Body Lutherie: Co-Designing a Wearable for Vocal Performance with a Changing Body

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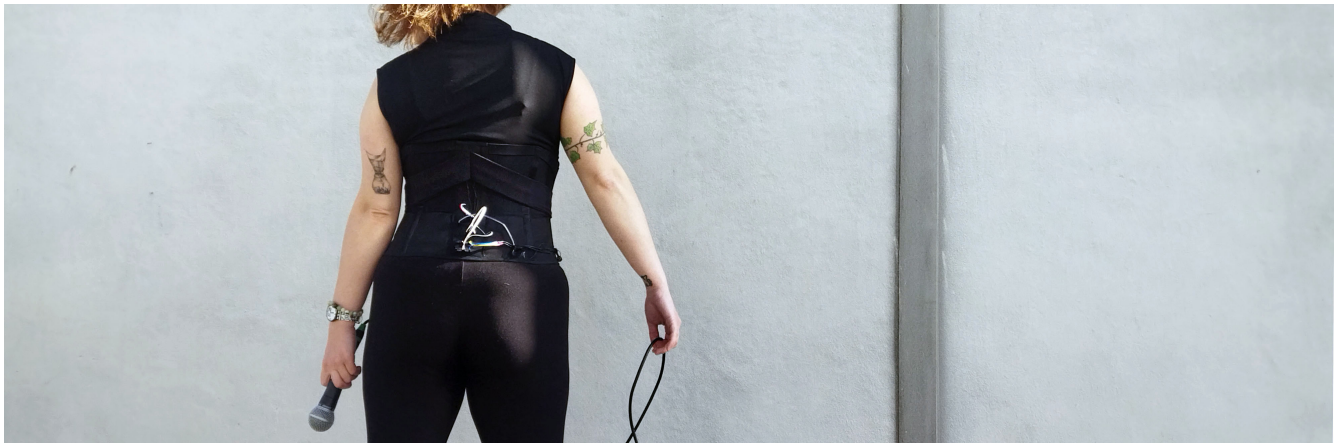

Figure 1: Body Lutherie in action: the breath-based vocal anti-corset, *Bones*, designed for the more-than-human voice.

ABSTRACT

Research at NIME has incorporated embodied perspectives from design and HCI communities to explore how instruments and performers shape each other in interaction. Material perspectives also reveal other more-than-human factors' influence on musical interaction. We propose an additional, currently unaddressed perspective in instrument design: the influence of the body not only the locus of experience, but as a physical, entangled aspect in the more-than-human musicking. Proposing a practice of "Body Lutherie", we explore how digital instrument designers can honour and work with living, dynamic bodies. Our design of a breath-based vocal wearable instrument incorporated uncontrollable aspects of a vocalist's body and its physical change over different timescales. We distinguish the body in the design process and acknowledge its agency in vocal instrument design. Reflection on our co-design process between vocal pedagogy and eTextile fashion perspectives demonstrates how Body Lutherie can generate empathy and understanding of the body as a collaborator in future instrument design and artistic practice.

Author Keywords

More-than-human design, vocal performance, eTextiles, agency, wearable interaction, co-design

NIME'24, 4–6 September, Utrecht, The Netherlands.

CCS Concepts

•**Applied computing** → **Performing arts;** *Sound and music computing;* •**Human-centered computing** → **Interaction design theory, concepts and paradigms;** *HCI theory, concepts and models;*

1. INTRODUCTION

Luthiers, crafting string instruments, work with living trees and their wood. Some properties of the luthier's materials are controllable: different species can be grown and harvested to specifics. But, other uncontrollable aspects — climate, weather, genetic expression, rainfall — also influence the wood. The tree brings its own agency and the luthier's intimacy with their non-human-yet-living collaborator shapes their choices as they meet design constraints and contexts [44]. The luthier's skill is derived in these decisions to work with the unique, living aspects of the wood [10]. The same can be felt in digital lutherie [52, 3]; a programming language's structure and parameters can shape choices in resulting sonic creations [36, 55].

Like trees, our living bodies are inconsistent, dynamic, and unpredictable, taking on strange and often uncomfortable qualities. In shaping our experience of the world, so too do our bodies shape our musicking. With ever-increasing attention on embodied perspectives in instrument design [43], practices such as somaesthetics [40] have analysed the subjective human experience of the body and its role in musical interaction. But, as much as our experiences shape our interaction, so do our physical bodies and their variability. Perhaps more so than musicians using physical instruments, the body's agency in musicking is intensely felt for vocalists. Both instrument and identity [45], the singing voice is

not only experienced, but also present itself as a physical, living aspect of the body. There are many aspects of the vocal body that are unable to be controlled.

This paper discusses our co-design, uniting Freire's perspectives of fashion, costume, and eTextiles with Reed's vocal performance and pedagogy, for the more-than-human physicality of a vocal body [17]. Drawing on somatic awareness [24], material-discursive practices [44], and Barad's agential realism theory [5], we propose Body Lutherie as a design practice to distinguish and appreciate parts of the entangled body that have a life of their own [18]. We outline the design of *Bones*, an *anti*-corset that emphasises expansion and shape changes in Reed's body over different time scales to capture her abdominal movements during vocal breathing. We work with an aesthetic eye for costuming, important in perception of vocal performance [16], in addition to functionality. We demonstrate through this co-design how the more-than-human can provide inspiration and guide the design of new musical instruments. We offer reflection and guidance on Body Lutherie and demonstrate how this practice can be utilised for NIME and broader human-computer interaction (HCI) research.

