

From representation to relationality: Bodies, biosensors and mediated environments

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ABSTRACT

In this article we propose a biorelational framework for performance with biosensors, in which interactions are not based on causality, control, and representation, but rather, manifest through shared awareness and agency across multiple, fluid assemblies of self, other and environment. The transdisciplinary scope of this study traces trajectories from the performing and somatic arts into philosophy, biomedicine, cognitive science and human-computer interaction. A brief survey of common approaches to interaction design with biosensors will contextualize discussion of our current practice-based research and creation project, 'Choreography and Composition of Internal Time'. In this project, we are examining temporal relationships between physiological processes, such as heart rate and breath, with rhythms in movement, music and mediated environments.

KEYWORDS

biosensors
biofeedback
biorelational
entrainment
embodied agency
interactive
performance

1. INTRODUCTION

The intersection of bodies and biosensors in contemporary performance provides a compelling context in which to interrogate attitudes and approaches towards embodiment and technology – implicit and explicit, as well as past, present and potential. Our discussion builds on the work of philosophers such as Manning (2009, 2013), Grosz (1994, 2011), Butler ([1990] 2008) and Varela (1992) to articulate the ‘body as a process’, which is in continual becoming through an intermingling of techniques and technologies. We challenge the concept of biodata in performance as a means to reveal deep, inner truths of biology, but rather invite biosensors as a means to complexify flows of relationality and agency within self, action and environment. The transdisciplinary scope of this study draws on current research in the performing and somatic arts, as well as philosophy, biomedicine, cognitive science and human–computer interaction, countering dualistic interpretations of mind/ body, internal/external, voluntary/involuntary and cause/effect.

A brief survey of socio-political attitudes towards the human body over time, from biological and social determinism, towards embodied agency, demonstrates ways in which these pervasive ideologies inform practices with biosensors. Examples of common approaches to interaction design with biosensors, including biocontrol, biofeedback and metaphorical uses of physiology, are presented and problematized. We emphasize the significance of engaging with bodies in movement, during which complex co-articulations and modulations of self and surroundings are enacted.

Additionally, we offer reflections regarding our ongoing practice-based research and creation project, ‘Choreography and Composition of Internal Time’ (MacCallum and Naccarato 2015). In this project, we are examining temporal relations between physiological processes, such as heart rate and breath, with rhythms in movement, music and mediated environments. Significantly, our initial focus on ‘internal’ time, referenced in the title, has directed us not into the body as a closed system, but rather towards the body as an open network of connections between self, other, and environment. Ongoing artistic experiments in this project have been designed to examine potential for interoception (sensing the physiological condition of the body), enaction (an immediacy of action and cognition) and entrainment (processes of non-causal attunement and flow between entities). Through this research, we seek to ground our creative practice with a fundamental understanding of embodiment as entangled and inseparable from biology, behaviour and context.

Our evolving vision is guided by a set of principles regarding encounters of bodies and biosensors, which we have come to articulate through our own practice, as well as via engagements with related work by artists, scientists and philosophers. These principles can be summarized as follows:

- It is impossible for the human body to be measured in its entirety, no matter how many biosensors are used. This is not due to a shortcoming in the biosensor technologies, but rather, it is because there exists no stable, complete body to be measured in the first place.
- Bodies are in continual becoming, through co-articulations and modulations across physiology, behaviour and context; these complex systems of relationality will always, necessarily, exceed representation.
- Biosensor data must be understood as mediated by aspects of the hardware and software tools, as well as the network with which it is recorded and shared. Thus, biodata is never only a result of biology, but rather carries traces of the system design from which it derived.

- Analysis of biosensor data, especially in relation to body, behaviour and context, requires interpretation and imagination on the part of the designers, users and observers.

It is within this interpretive and imaginative space – between bodies, biosensors and networks – that our collaborative research and creation is thriving. Our ambition is to articulate and actualize biorelational frameworks for performance with biosensors that are not based on causality, control and representation, but rather, which manifest through shared awareness and agency across multiple, fluid assemblies of self, other and environment.

