The Body as Sound: Unpacking Vocal Embodiment through Auditory Biofeedback

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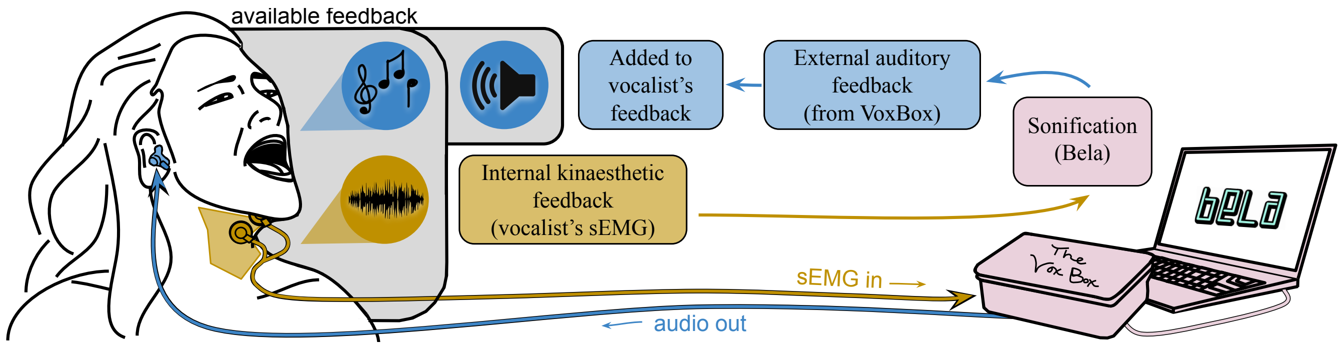

Figure 1: Externalising internal sensory experiences with the VoxBox: the vocalist's internal laryngeal movements (internal kinaesthetic feedback, yellow) are captured with surface electromyography. The VoxBox uses the sEMG data to generate a sonification (external auditory feedback, blue), which is added to the existing auditory feedback while singing (grey box).

ABSTRACT

Multi-sensory experiences underpin embodiment, whether with the body itself or technological extensions of it. Vocalists experience intensely personal embodiment, as vocalisation has few outwardly visible effects and kinaesthetic sensations occur largely within the body, rather than through external touch. We explored this embodiment using a probe which sonified laryngeal muscular movements and provided novel auditory feedback to two vocalists over a month-long period. Somatic and micro-phenomenological approaches revealed that the vocalists understand their physiology *through* its sound, rather than awareness of the muscular actions themselves. The feedback shaped the vocalists' perceptions of their practice and revealed a desire for reassurance about exploration of one's body when the body-as-sound understanding was disrupted. Vocalists experienced uncertainty and doubt without affirmation of perceived correctness. This research also suggests that technology is viewed as infallible and highlights expectations that exist about its ability to dictate success, even when we desire or intend to explore.

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CCS CONCEPTS

• **Applied computing** → *Performing arts*; • **Human-centered computing** → *Empirical studies in HCI*; *HCI theory, concepts and models*; Sound-based input / output.

KEYWORDS

embodiment, tacit knowledge, sensory translation, auditory feedback, musical interaction

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1 INTRODUCTION

Recent work in HCI demonstrates the need for attention to bodies and relationships which develop between technology and humans, with a shift from viewing the body as an object for interaction to the body as a lived experience [59, 88]. This focus on the experiential relationship we have with our bodies, and with the technology that extends them, combats the view of the body in third-person observation as being merely a mechanistic entity which is capable of physical gesture and sensory ability. Such perspectives can lead to misinterpretation or cases where technology dictates how bodies should be [10, 72], contrary to the individuality and plurality of bodies and our experience living in them [85]. In working with or designing for bodies, we shape and design bodies themselves [32]. Therefore, we must be aware of the first-person experience and felt human *understanding*, which is inseparable from and shapes interaction and perception.