2. BACKGROUND

We first introduce embodiment and material-led design, in both NIME and broader HCI, to outline our proposed practice of Body Lutherie. Utilising Barad's agential realism, we de-centre elements of human experience to refocus on the more-than-human voice as contributor in musical interaction. We conclude with relevant eTextile approaches, through which we will enact this framing for vocal design.

2.1 Vocal Embodiment

Interaction happens via sensory perception through our living bodies [41]. Shaped by our sensory experiences, this embodied perception happens through our active role in our world [12, 56], extending to how we feel and think as we interact with other phenomena in it [38]. Perception and action cyclically shape each other, constantly evolving as we learn. Other living and non-living agents we interact with, like technology, become entangled in this cycle [18]. Instruments, including digital musical instruments (DMIs), become musical through our interaction with them [65] and musicians and instruments continually become entangled with each other in music-making [64, 43].

In HCI, and particularly within the NIME community, somaesthetic practices have been used to explore this embodied, sensory experience within musical practice [40]. Soma design practices [24] use the "somatic-turn" inward to the lived experience of interaction through bodily senses [54]. Constantly changing, our experiences of our living bodies provide space to examine and appreciate individuality and subjectivity [25] in musical practices and give attention to the role the body plays in this perception [24]. For instance, we can "make strange," our habitual behaviours to understand typical embodied experiences [37].

Cotton et al. engage with somatic experiences of breath in vocal performance. Cotton performs with a wearable, breath-sensing, pneumatic-actuated corset. In The Body Electric, this disrupts her habitual breath to examine sensory experiences of expansion around her body [8]. Similarly, the shape-changing garment can externalise the sensation of the breath, giving this somatic experience a life of its own [31] and demonstrating symbiotic relationships between the sensors and Cotton's senses during vocal performance [62]. In an examination of intercorporality, these internal sensory experiences of breath can be shared through haptic feedback and felt externally by others [32]. Reed et al. similarly examine somatic aspects of breathing in laryngeal movement via surface electromyography (sEMG) [48]. Reed's autoethnographic examination of her laryngeal muscles through sonification in vocal performance reveal how sensory experiences can be disrupted, highlighting how the body moves in unexpected and uncontrollable ways [49].

These examples focus on the authors' somatic experiences as vocalists; by disrupting habits and highlighting aspects of the living body, beyond typical sensory experiences, it becomes clear that the vocal body has a life of its own. The breath becomes strange [31] and the movement of muscles, previously unnoticed, becomes obvious and disruptive [49, 50]. With attention to these uncontrollable or imperceptible aspects of the body, our present research finds its place: we focus on the physical body, its semi-controllable states, and its agency in co-constituting our interaction.

2.2 Body Materiality

To focus on the physicality body as a factor of our experience with it, we draw also from the "materials-turn" in design research [13]. Materiality gives attention to how more-than-human agents, particularly physical materials, "talk" to designers; their properties (textures, pliability, density, appearance, etc.) are entangled with our experiences and contribute to the design of interactive systems [61]. This material focus is rooted in posthumanism [27]: Materials have no inherent meaning, but instead acquire meaning through our interaction [5]. Material properties can provide inspiration and enforce constraints [20]; for instance, textiles lend their own qualities to decisions in wearable design [30, 47]. Materiality is also part of the luthier's consideration: working with sensory-based material perception and selection [46] is part of the woodworking process [44]. Such posthuman perspectives have also been extended to discuss *data*-as-material [63, 2], for instance the social properties of biodata [26] in boundaries between human and machines in performance [33].

Drawing on and uniting these two turns — the somatic and material — we can examine the musical body as material to emphasise its agency, influence, and entanglements. As if a material, the voice only acquires its presence and meaning through encultured and contextualised perceptions of it. Nina Sun Eidsheim's organology of the voice demonstrates how the voice is not treated like other musical instruments [16]. The perception of the "voice" includes the space in which it resonates [15], as well as socio-cultural aspects that further dictate its meaning [14]. If the voice were perceived like other instruments, we might discuss it in such material-discursive ways, focusing on physiology, respiratory organs, and soft tissues. This body-as-material focus reframes the "voice" as a a dynamic collection of interdependent, more-than-human elements [7].

2.3 Body Lutherie

To examine the body's agency in vocal interaction, we take an intentional, conscious view of the voice as more-than-human organ [23], existing as its own within the entangled cultural influences and our experience living in it. We term this approach *Body Lutherie*, inspired by the material-led knowledge of luthiers in their designs with living materials. However, in comparison to traditional lutherie and working with wood, we can only design with the body we have. Our approach emphasises the body's quirks and ever-changing, growing qualities, both physically and experientially, to be

creatively included in DMI design. Body Lutherie highlights these aspects of the more-than-human as parts of a human assemblage [7]; parts of the physical body work as an musical ecosystem in vocal performance to co-constitute the experience of singing. Our ideal in a practice of Body Lutherie is to design for and appreciation the agency and influence the physical body brings to musical interaction.