2. MOVING WITH DETERMINATION, BEYOND DETERMINISM

Over the past century, the integration of biosensors in performance has been shaped by shifting social, cultural and political attitudes towards embodiment in art, science, medicine and philosophy. Early applications of biosensors in performance are recorded in the work of Étienne-Jules Marey (1830–1904), a French physiologist and artist renowned for his contributions to cinema. Marey endeavoured to reveal what he understood as the natural body through a combination of mechanical sensors, transducers and inscriptions that measured the ‘invisible movements of blood, breath and neuromuscular oscillations’ (Salter 2010: 222). Marey’s view of the natural body reflected widespread beliefs of the time regarding nature over nurture, that is, that human identity is biologically and genetically determined. This viewpoint, coined biologism, was seen to be propagated by Darwinist Evolutionism, and taken to tragic extremes in the Eugenics movement – making the ethical implications of work with biosensors explicit (Turner [1984] 2008: 2).

In opposition to biological determinism, models of social determinism gained popularity during the mid–late twentieth century. In social determinism, the shaping of the body is understood to take place via external forces; the body is a ‘blank slate’ onto which meaning is culturally inscribed, and manifested through thoughts, actions, habits and attitudes, in ways which appear ‘natural and automatic’ (Blackman 2008, Chapter 1, ‘The disciplined body’; Butler [1990] 2008: 177). In postmodern dance since the 1960s, several choreographers have explored the deconstruction of everyday gestures and postures that inhabit the body; for example, dance scholar Janice Ross (2007: 264) explains how choreographer Anna Halprin addressed cultural inscription in her piece *Lunch* (1968), by having a group of dancers ‘perform’ eating in slow motion, thereby highlighting ‘the internalized constraints that rule us in as common a practice as eating’.

The concept of internalization is discussed at length by French philosopher Michel Foucault ([1975] 1995), who posits that power does not operate through external prohibition and constraint, but rather through multiple, internalized practices of self-surveillance and self-regulation, which come to form particular types of bodies, desires and capacities for action. In Foucault’s own words, disciplinary power:

trains the moving, confused, useless multitudes of bodies and forces into a multiplicity of individual elements – small, separate cells, organic autonomies, genetic identities and continuities, combinatory segments.

Discipline makes individuals; it is the specific technique of a power that regards individuals both as objects and as instruments of its exercise. ([1975] 1995: 170, original emphasis)

While Foucault's work is useful for addressing the operation of power in, on, and through bodies, American philosopher and gender theorist Judith Butler argues that Foucault's proposal still assumes the existence of a stable body prior to internalized cultural norms – a body, that is, that must be 'destroyed and transfigured' time and again by 'history as a relentless writing instrument' ([1990] 2008: 177). Blackman reinforces Butler's perspective, stating that:

Cultural norms are not simply internalized but engender a background of felt orientations to the world that are not easily verbalized or understood. It is this realm which often discloses embodied experience, and which needs a more complex understanding of self-formation than internalization can invoke and suggest. (2008, Chapter 3, 'Corporeal feminism')

Butler further complicates the notion of internalization by pointing out that references to "inner" and "outer" make sense only with regards to a mediating boundary that strives for stability' ([1990] 2008: 182). In Butler's words:

The critical question is not how did that identity become internalized? as if internalization were a process or a mechanism that might be descriptively reconstructed. Rather, the question is: From what strategic position in public discourse and for what reasons has the trope of interiority and the disjunctive binary of inner/outer taken hold? In what language is 'inner space' figured? What kind of figuration is it, and through what figure of the body is it signified? How does a body figure on its surface the very invisibility of its hidden depth? ([1990] 2008: 183, original emphasis)

Butler's remarks are significant with regards to the integration of biosensors in performance, in which biodata may be mistakenly interpreted as revealing the isolated, inner state of the body. As we will discuss in the coming sections, a contextual approach to examining biodata reveals complex flows of physiology, behaviour and context, such that perceived boundaries of inner and outer, and self, other, and environment, become uncertain and unstable.

3. MAPPING INTERACTION: FROM REPRESENTATION TO RELATIONALITY

Although philosophers have criticized biological and social determinism as reductionist and essentialist, we observe that these ideologies persist, intentionally or not, in performance practices with biosensors to present day. In contemporary music and dance from the mid 1960s onwards, the integration of biosensors in performance has been widely characterized by control-based mappings between aspects of biodata with parameters of other media, such as sound, lighting and video – an approach that we will call biocontrol (Ortiz et al. 2011: 12). This pervasive approach is evident in the work of early composers with biosensors such as Alvin Lucier, Richard Teitelbaum and David Rosenboom, as well as more contemporary researchers such as Benjamin

Knapp, Marco Donnarumma and Atau Tanaka. Choreographers including Wayne McGregor, Isabelle Van Grimde, Robert Wechsler, Anne Holst and Jean-Marc Matos, Jess Curtis, and Louise Wagner have integrated biosensors in dance with similar techniques of interaction.