Arts, whether through music, dance, or other fine arts, provide an interaction space which is at times directly anti-utilitarian: paralleling the idea that bodies are more than just mechanical entities accomplishing tasks, artistic practice focuses often on the subjective individuality of human experience. There is no "accuracy," per se. While requiring refined technique and control over the body, the *experience* of artistic practice cannot be fully measured through the typical third-person observational standpoint because it is inherently internal. We here focus on a unique musical interaction in the vocalist-voice relationship: Moving from the third-person view of the body as an object capable of sensing and action to the first-person perspective of the body as loci of experience, the voice presents a unique paradigm of interaction in that vocalists rely also on their own external sound production for this first-person experience.

In this paper, we explore the vocalist-voice relationship through a somaesthetic approach, designing a probe to disrupt the habitual and externalise the internal experiences which form embodied vocal interaction [33, 36]. We capture the internal sensory experience using surface electromyography to detect laryngeal muscular activation. Rather than measure it from an objective, observational point of view, we present it back to the vocalist as an external auditory feedback. For the vocalist, they are made aware of movements within their body which would normally be unconscious or embedded in larger action paths. We present a case study of working with two vocalists over a month-long exploration of their practice with the probe This approach allowed the vocalists to uncover new understanding and awareness of their practice and previously unconscious movement. Using additional micro-phenomenological inspired methods [68, 71], we co-investigate the experience with the vocalists to uncover how the feedback also disrupted their existing understanding of the voice, resulting in personal doubt and blame, in deference to the perceived ability of the technology to dictate correct behaviour.

This work furthers the focus on technology design for bodies beyond their physicality. We demonstrate the intertwined, multimodal understanding of singing as an artistic practice and how technology can align with or disrupt existing embodied understanding. Based on the work with the vocalists in this work, we also reflect on the perception of technology as providing "ground truth" about bodies and how this expectation shapes the way humans feel about and view their bodies and movement.

2 RELATED WORK

2.1 Bodies, Lived Experience, and Entanglement

Third-wave HCI centres interaction through and with our bodies, moving away from work- or task-driven, "purposeful" objectives, to focus on social, cultural values in interaction, human understanding, and being in the world in everyday life [19, 28]. Post-phenomenological approaches focus on how our lived experience is intertwined with the body as part of our identity. The mind and body are inseparable and every action depends on a highly internalised working routine formed as a result of this being in the world [29, 94]. Perception and action are linked [14, 91]; the feedback we get from the world and from technology cyclically influences our behaviour [21], which is informed through the sensory information we get from acting and living in our environments [22, 23]. Over time and with experience, the line between body and technology begins to blur and effectively these become one functioning entity [63]. Technology becomes a part of lived experience, and indeed who we are [21, 97] and the way we think of ourselves [60].

Embodiment-focused design has begun to address the role that technology plays in perpetuating or challenging existing assumptions [3] that generalise what is "normal" [85] and influence human behaviour and attitudes about bodies [20, 61]. Individuality and diversity in lived experience shape our living bodies; there is no singular physical 'body' entity [85]. Considering individual perceptions shaped by gender, race, physical health and (dis)ability [85], and culture [99], the HCI community has turned focus to first-person perspectives and the soma [32, 53] — the "inner" living body and our connection with it — rather than a hypothetical end user [64] or a view of bodies as external, mechanistic systems. [65, 74] The knowledge of embodied practice can aid the development of context-specific technologies that work with our existing awareness and understanding of our action [16, 38].

2.2 Tacit Knowledge and the Voice

Tacit knowledge arises from living in our bodies [66, 87] in a way that is inexplicable and goes beyond language [2, 13]. In addition to the typically discussed sensory modalities in interaction, we understand our experiences through proprioception and interoception, which provide awareness of the state of the body, movement, and tension and effort in action [9, 61]. This further challenges the notion of the body as a purely mechanical agent; driven by mechanoreceptors and neuromuscular processing, this internal understanding is not externally measurable, compared to other feedback about the body [40]. As well, much of the fine-grained sensory dimensions of our interactions are lost in the rapidness of experiences [68]. Between the richness of pre-reflective experience in the moment and reflective awareness, there is a reduction in the details of sensory perception that can be recalled without evoking the original experience [69].