Vocalists already acknowledge the body as both 1) part of the identity [45] through sensory-based understanding and self-recognition, and 2) an uncontrollable, often fickle, and separate force to be listened to and respected. Physiological changes like hormonal cycles, fluctuations in hydration, fatigue, age, and environmental stressors change our physical body and experience [22, 7], requiring us, vocalists or not, to adapt [21]. Vocalists make considerable efforts, even adopting near-superstitious behaviour, for vocal hygiene and care-taking [1].

Previous NIME research, such as that by Jensenius, Donnarumma, Tanaka, and Martin (with many others) demonstrate the body's agency, positively exploiting uncontrollable aspects of bodies through sonic interaction. Jensenius uses involuntary action like body sway, micro-movements [28, 29], and muscle tension in standstill performance [39] for interactive sonification. Similarly, Tanaka and Donnarumma explore the noisiness of muscles and the limits of gesture through sEMG sonification [58, 11, 59]. Tanaka also explores tension and restraint through playing with the boundaries between self and his physical body [57].

A practice of Body Lutherie can likewise distinguish the physical voice from the other concurrently arising perspectives of the embodied and encultured voice. Utilising Barad's theory of agential realism and the entanglement of agents as non-ontologically separate entities [5, 4] we make a particular agential cut [6] between these perspectives. Similar distinctions have been made with breath sensing: Body receptivity involved understanding how the voice was affected by movements and the influence of the self and voice on each other [60]. To be clear, we do not argue that the voice is not embodied and is not part of the human; rather, we cut apart aspects between the self (things we can perceive) and the unknown self (things we cannot) as inspiration for design with the more-than-human voice [17].

2.4 Fashion for Bodies and Voices

We enact our design for the vocal body through wearable eTextile design. When designing for and with the body, decisions are made as to the meaning of wearable garments for both inward and outward representation. The universality of clothing is something we all understand and utilise in our everyday lives [51]. Within the broad discipline of clothing design, we draw from a combination of costume, fashion, and garment technology perspectives. The research of textile historian Mary Schoeser illustrates that humans did not evolve and subsequently learn to weave, but rather the physical, structural act of weaving created conditions to facilitate complimentary structural evolution in the brain [53]. Similarly, Body Lutherie allows the structure of the body to guide design [61]. Interacting with the living canvas of the body, its conscious and unconscious functions, and the structure and materials of the garment - and responding to the often unpredictable, dynamic intersections of these factors - is what enables successful iteration and evolution.

We draw inspiration from vocal wearables at NIME, for instance the previously discussed vocal wearables [48, 51, 8, 32]. Of particular interest, *The Body Electric* is designed around Cotton's body and perception of her breath. The breath is semi-autonomic; when we are not consciously controlling it, the body takes over and functions independently, subtly outside of our realm of active experience. The observable expansion of the abdomen occurs as the result of diaphragmatic tension and control in singing, providing a visual representation of this constant rhythm.

As we design for Reed's body, it is important to note that the abdomen and belly, which expand with the movement of the breath, are of a particular sensitivity in the culture and environments in which she has grown up and lived. Physiological changes and fluxes are more commonly experienced by women and entangled with social taboos and expectations of women's bodies [22]; self-worth and vocal perception is commonly derived from the appearance of the physical body and its ever-changing shape through one's life [16]. However, much of the body's shape is uncontrollable and a result of genetic factors and environment.

3. CO-DESIGN FOR THE VOCAL BODY

We now turn to our design of *Bones* for Reed's body. Freire is an expert in textiles, costumes, and electronic garments, having previously designed interactive wearables for artists such as Imogen Heap [42] and cutting highly technical costumes for feature film [35]. Reed is a semi-professional experimental vocalist, and vocal interaction researcher. We introduce Freire's perspectives of bodies as a structural, living architectures and Reed's of her body as her collaborator:

3.1 The Structural Body

As a designer, especially in costume, we learn to see a person situated in their body. For example, costumes are often discreetly designed to empower and augment an actor or performer's inherent characteristics, expressed subconsciously through their physical body. It is the costumer's job not only to to tell a story, but to build the garment in a way to better enable the embodiment of a state or character. The preferences of the wearer and the overarching design brief may initially exist in opposition. This is balance negotiated at the technical level, reading the body as a material in itself. The person, their body, and the garment exist as a nuanced collaboration, rather than the oversimplification of the garment as a technical outerlayer over the body. A risk in designing complex wearables is the feeling that disparate elements have been combined and simply layered. Unifying these layers requires consideration of these aspects with equal importance, including changing physicality of the body both naturally over time and through the influence of materials as the design is developed.

Design benefits from a simultaneously functional and aesthetic approach as these elements should not be considered in isolation. The structural architecture of pattern cutting also requires a balance of instinct and observation and can be described from two predominant perspectives: technical (flat pattern cutting) and intuitive (draping). Complex garments utilise both, and deciding where to combine the two approaches requires physical prototypes and iteration.

The idea of a corset describes a highly engineered garment which has for centuries been used in differing degrees of collaboration with the body, both for support (medical), aesthetic control and constraint (waist reduction). Concessions may be necessary for the functionality of a garment, which might not best suit the preferences of the collaborating body, e.g., if comfort is a priority but restrictive elements must be in place for optimum functionality. These affordances are the conversation the designer/maker facilitates between the body and the garment. The maker must understand how to leverage the selected materials to best

suit the integrity of both body and garment. It is in the process of prototyping that material properties themselves have a voice in the conversation.