In scenarios of biocontrol, sensors are used to measure an aspect of physiology, such as brainwaves or heart rhythms, which are then broadcast in (near) real time, giving the illusion of translation or mapping between body and media. Mappings can range from legible to obscure; in many cases, designers complexify visual and sonic outcomes by layering multiple mappings simultaneously, or by adding randomness to algorithms. However, even in the most obvious instances of cause and effect between body and media, the directness of this mapping is an illusion. The process of deriving biodata via sensors and using this data to inform aspects of other media is shaped by the hardware, software, designers and context of the performance. When we hear a drumbeat that is meant to represent the beating of the human heart (i.e. mapping a heartbeat to a drumbeat), we are not merely learning about the heart rate of the performer. Rather, the designers have made a series of choices, including: which peak of the ECG to sonify; the sampling rate of data from the ECG monitor; the placement of electrodes on the body of the performer; and the quality and volume of the drumbeat – to list but a few of the mediating elements that impact perceptions of a one-to-one mapping. While creating the illusion of control between body and media is a popular strategy, and one that, in our experience, yields a certain satisfaction from performers and observers alike, we are concerned that relying heavily on this approach propagates a reductionist and binary understanding of the dynamics at play between bodies and media.

In performances that involve biocontrol, the media also serves as a form of biofeedback, interpreting and projecting back to the performers aspects of their physiological condition (all be it in a mediated form). Certain projects even claim to respond to the affective and emotional ‘state’ of performers, based on physiological readings; this claim vastly oversimplifies the relations of physical and emotional processes – processes that are never stable, but always becoming – and further, reinforces binaries of inner/outer and body/mind. One example of this is the AffecTech installation developed in 2008 by a team of researchers at the Sonic Arts Research Centre (SARC) in Belfast. In this installation, two participants were invited to sit in chairs fitted with galvanic skin response and pressure sensors, from which the sonic and visual surroundings came to life. The team explains that: ‘In the development of the AffecTech system we used a biological analogy, the sensors as its eyes/ ears/skin, the audio-visual system as its face/mouth, and the decision-making systems its “brain”’ (Coghlan et al. 2009: 2). This analogy situates perception within the human brain and sensory organs of the body itself, as a closed system. Regarding future improvements to the installation, the authors suggest: ‘In order to make AffecTech capable of emotion or affect sensing, the system would require more channels of sensor data, so that they can be cross-referenced (Russel, 1980) and in future versions we would recommend the addition of Heart Rate and Respiration sensors’ (6). This statement is troublesome for several reasons: first of all, it assumes the existence of a stable and complete body that can be measured in its totality, given access to enough sensors; second, it presumes there is a method by which correlations can be drawn between physiological data and affective states – but, we reiterate, these states never exist in a stable or static form that can be isolated and represented by other means.

With regards to the purpose and potential of biofeedback systems, composer David Rosenboom, who has worked with encephalogram (EEG) sensors for decades, states that:

A biofeedback system may be mistakenly viewed as simply a method for stabilizing particular behaviors and, thus, as a static equilibrium system. In fact, these processes all involve the self-organization of dynamical regimes within the organism, aided by the additional information feedback loops of the biofeedback mechanism, in such a way that the evolution of these regimes will tend toward a dynamic that promotes the self-renewal of the organism. (1997: 17)

While Rosenboom's explanation of biofeedback emphasizes a dynamic flow between physiology and behaviour within the organism, it still suggests the existence of the body and media as separate entities that can be made to interact. With regards to biofeedback in his recent production, *Ringing Minds* (2014), some seventeen years later, Rosenboom writes:

Using a technique called hyperscanning, the brains of several musical listeners are treated as one hyper-brain to investigate concepts about complexity and structural forms manifested concurrently in music and multiple brains, along with resonances that can be detected within and between listeners and performers. In *Ringing Minds*, resonant patterns detected in the hyper-brain's activity are sonified with a field of ringing, electronic sound resonators. [...] When, in turn, the hyper-brain responds to sounds created spontaneously by the musicians, the resonator field undulates. (2015)

In the above scenario, attention has grown to encompass flows between the many human performers with one another and with the music. However, Rosenboom's references to concurrent and spontaneous reactions and sonification of brain activity reinforce a view of the media as a means to represent the inner workings of the body.