Interaction with and understanding of the voice is not immediately accessible and therefore depends on strong sensorimotor links and tacit knowledge [39, 79]. The vocal musculature exists within the body, requiring the vocalist to have a critical understanding of their action-to-sound pathways [27] and how to control their body without tactile or visual feedback [30, 31]. The perceptual division between body and musical instrument is extremely blurred [49, 50, 63, 84] and the instrument is viewed as part of the musician's identity and view of self [4]. This is especially the case considering the blend of internal and external feedback which comprise the first-person experience of the voice, which, as an instrument, is already part of the physical body [67].

However, being externally inaccessible to other parties, the most common way of interacting with the voice, either for the singer, another human listener, or a technological agent, is not through the body but rather its sound [75] — listening to and analysing the vocal audio feedback by ear or through recording and digital analysis. The experience of singing therefore plays with the boundary of interior and exterior sensory feedback, relying on a multi-modal understanding of kinaesthetic feedback from within the body and the external, auditory presence of the voice [27]. One major difficulty in developing technology which works with this embodied interaction comes from the fact that technological agents require some way of measuring gesture and action for input. At the moment, most digital systems work with external feedback data, such as overt movement or audio; such externally observable signals provide an information source that is, at best, a proxy for the inward experience. When the system's interpretation relies only on the results of a movement or interaction, we can lose its meaning and the intention in that action [94].

2.3 Exploring the Habitual through Somatic Approaches

Different somatic approaches have been used to provide designers and practitioners with a way to convey the sensory experiences which emerge [80]. For instance, disrupting habitual practice brings attention to internal sensory elements of interaction [25] and tacit knowledge we normally would not be aware of [33]. This shifts perspectives from the third-person inquiry of *What can we observe about the body,* to first-person attention of what constitutes an individual's relationship with their living body. In design practice, somaesthetics have been used to explore embodied understanding of interaction [35, 83]. Tacit knowledge can be made more at-hand to an individual through awareness of their movement or changes introduced into their typical behaviour during a task [34], *making strange* the lived body [52] and experiencing how we understand through *bodily ways of knowing* our movement, action, and emotion [33]. This can further inform the design process by using existing embodied relationships as a source for creativity and reflection on one's movement [12, 55].

Somaesthetic inspired design practices using additional biofeedback have explored such connections with bodies while singing. This has been particularly focused on capturing internal sensory experiences as a direct method of interacting with embodied awareness and technique. Laryngeal movement has been expressed through sonification [75, 76] and breathing through external tactile feedback [11, 12, 92]. Use of these more direct methods of interacting with bodies, rather than just the vocal audio, challenges and augments the habitual relationship between the vocalist and voice and allows an individual to apply their bodily ways of knowing to learn through experiencing in and through the body, acknowledging it as more than an object [33]. This somatic approach has provided introspection into elements of control and the boundaries between the body as internal self and external presence, moving from connection, to disconnection, and ultimately questioning of the internal relationships with and through the body [12].

In taking a somaesthetic approach to make strange and provide additional feedback of body movement, we can provoke exploration of the balance between internal and external sensory experiences while singing. Biofeedback in this way displaces the internal sensory experience, manifesting it as an external stimuli or representation of the body. This feedback occupies the third-person perspective of the voice normally used for listening to one's own voice; in the same way, the externalisation of these internal sensations is fed back to the vocalist to be re-internalised in their lived experience and understanding of and through their body.