Our relationships with garments are symbiotic. They ideally become an extended part of us and the design process aims to harmonise where and how these elements intersect. We must see Reed's body and the garment as two collaborating actors, and the co-design process as a unified whole; a living entanglement of the conscious and unconscious, the human and garment. Careful observations along with tacit knowledge can enhance the design and how body and materials move in collaboration.

3.2 The Collaborative Body

Reed's relationship with her body is often as "other". Her vocal breath is linked with experiences of her past vocal teachers encouraging, albeit in a negative attitude, the benefits of "looking fat" to provide space for full diaphragmatic movement in singing. While singing, the diaphragm is contracted to create space for the lungs. Maintaining tension controls the breath, so as to not run out of air too quickly. But, this becomes very automatic, "I don't think about it much unless I know I will be strained for air in a particular vocal passage. My body just does its thing. I have had to spend a lot of time becoming comfortable with this idea of not looking as I would maybe like others to see me on stage." Similarly, Reed described her own perspectives on the superstitious vocal hygiene habits most singers take: "You have to pay attention to how your body is on a particular day... sometimes just wake up and know your body isn't going to cooperate or behave the way you want, and you need to plan how to behave if you've got a performance. You're almost at the mercy of your own body."

Discussion around Reed's explanation of her body and negotiating or collaborating with it inspired our Body Lutherie approach. To further the uncontrollable presence of the body, an unexpected shift in Reed's health and caretaking of her body after finishing her PhD and beginning a new job provided more unexpected variation: during the course of the eight-months of design at the time of this writing, Reed has lost 11 kg. This shifted the physical shape of her body, her experience of its agency in her vocal practice, and her perceptions of self over the design process.

4. DESIGN STAGES

Working with Body Lutherie, we designed a breath-based vocal corset, *Bones*.[1] We outline the design stages and construction from sensor to toile, intial and revised V1 prototype (Figure 2). Freire and Reed live in Spain and the UK, respectively, so the garment was fitted and adjusted over the eight months in a series of three week-long, in-person meetings in Germany while implementing it into collaborative performance [19].

4.1 Design Concept (Month 0)

The anatomy and discipline of controlled breathing helped us to identify the parts of the garment which would need to move and accommodate the vocal behaviour. We focused on the movement of the diaphragm in Reed's lower belly, at hip height. Observation of the physical abdomen allowed the body to lead the design and provided a starting point to inspire, describe, and devise a structured garment

[1]For reference, a video outlining the final design and demonstrating the sensing mechanism in performance can be found at https://youtu.be/nInRaOlby9Q?si=kiG_mpzaSpXqfw8S