In her book *Relationscapes*, philosopher and Tango dancer Erin Manning problematizes the concept of mapping between bodies and media, stating that this representational approach:

rarely moves beyond the limits of interactivity. It does not move the relation: it foregrounds mediations between different systems whereby one portion of the system is necessarily preconstituted. In most cases this means working with a stable body-concept. From stable to unstable and back, but never really metastable. New ecologies of experience are rarely created under these conditions. (2009, Chapter 4)

The question remains then, under what conditions, however rare, might a biofeedback system move beyond the aim of representation, in order to activate complex flows of relationality between performers and media? If we accept that biofeedback itself is always mediated, as opposed to being an objective expression of physiological state, it follows that the media provides

interpretations not only of biology, but rather, expressions that encompasses the complex interactions of one's physiological state and behaviour with the overall context. In this hybrid form of feedback, which we will refer to as biorelational feedback, the many elements of body and media are in continual flux and transformation, and as such, cannot be isolated and identified in static terms. Engaging with biorelational feedback as an interpretive form of expression in the performance process has potential to inspire fluid relations between self, other and surroundings.

Moreover, it is crucial to consider how performers are engaging with the biorelational feedback provided. Are they meditating calmly on each shift in the sounds and lighting? Are they executing complex choreography or instrumental music? Are they distracted, exhausted or anxious? Performers are not passive receivers of feedback, but rather, play an active role in characterizing relational interactions. As such, what types of practices facilitate embodied awareness and agency for performers within a mediated environment? Further, how are shifting understandings of embodiment colouring the intentions with which performers enter an interactive space?

4. MOVING THE RELATION: TOWARDS EMBODIED AGENCY

Since the 1980s, a search to articulate corporeal agency has placed emphasis on the material and somatic body as a hybrid site of action and cognition, through which individuals negotiate dynamic environments. In the writings of Kupperts (2007), Butler ([1990] 2008), Grosz (1994, 2011) and Manning (2009, 2013), the body is described as a process, which is unbound by the skin, seeping in and through multiple, fluid relationships of self, other and surroundings. Haraway (1991), Hayles ([1999] 2008), and more recently Bradiotti (2013), theorize performative renderings of cyborg and posthuman bodies that blur boundaries between human/machine and biological/computational. Blackman elaborates on this viewpoint, explaining that:

bodies are made and remade through the mediation and modulation of biological capacities that are always dynamic and in relationship with what we might term 'the outside': machines, practices, technologies, and so forth. In this sense, 'biology', or matter, is not an entity but is defined as a relational, dynamic process which is enfolded with the 'outside'. The use of the term 'fold' points towards the complex entanglement and interweaving of the inside with the outside to the extent that it is impossible to make such distinctions or differentiations. (2008, Chapter 5, 'Corporeal thinking')

Performance artists such as Eduardo Kac, Orlan, VNS Matrix and Stelarc have employed biotechnologies as a means to critique the concept of the body as a stable, self-contained entity. Additionally, practice-led research projects world-round are investigating contemporary intersections of movement, new media and philosophy; examples include Jaime del Val's Metabody Project, Erin Manning's Sense Lab and Susan Kozel's Mesh Performance Practices. Shifting perspectives regarding embodiment are reinforced in studies from cognitive science, neuroscience and human-computer interaction, which situate cognition within the material body itself – the moving body, that is. As emphasized by William Clancey in his book *Situated Cognition: On Human Knowledge and Computer Representations*: 'All human action is at least partially

improvisatory by direct coupling of perceiving, conceiving, and moving – a coordination unmediated by descriptors of associations, laws, or procedures’ (1997: 2, original emphasis). Biologist and philosopher Francisco J. Varela contributes to this sentiment with his explanation of virtuosity as an ‘immediacy of perception and action’, whereby behaviour is not merely reflexive, but rather emerges from an individual’s embodied memory to form a ‘readiness for action’ in each successive moment (1992: 2, 9). An individual’s impulse to move, for example in relation to biofeedback, is not easily localized in body or mind, but rather materializes via: ‘a coherent global pattern that emerges from the activity of the simple local components, which seems to be centrally located, but is nowhere to be found, and yet is essential as a level of interaction for the behavior of the whole’ (Varela 1992: 53). In embodied interactions within mediated environments, agency is distributed beneath and beyond the skin, involving promiscuous encounters between human and non-human performers.

