range through the constraints placed on me. The system was highly sensitive to extraneous movement, so the performance responded with relative stillness. The system changed in an instant in response to momentary shifts in whatever signal I generated: The signal processing method no longer required a calculation over multiple seconds to generate a measurement. Therefore, my sensitivity to the sonic effects of my own actions increased to the point that I started to be able to anticipate a shift in sound before it became audible.

I described this to Pauline Oliveros during my last conversation with her, which took place in 2016. She described to me the work of Benjamin Libet, a vein of research she had recently discovered. Libet studied the bereitschaftspotential, an event-related potential in EEG that indicates preparation for movement, and published research suggesting that this “readiness potential” precedes a participant’s recorded awareness of their intent to act [15]. Oliveros related this delay to the tape loops she adapted for improvisatory composition: “The time delay of one-third to one-half second between evoked potentials in the brain and cognition discovered by Libet is fascinating with respect to my trust of bodily response before cognitive recognition during improvisational performances” [16]. She attributes this anticipatory response to the bodily wisdom she built over decades of improvisation, a wisdom that was more powerful than her cognitive decision-making process.

I have performed Vessels several times as part of a combined lecture and performance. Inevitably, when there is an opportunity to field questions, I am asked to describe what I “do” to perform the brain. I increasingly echo Oliveros’s observation in my response. I am performing not the brain but rather the body. After learning that I could anticipate a change in sound before it happened, I observed that this came coupled with the natural interoceptive process: My conscious attention came coupled with my awareness of my heartbeat, my breathing, even my sweat. I learned to manipulate the breath in order to achieve large changes in sympathetic nervous system (SNS) activity, which would in turn create ripples in the brain and body signals I performed. The SNS is the “activating” branch of the autonomic nervous system, which maintains homeostasis between bodily systems [17].

After beginning a Vessels performance with slow listening, I then consciously slow down my breathing, usually to between six and 10 breaths per minute, holding a hand to my stomach to make this clear to the audience (Fig. 2). The heartbeat follows, and I hold a stethoscope to my chest to mix its sound in with the drone. Doctors and scientists have identified a 0.1 Hz oscillation in the electrical resetting phase in the QRS complex (the largest peak seen in a heartbeat signal) that corresponds to a cycle over which the SNS operates, known as the Mayer wave [18]. There is a demonstrated re-
lationship between this SNS operation and the rate at which we breathe [19].

My performance experiments uncovered this Mayer wave: I learned through sonic experimentation that slowing the breath to around 0.1 Hz (six breaths per minute) would create large shifts in the sonic output of my system, when sustained over several minutes. My collaborators at MIT and I applied this knowledge to the development of music that invites slower breathing, demonstrating profound shifts in SNS activity [20]. However, sustaining a single-pointed bodily attention on stage for a half-hour or more, necessary to create audible shifts of this magnitude, is not always possible for me when on stage.

I often rely on my flute-playing as an attention anchor throughout this process. The long tones we are trained to use as a warm-up exercise lend themselves naturally to this process, and much of the remainder of my performance relies on playing one note for each breath I take, to further focus my attention and communicate my breathing pattern to the audience. I employ circular breathing, which over time causes my heartbeat to slow down dramatically. I add multiphonics and sing into and on top of the flute to create more complex timbres, meshing the live acoustic sound of the flute with the processed drone. As these sounds are looped and layered in my performance software, the resulting piece forms an expressive arc of increasing complexity. The loudness of the resulting mix presents a contrast with the persona I must project on stage, as my movements are still severely limited.

Although my attention is pointed inward, at the sound created by my own body rhythms, audience members have reported strong empathetic reactions, the kind I always thought were reserved for more traditional, hyperexpressive performances. Although my colleagues and I have investigated underlying psychoacoustic explanations for this empathetic entrainment [21,22], I am also convinced that the theater of brain performance, in promising a more direct and raw translation of performer experience into sound, becomes a self-fulfilling prophecy. Vessels, as my most complete exploration thus far of the performance possibilities enabled by brain-music interfacing, encompasses both ends of this technological-performative spectrum.

References and Notes

10 Leslie and Mullen [7].
21 Leslie et al. [20].

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Manuscript received 2 January 2020.