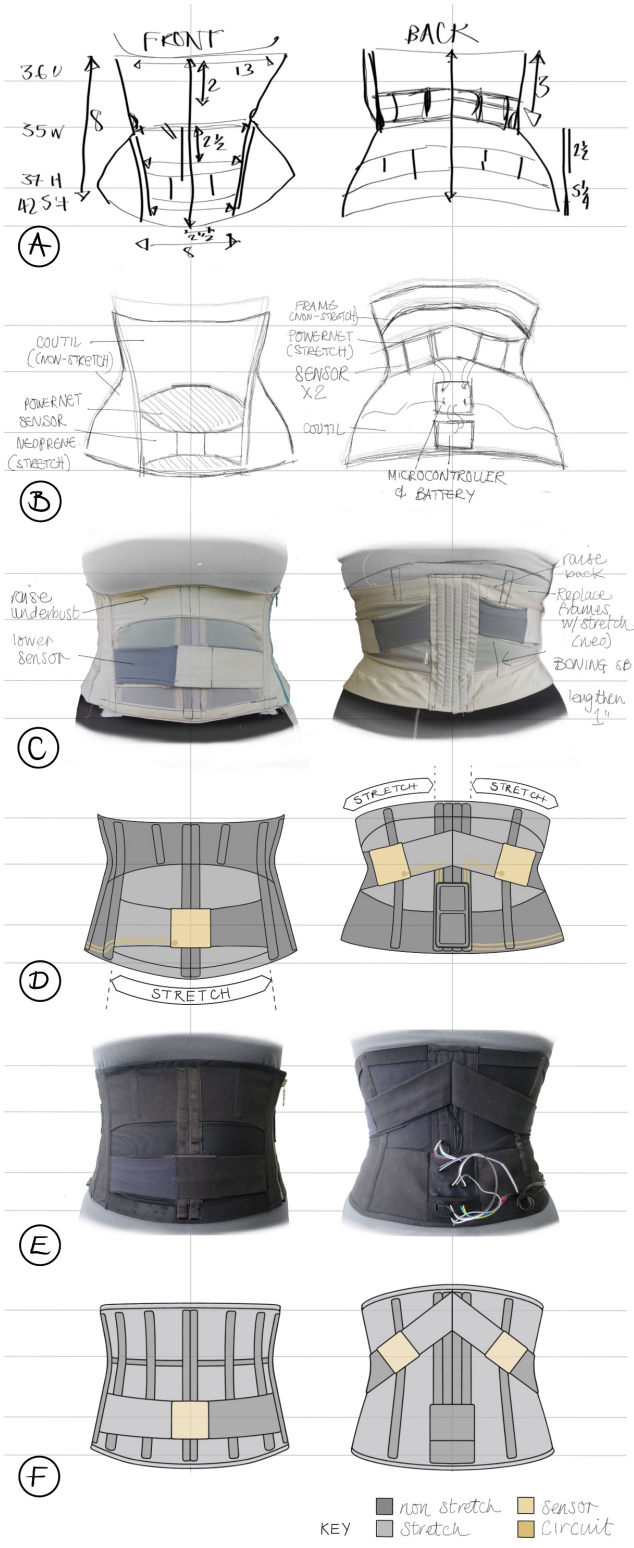

Figure 2: Evolution of *Bones*: A) Measurements, B) Concept Sketch, C) fitted toile, D) final design, E) V1 prototype, and F) V2 revised design

with both practical and aesthetic considerations. Observation also revealed that Reed's back, below her ribcage, also physically moves during vocal breathing. This sensation is absent from Reed's own sensory awareness; yet, the body's presence is visible. Freire's design honour the unconscious movement and the body's presence in its own right, placed a secondary focus on the back.

Reed, drawing inspiration from Cotton et al. [8], envisaged a 'corset' to capture this physical movement; however,, the design and restriction of a corset seemed antithetical to the dynamic qualities of the abdomen. Freire envisaged a design to balance the body's presence against a powerful visual silhouette and the collaborative notion of a support garment to devise *Bones*. The design is more an *anti*-corset, inverting the usual notion of a garment that sculpts and controls the body by restriction. Using a combination of stretch and non-stretch panels and leveraging the architectural engineering of a corset, the construction frames the body so that movement is localised in specific areas, to support rather than restrict the movement of Reed's breathing.

4.2 Shearing Sensor

We created a mechanical capacitive eTextile sensor using two layered straps of opposing stretch and non-stretch materials. The sensor comprises two panels of silver plated conductive material (Techniktex P130b), stabilised with a bonded film (Bemis Sewfree), aligned and centrally mounted on the straps. One of the conductive panels is additionally covered with a powermesh layer and Bemis to isolate the panels for capacitive sensing (Figure 3). The sensor uses the tension of the body during inhalation to create a shearing motion. The selected materials respond to gentle pressure without being restrictive or changing the body's shape. Capacitance between the conductive layers is measured as they shift apart, facilitated by opposing strips of stretch (grey) and non-stretch (ecru) fabrics (Figure 4). The aim was to keep the sensor as minimal as possible and for the material to disappear within the overall garment design. *Bones* contains three custom shearing sensors, two across each side of the lower back ribcage and one across the mid-section of the abdomen at the hip line, where we felt Reed's breath. The capacitive sensing was done using an off-the-shelf FDC2214EV board from Texas Instruments, connected through I2C to the micro-controller, a TinyPico.

4.3 V1 Toile (Month 1)

The design process began as a flat paper pattern made by Freire from a series of Reed's precise body measurements (Table 1). For a corset, this includes a small calculated reduction in Reed's natural measurements to create a snug fit. A *toile* is then made: the first physical iteration with which a design can be fitted onto Reed's body (Figure 6). The toile serves as a physical conversation to draw style lines on the body, tweak proportions, and to initially place active components according to the body's movement. Often a toile will be made knowing some proportions to be incorrect, purposefully creating a way to make corrections more accurately once on the body. The same garment rendered in different materials may be a completely different experience, so toiling materials should closely resemble the structure, stretch, and movement intended for the final design. Toiling and iterating is important because small changes often require a rebalancing of the entire garment and each person may experience materials differently. It is an opportunity to present materials in a physical form to understand what will best serve the overall design.

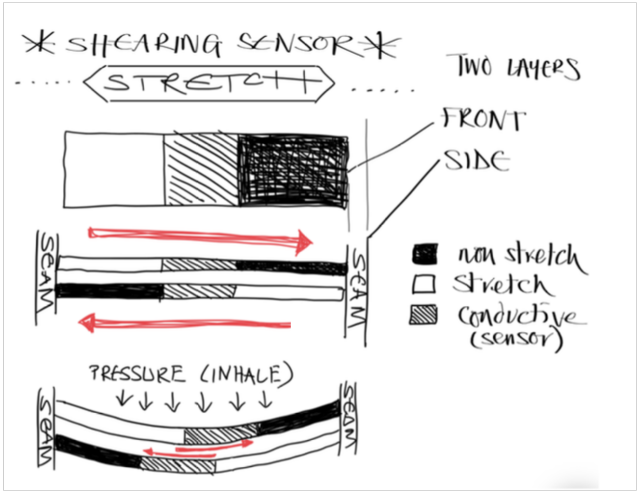

Figure 3: Sketches of the shearing sensors: two separate fabric layers, with opposing stretch and non-stretch panels, control the movement of conductive fabric in the centre.