Embodiment is a process in motion, and in relation. Manning emphasizes the significance of movement – from its potentialities to manifestations – within body–environment couplings. She claims that via movement we do not only enter space–time – we create space–time – in immeasurable ways.

Movement provokes duration even as duration provokes movement. Measurable quantity is anathema to duration. This is why the displacement itself – the movement from a to b – is not what is essential about movement. Movement is the qualitative multiplicity that folds, bends, extends the body-becoming toward a potential future that will always remain not-yet. This body-becoming (connecting, always) becomestoward, always with. I move not you but the interval out of which our movement emerges. We move time relationally as we create space: we move space as we create time. (2009, Chapter 1, ‘Intensive magnitudes’)

In the absence of dynamic body movement, streams of biodata provide limited information regarding flows of relationality and agency between physiology, action and environment. Movement affords performers – animate and inanimate – opportunities for expanded awareness and unexpected entanglements. Further, movement directs attention not towards what bodies are as static entities, but rather, towards what bodies – diverse and connected bodies – can do, in a wealth of contexts.

5. MANIPULATIONS AND METAPHORS OF THE HEART

While many aspects of an environment and of movement can be recorded with sensors in a noninvasive manner (e.g. motion tracking, contact microphones, pressure sensors, light sensors, accelerometers and much more), physiological sensors, especially for the brain and heart, present unique challenges. In the case of electroencephalogram (EEG) technologies for assessing brain activity, it is generally necessary for subjects to remain still; even minor movements of the jaw can cause artefacts in the data. With recent advances such as MoBI: mobile brain/body imaging (which synchronizes EEG and motion capture data), as well as the eXtreme EEG (a reusable EEG electrode cap worn during a range of activities), perhaps this is beginning to change (Brain Products 2015).

In the case of an electrocardiogram (ECG) for recording heart activity, the subject can move to a degree, however, motion of the muscles surrounding the heart, or of the electrodes and lead cables attached to the body, can result in noisy data. Importantly, signal noise should not be understood in opposition to the ECG data; rather, noise provides additional information regarding the performer and environment, which may be used or filtered in different ways, depending on the intentions of the designer. Vast improvements have been made over the past decade to wearable, wireless ECG technologies for sports and clinical medicine. Unfortunately these devices, such as strap-on modules and textiles with dry electrodes, often come with proprietary software and narrow bandwidth filters that are based on the assumed repetition of predictable motions, e.g. running or cycling. Additionally, the Bluetooth and Wi-Fi sensors in these devices offer varying degrees of reliability in terms of transmission range and latency. As such, these products prove ineffective for recording continuous heart rhythms during unpredictable and dynamic body movements, like in contemporary dance.

Given the difficulty of working with ECG devices and data, many artists adopt strategies such as: sampling data only in moments when the performer remains still; averaging ECG data over a selected duration, so that changes in heart rate appear smooth and predictable; and/or addressing the physiology of the heart solely as a metaphor. To provide an example, which is far from isolated, in an interview about her piece *Throb* (2012), New York-based choreographer Jody Oberfelder explains how she staged:

two dancers wearing heart monitors and a pretend scientist on the stage tracking their heart rates as he asks them to perform emotionally valued concepts like 'surprise.' It was very physical, and he changed the music according to their heart rates, so they would come up at intermittent moments during the piece. (Taylor 2014)

Here we observe selective sampling and averaging of heart rate data, as well as interest in the emotional reactivity of the heart. Through the sampling and averaging of ECG data, the heart rate is presented as a normalized, metronomic pulse, when in fact the variability within a healthy cardiac system is extremely adaptive and rhythmically complex. The normalization of a performer's ECG or other biodata represents a technique of power constructed by the author of the work who has inserted herself in between a performer's physiology and its external representation. The author is now in a position to conform the performer's data to meet any number of intentions. The locus of this power relationship lies not in the altered externalization of the performer's physiology, but at the point at which the author's agency intersects with the performer's situated decision-making. By this, we do not mean to suggest that there could ever be a pure delivery of biodata; the flow between biology, sensors, and network is always mediated by a number of processes, human and non-human, which the authors may or may not make explicit.

Oberfelder's next creation, *4 Chambers* (2014), is a metaphorical reflection on the heart through the spatial and structural organization of the installation into chambers. A similarly metaphorical approach was adopted in the project of *The Heart* (2005) by choreographer Wayne McGregor/Random

Dance, a collaboration with heart imaging specialists. In a video interview on the project's archival website, McGregor explains that:

The work of the heart as both a pump and an electrical device has resonance in the way in which I've thought about structuring the bodies in the space, so that actually through the piece you start off with pretty much an ensemble and an individual. By the end you're working with a plural set of bodies that are behaving almost like blood flow, if you'd like. They're really rapidly working through choreographic ideas, which are related to this idea of the physicality of the body itself, so again this internal/external, outside and inside. (2005)

Metaphorical approaches to the heart, based on plentiful cultural inscriptions, remove the material potentialities of the heart from the performance altogether. By relying solely on metaphors of the heart and circulatory system, the heart becomes objectified as a self-contained, static entity, separate from an individual's body and environment. These constructions enforce perceptual boundaries between internal and external embodiment, and significantly, posit cardiac function as an involuntary process, void of agency to impact self and surroundings. While the act of integrating more continual readings of biodata does not in itself interrogate the complex articulations of biological and cultural processes in movement, we suggest that it does act as a precursor from which this co-articulation may begin.

6. TOWARDS A BIORELATIONAL FRAMEWORK FOR INTERACTIVE PERFORMANCE

We now turn to our own practice-based research and creation project, 'Choreography and Composition of Internal Time', as it relates to the artistic, technical and conceptual issues discussed thus far (MacCallum and Naccarato 2015). Presently, we are engaging with biosensors as an intervention in our choreographic and compositional process. We do not view biodata as revealing the inner workings or truths of the body, but rather, as evocative of the continual flows amidst physiology, behaviour and context. These dynamic relations between bodies and media are never stable, and as such, refuse static representation. We are working with engineers to develop a prototype for a wearable, wireless ECG monitor, which records heart activity continually during dynamic and unpredictable body movements. Additionally, we are designing software environments that sonify and visualize biodata in relation to behaviour and context in various ways. With these hardware and software tools, we are enacting practice-based experiments, as well as performance studies, through which we aspire to interrupt and enrich our choreographic and compositional collaboration.

We began working together in late 2013 with plans for an evening-length production, still to come. In this piece we envision twelve contemporary dancers wearing ECG sensors, from which click tracks are generated in real-time to guide twelve corresponding musicians. The choreography will be designed to motivate intentional arcs in the heart activity of each dancer over time, in line with the musical score. Each musician, click track in ear, must negotiate between the shifting heart rate of a dancer, versus the prescribed temporal progression in the polytemporal score.

Prior to any research, we thought the above proposal was relatively practical and achievable. We planned to use off-the-shelf heart rate sensors, and have the dancers control their heart rates through physical exertion, with biofeedback from the music. Admittedly, we underestimated the complexity of the technical, artistic and conceptual elements involved. Most every critique presented thus far regarding causal, control-based and representational interaction design applied to our original vision. As we came to realize this, we put our plan for a single production (temporarily) on hold, and decided to invest in an intensive period of practice-based research.

Early on, we confronted the question: to what degree can dancers intentionally control shifts in heart rate over time? Obvious instances of cause and effect between physical exertion with heart rate aside, we began searching in/with/ through individual performers to understand a range of subtle and extreme physical, emotional and psychological shifts that interrelate with cardiac function. We recognized that given the autonomic character of the cardiac system, it is impossible for the dancers to exert control over the temporal activity of the heart directly (Lang 2009: 393). Instead, we began to explore reproducible relationships between the behaviour of the heart with other physiological processes such as respiration, and activities including movement, visualization and memory techniques, human interactions (e.g. eye contact, touch and weight-sharing), and environmental interactions (e.g. music and lighting).