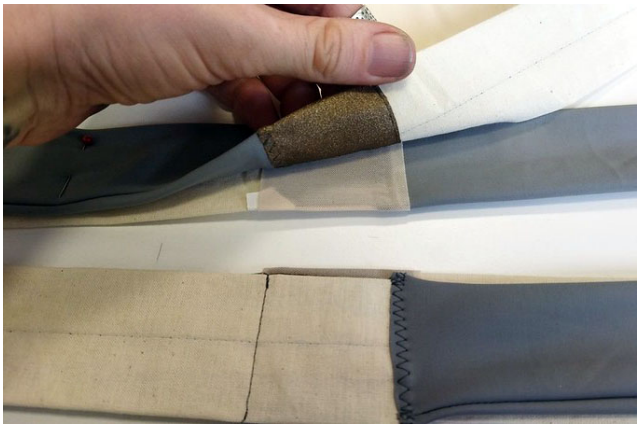

Figure 4: Layers in the shearing sensor, showing the corresponding layers of conductive fabric in the centre in gold, lower one with an added a layer of pink powermesh to isolate the two conductive panels.

4.4 V1 Prototype (Month 3)

The intial pattern was refined using alterations physically sketched on the toile during fitting. The proportions changed more than expected, due to the accurate placement required for the sensor on the abdomen. Additionally, Reed's body shape had dramatically shifted. When the toile was fitted and the body constrained within materials, we found that most breath-movement happened at a lower point on the abdomen than the initial measurements and unconstrained body had indicated. This is partially due to how the softness of the body works around the corset as an additional actor, controlling stretch in specific areas of the body, combined with the shape changes of Reed's body. The pattern was revised and the V1 prototype constructed to a stage suitable for another fitting. The main body of the garment and sensors were constructed and fitted again before completion, due to the influence of changes in materials when moving from toile to prototype (Figure 7).

4.5 V1 Prototype, refitted (Month 7)

After some months, we met again to finalise the V1 prototype in preparation for a performance. Reed's body had again shifted in shape (comparisons in Table 1), meaning

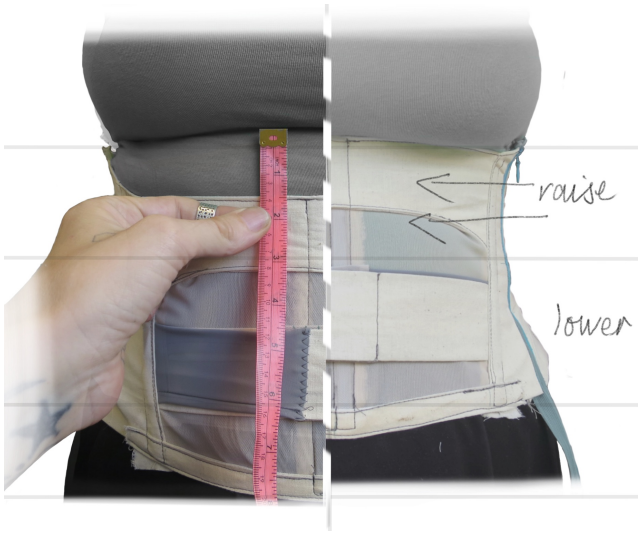

Figure 5: Toile fitting: Substantial changes in the overall placement (left) from initial intended fit (right).

the corset had to again be reduced and refitted to her body (Figure 8). The shape of the design was also adapted to take into consideration future fluctuations in size. The 'corset' had developed into what could be alternately described as a 'belt', removing some of the shaping and making the overall design more refined and subtle, without losing any functionality. Prototyping over an extended time period gave valuable information as to *how* Reed's body changes, allowing this to become part of the design development. Interestingly, weight changes are often viewed as monolithic increases or decreases; as seen in the comparison of measurements, we see that some measurements have increased while others have decreased. After refitting the corset, the garment edges were bound and reinforced to create a finished garment for Reed's body at the time (Figure 9).

5. DISCUSSION

We here share and discuss our personal reflections of the design process. Further, we outline design rationale for a future V2 prototype of *Bones* and propose how future designers can use Body Lutherie to generate empathy and understanding in the design of DMIs and broader HCI.

5.1 Who Wears Who

We approached the more-than-human aspects of voice in our design of *Bones* as structure and collaborator. This framing allowed us to remove some of Reed's experiential embodiment, just for a moment, to see how the body itself contributes in vocal interaction. Namely, we see how this agential cut to separate the physical body from the experiential body can help to counteract some of the negative dispositions or worries about the body. Reed's initial mindset was rooted in tension between societal expectations of women's bodies and bodies in vocal performance [16].

Engineering such a garment can give us useful information (e.g., in V1, the prototype began by controlling areas of stretch). A typical approach from a systems design perspective might aim to get as much from the sensor as possible. From our Body Lutherie standpoint, the V1 garment was most useful to inform *how much* control is needed for the garment to work optimally. Small changes and layering of materials can drastically change the effectiveness of the sensor mechanics. The garment does not and cannot exist

Figure 6: Annotated toile-in-progress: Implementing the abdominal (top) and back (bottom) shearing sensors around areas of expansion in Reed's body into the unfitted toile.

as the control point of the dynamic body; this approach is largely antiquated. Once we have a design which can indicate movement, comfort, and the effectiveness of controlling or allowing these physical aspects, the best solution may be a completely new approach and redesign, treating the initial prototype simply as a complex/laborious but essential measuring tool.