In an initial series of experiments, we focused on heart rate and breath, for which we used both ECG and respiration belt sensors. To be clear, our intention was not to conduct scientific experiments, but rather, to investigate practices by which an individual's embodied knowledge of temporal relations between heart rate and breath can be mobilized for specific goals, within diverse performance contexts. During sessions with two different performers, we identified reproducible patterns of variation in the heart, which relate to holding the breath, deep or shallow panting, slow inhales and exhales, and other combinations of duration and amplitude in respiration. We repeated the breathing structures with each dancer lying supine, sitting, standing, walking, and eventually improvising movement, and still observed familiar patterns of relation between ECG and respiration data throughout, but with a base increase or decrease in heart rate based on physical exertion. Given this information, we developed a short solo study for a dancer with electronic sound as pitch-based biofeedback; in this study the choreography of breath and movement was designed to guide arcs in the heart activity of the dancer over time based on a prescribed model. Two different



Figure 1: Bekah Edie (left) and Teoma Naccarato (right) rehearsing Study #1 at IRCAM. Photographs: © MacCallum and Naccarato (2015).

dancers performed this solo many times, each time producing traces of data that aligned reasonably well with those of previous performances as well as with our constructed model.

Importantly, our success in reproducing biodata from multiple runs of the solo study does not mean that the dancers were controlling their heart rates. Reproducing an arc in heart activity requires a negotiation between a wealth of physical, emotional and psychological variables that are always in relation, and always in transformation. We observed that various behaviours (e.g. sprinting as well as panting) may produce similar quantitative results, while mirrored behaviours in multiple performers may result in disparate data. Further, heart activity can fluctuate in a single performer from day to day, and based on context. For example, during our first-ever live performance with ECG sensors, the dancer was unable to lower her heart rate below 120bpm, far higher than the intended 60bpm.

This variability in heart activity is not a problem; on the contrary, the adaptability of the heart within dynamic systems is what interests us. In fact, we aim to create compositional and choreographic techniques that require such variability as the source for emergent and dynamic properties. Rather than attempting to stabilize relationships between body and media (which would be impossible, in any case), we aim to cultivate the interoceptive capacity of each performer regarding visceral changes, such as shifts in cardiac rhythm, as relational events within the multi-directional flow of self, action and environment.

Given our focus on practices of relational awareness and agency, a core aspect of our research is the design of environments with biorelational feedback from sound and lighting. Through structured movement improvisations, we are investigating embodied strategies by which performers may tune their corporeal state with that of fellow actors, animate and inanimate. Our approach to tuning relates to the notion of entrainment, in that it embraces processes of non-causal attunement between multiple, modulating entities (Himberg et al. 2013). We also began to experiment with two dancers tuning in relation to one another, raising questions regarding the potential of kinaesthetic empathy to impact heart activity between partners (Foster 2010).