Where a corset is typically designed to give support (medical) and shape (fashion/aesthetic), these features have not always been sympathetic to the wearer, instead conforming to trends which negatively contort the body, the external influence of what the body *should* be. This is not new from garment design; the Playtex corsetry and lingerie factory made the Apollo spacesuits using complex techniques from this area of expertise: "a triumph of intimacy over engineering," as the epic tagline from the publishers synopsis highlights [9]. In this sense, utilising corsetry as a conversation and collaboration with the wearer is a relatively modern approach. Utilising Freire's treatment of the body as a flexible, dynamic material from a costuming perspective, the physical mobility of the diaphragm became a powerful force for interaction. The anti-corset emphasises these shape-changes; rather than conforming the body to the garment (e.g., the garment wearing you), the garment adapts to the body as it is, with all its dynamic messiness [34].

5.2 Cutting Apart, Cooperation & Empathy

The Body Lutherie approach is helpful to recognise the body as independent from our expectations of it. Especially in vocal performance, performer experience and expectations are often misaligned with actuality; disrupting the experience from the body can drive us to examine unconscious processes and our own behaviour [50]. Reed describes this relationship as revolving on trust and cooperation, as is seen in vocal pedagogy: "The way I understand my body is not

Figure 7: V1-in-progress: Remaking the corset and adjusting the sensor placements, fitting the garment with pins to Reed's abdomen (top) and back (bottom) after weight loss.

the same way I understand a person — we do not have a direct, spoken communication, but I know and trust that we understand each other." Through acknowledgement of the things we cannot change, we learn to listen to what is there and grow, adapt, and create with it. In this sense, the self and body, one element from an embodiment perspective [38], can be viewed as two separate-yet-entangled entities with this different agential cut [18]. The body does have agency and a right to exist as it is; tuning our musical interaction and using the more-than-human aspects of singing as a positive aspect can shape this trust and collaboration in performance and instrument design.

Narrating from Reed's point of view: "One thing that struck me in testing *Bones* is that I realised I am not so aware of these state shifts in my boy. Not to say that my action is not without intention, but rather that I let my body and internal awareness guide the process. I don't try to force movement. Over time and with more experience, I stopped paying so much attention to my breath. It's just there at times. I didn't realise how much my body was working and how this, especially from its physical presence, is visible and alive within me. Measuring this changeability was our goal, but at a small scale, in the changing of the abdominal and back muscles over a performance. However, in the design process, there were several-month-long periods where I did not see [Freire] in-person. In this time period, in my life outside of my music had changed, I had been looking after my health and started breaking unhealthy habits. As a result, I had lost about 7 kg between the first fitting of *Bones* and the next (between Months 1-3) and then 4 kg

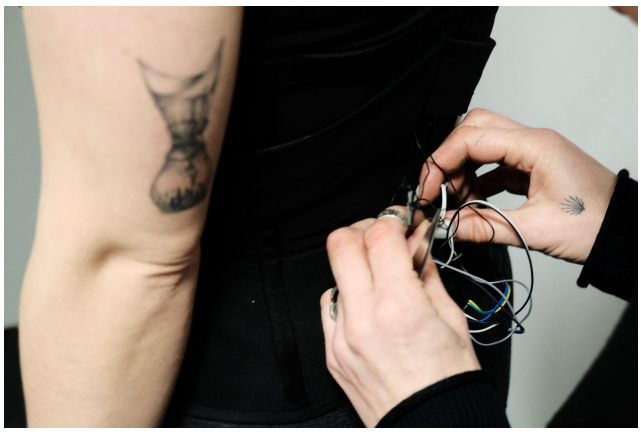

Figure 8: V1-in-progress: Re-pinning the corset shape (top) and fitting the shearing sensor (bottom) to a account for further changes in Reed's body.

Figure 9: Finalised V1 corset, fitted to the (latest) shape of Reed's abdomen (top) and back (bottom).

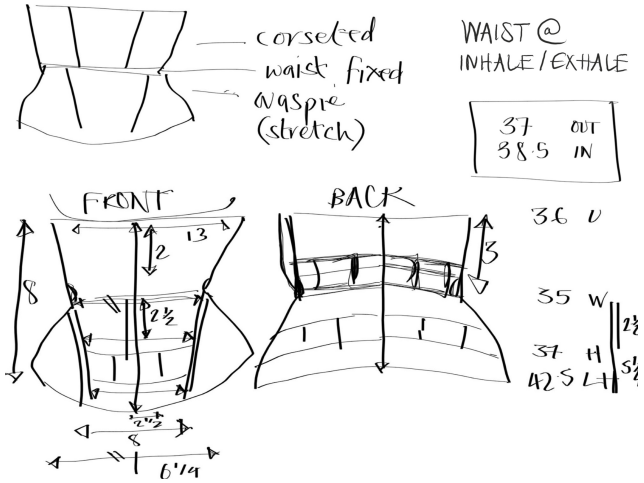

Figure 10: Measurement guidelines to map the shape of the body and fit the corset over the eight-month design period.

measurement	toile (M0)	v3 (M8)
underbust	36”	32 1/2”
waist	35”	31”
high hip (bone)	37”	37 1/2”
low hip (widest)	42 1/2”	39 1/2”
underbust to waist (front)	3”	2 1/2”
underbust to waist (side)	2”	2 1/2”
underbust to hip (front)	8”	7”
waist to high hip	2 1/2”	3 1/2”
waist to low hip	5 1/2”	5”
across front (underbust)	13” (s2s)*	16 1/2” (actual)
hip bone to hip bone	8” (s2s)*	13” (actual)
centre to hip bone (1/2)	6 1/4”	6 1/4”

Table 1: Differences between Month 0 (M0) M8. (*seam to seam, across front panel, as opposed to actual hip bone to hip bone.)

beyond that before the most recent fitting (Month 8). Of course, none of the sensors worked as they had before and the garment and Freire's construction of it had to react to this change in my physical instrument. This will happen again and again, as our bodies are constantly changing.”