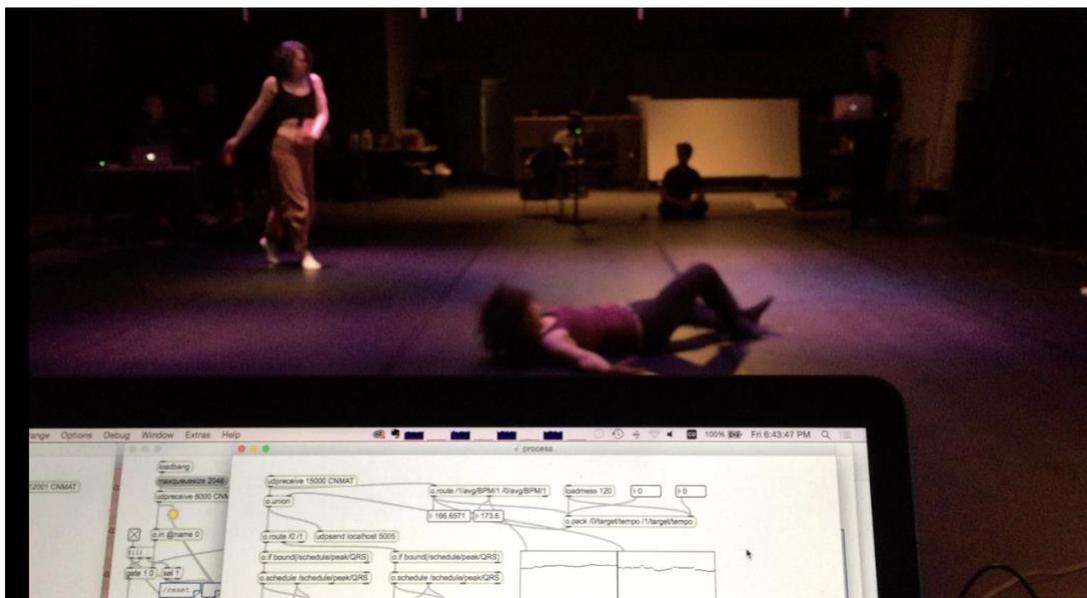


Figure 2: Photo from practice-based experiments at the Synthesis Center, Arizona State University. Photograph: © MacCallum and Naccarato (2015).



Figure 3: Rehearsal of Study #2 at UC Berkeley with percussionist Loren Mach and dancer Teoma Naccarato. Photograph: © MacCallum and Naccarato (2015).

Following the tuning experiments with dancers and musicians, we began the creation of a second performance study (#2 on our website) (MacCallum and Naccarato 2015). In this eight-minute piece for dancer, percussionist and live electronics the choreography was once again designed to motivate gradual and intentional shifts in the heart activity of the dancer over time, roughly corresponding to the continual changes of tempo outlined in the musical score. ECG data from the dancer was used to inform the tempo of the live electronics, and further, to generate a real-time click track for the percussionist. As the percussionist played on the vibraphone (vibes), click track in ear, we asked him to explore ways in which he could engage with the click track as a partner, rather than as a dictator of tempo; the agency of the live musician in this study is a fruitful area that we will examine further in our practice.

In addition to temporal feedback regarding heart rate, the dancer was listening for the difference in pitch between the live electronics and the vibes. The pitch of the electronics reflected the heart rate of the dancer in realtime (as interpreted from ECG data and mapped to ranges of frequencies, with some randomness as part of the algorithm). In contrast, the pitch of the vibes was set in proportion to the temporal progression of the score (higher frequencies=faster tempo, slower frequencies=slower tempo). In this way, the pitch of the vibes also expressed the ideal arc of the heart rate for the dancer over the course of the piece. In each performance, the dancer and musician enacted a shared construction of time – a situated construction of time – within the liminal space between plan and action. Through her embodied, relational awareness, the dancer endeavoured to harmonize the two musical tones, and by extension, the multiple, continual becomings of self and surroundings.

Our vision for an evening-length production with twelve dancers and twelve musicians, described at the beginning of this section, is a monstrous undertaking in comparison to this study. With 24 performers onstage, as well as live electronics, the flows of awareness and agency will be exponentially complex. We are currently developing a piece along these lines with three dancers and three musicians, and the technical, aesthetic and conceptual concerns continue to proliferate in challenging and stimulating ways. Our practice is highly self-reflexive, as we remain vigilant in observing and shaping the implicit value systems regarding embodiment and technology that inform

our creative practice. Via sustained collaboration, we seek pathways towards a biorelational framework for performance with biosensors, that manifests through fluid assemblies of selves, others, and surroundings.

7. CONCLUSION

From the early twentieth century to present day, the integration of biosensors in artistic performance has evolved alongside socio-political attitudes towards the human body, ranging from biological and social determinism, to more embodied approaches which attend to the moving body-in-process; a body that continually makes and a remakes itself through a relational interplay of techniques and technologies. In this article, we reflected on the implications of common approaches to interaction design with bodies and biosensors, including biocontrol, biofeedback and metaphor, and proposed the importance of biorelational frameworks for performance; that is, dynamic systems that involve an oscillation of awareness and distribution of agency between diverse actors – human and non-human. In our current practice-based research with dancers, musicians and biosensors, the practical and ideological approaches to embodiment aforementioned are informing a long-term, transdisciplinary investigation of temporal relationality between rhythms in physiology, movement, music and mediated environments. The intervention of biosensors in our choreographic and compositional process is intended to destabilize familiar and normalized assumptions and constructions of embodiment, such that the questions and aesthetic material in our creations may stretch and transform.

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