This Body Lutherie perspective furthers the feeling of empathy and collaboration with the body; rather than something to be controlled and mastered, vocal practice and instrument design might benefit from allowing the body, as a material, guide the way [20, 61]. Recognising our sphere of control and limitations of our physical bodies can lead to embracing uniqueness and variability [34]. This deference to the more-than-human can offer insight for new designs and interactions, such as depicted here. In the end, this can lead to deeper connection and appreciation of the body itself in addition to our experience of it [25].

5.3 Developing Body Lutherie

Drawing on material-discursive approaches [61], we proposed the practice of Body Lutherie for the NIME community and interaction designers more broadly. Our design of *Bones* demonstrates how conscious focus on the body itself, beyond our experience of it, can guide the design of vocal controllers. In order to adopt this practice more broadly, we suggest the incorporation of costume practices as done here. Body-mapping strategies for experiential aspects captured in somaesthetic appreciation design [40], sketching, photography, and pattern-making for the physical body can be used to highlight the role the body plays in instrument design. Often these elements are performed but not documented. Given stigmas around the changing body, such as those felt in cycles of weight-shift, it is crucial to acknowledge and empathise with the body in musical interaction. Documentation and dialogue around the body can shift from conforming to sensors and wearables [62], to honouring bodies and their contribution to musicking. Future work in this space should continue to share these practice, potentially resulting in the development of a framework for Body Lutherie or a “work-book” style approach to foster creative conversations and approaches to working with the more-than-human aspects of instrument design.

In the space of vocal bodies, there are many other more-than-human, physiological aspects to explore through Body Lutherie. The hidden physiology of the larynx [48] and other internal organs in singing are wordlessly understood through singer experience [49, 50]. Applying a body-focused design to complement the somatic approaches previously used by vocalists has the potential to highlight vocal interaction by comparing and contrasting these distinct agential cuts. Body Lutherie as an approach is applicable to other body-based musical control; for instance, gesture-based relationships in performance have been explored through the messiness of sEMG [57] can be further examined through these post-human perspectives of the body. Perhaps most excitingly, we hope Body Lutherie will generate new creative and experimental perspectives through working with the input of the body and its noisy, uncontrollable influence [57, 49] as a full collaborator in musical performance.

5.4 V2 Revised Design (Beyond Month 7)

Through the toile, prototype, and work with Reed's changing body, we assessed the benefits of controlled structural design and identify a new approach for further development: making the whole garment stretch, rather than enabling movement in specific areas. If it works as effectively, this design approach benefits from its potential to fit more bodies, as well as natural fluctuations in individual bodies. A hybrid approach may be optimum for specific bodies and an assessment to compare designs will give us this information. A ‘one size fits all’ approach is often a necessity for a design to accommodate multiple bodies, but this often results in quite the opposite, with the average of people falling in between a sensible designation of sizes. However, using elements of this design approach is beneficial to factors such as the body changing over time, small fluctuations in weight, differing comfort levels due to hormonal cycles, injury, fatigue or emotion. Such changes are present for most, but not all people. The revised design goes to the opposite extreme and focuses on accommodating the changing body. The next assessment will be to see at what cost: Are the sensors as effective? The original design works well. It is stable, comfortable and aesthetically pleasing, but is heavily engineered. While our design development process made it less specific to one unique body *shape*, it is still specific to body measurement i.e., size, in regards to the range of optimum functionality. The intention is to streamline the construction, but we hypothesise that ultimately a hybrid approach will be optimal. To achieve this requires realisation

and comparison of both design concepts to find the balance between the two. A living design, like a living document, requires a liminal approach which builds in the capacity for change. Sometimes there is a need to go backwards to move forwards - exploring and subsequently consolidating seemingly very different branches of an idea - which is not always an obvious trajectory when designing, iterating and refining a complex design concept. Future work with Body Lutherie can provide a strategy for embracing the more-than-human in designing for the body, reacting to the materials as they change unexpectedly, without forcing an outcome.

6. CONCLUSION

We present a breath-based vocal wearable, *Bones*, and our approach through Body Lutherie to design this new instrument. We collaborate with the more-than-human voice and its shifting characteristics to inspire our design process. The paper demonstrates how agential cuts to selectively and consciously distinguish the body from our experience can reveal new open new collaborative opportunities and instrument creation. We discuss Body Lutherie's future in NIME and HCI research, proposing strategies for others to apply this perspective to their own instruments and bodies.

ACKNOWLEGEMENTS

We would like to thank our colleagues and friends Paul Strohmeier and Valentin Martinez-Missir for their inspiration and musical explorations during our design process. We would also like to thank our physical bodies, for working with us during this research and design process.

ETHICAL STANDARDS

We have no conflicts of interest nor sources of funding beyond our listed affiliations to declare. We have sought to develop NIME's environmental values by re-purposing fabrics and off-cuts during prototyping to reduce textile waste.

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