3 METHOD AND DESIGN RATIONALE

Lived experience is comprised of aspects that are internal and others that are external and also measurable. The affordance of examining these modes with the voice is in the interlinking of these experiences; both internal kinaesthetic and external auditory feedback provide the basis for the vocalist's understanding. The perspective taken in this paper is unique in that it shifts the perspective: the boundary between internal and external feedback is manipulated to provide vocalists with an external representation of something they would normally perceive internally. This re-introduces a familiar sensory perception in an unfamiliar way. This study aims to investigate how the vocalists' awareness and understanding of their movement changed with the introduction of this novel feedback.

We therefore adopt a somatic approach in creating a design probe which would allow vocalists to interact with their embodied practice through novel auditory feedback. Given that the existing relationship relies on coordination of sensorimotor control and auditory feedback, we use surface electromyography (sEMG), employed in previous vocal interaction studies [75, 76], as a way to externalise the internal kinaesthetic feedback. We worked with two vocalists as they explored their embodied vocal practices while engaging with this novel feedback about their movement. This study focused on co-exploration through a long-term interaction with this feedback.

It is important to note First Author (FA) is a semi-professional vocalist and conducted this study with experience having used the methods outlined in this study and been engaged with the technology and its iterative design for over a year beforehand. FA's experience in examining their own lived experience directly influenced the structure of the study and the approach used. As well, in leading the study and working frequently with the vocalists, FA's background provided an environment where the participants were able to speak with relatability, expressing themselves without need for explanation of the domain-specific experiences, and with understanding throughout the learning and exploration of their practice.

3.1 Surface Electromyography

We use sEMG as a data source for capturing the internal movement of singing. The vocal musculature relies on proprioceptive awareness to control and position in the highly skilled movements of professional singers; although we cannot directly measure this experience, we can measure the movement, which would normally not be visible from an external measurement. Using electrodes adhered externally to the skin, sEMG measures the neural impulses which cause contraction of the muscles beneath, providing a way to measure movement without directly seeing it [89, 90]. The sEMG would therefore allow for direct interfacing with the physical vocal movement, as opposed to the resulting vocal audio [75]. sEMG has been employed in a number of musical contexts to detect [15, 90] and provide new gestures during musical performance [43, 46], allow musicians to explore their movements in spontaneous composition using the body [18, 44, 54], provide feedback about control, restraint, and interaction with the body [42, 89], and reinforce motor learning [45]. In vocal contexts specifically, sEMG has been sonified to provide information about the body's movement in external auditory feedback for interaction while singing [76]. Similarly, sEMG has been sonified for therapeutic uses, as this externalisation of internal bodily sensations is found to be useful in reinforcing learning [5] and providing understandable information about changes in movement and effort [51, 93]. Sonification of biofeedback is found to be engaging and rewarding in rehabilitation through the emotional cues provided within music [41, 56], which may further strengthen the learning process in terms of skill practice.

3.2 Micro-phenomenology

This work primarily involved the use of interviews inspired from the micro-phenomenological discipline [68]. Micro-phenomenology has been used to explore tacit knowledge and provides in-depth, fine-grained detail about individual moments in experience. Rather than evaluating the technology itself, the experience itself, as it was lived, is determined. The discipline centres around gathering pre-reflective structures of interaction [98]: sensory awareness in the moment of experience occur rapidly but can be uncovered and brought to awareness through the evocation of an experience [68, 70]. The micro-phenomenologist and participant co-investigate the experience through a micro-phenomenological interview. This method can reveal details about the experience which would have been unconscious at the time, resulting in a clearer diachronic structure (the entire experience chronologically) and synchronic elements (dimensions in a clear-cut moment) of the experience. Synchronic details form the "landscape" of an experience, while diachronic details depict that landscape's evolution [71]. This is complemented by further reflective accounts of the experience gathered through semi-structured interviews, analysed using inductive thematic analysis [6, 7]. We therefore use this discipline with the aim to balance exploration of reflection-in-action as the vocalists worked with their biodata and post-hoc reflection-on-action [81, 82].

The goal of this study was ultimately for the vocalists to explore their lived experience through working with the sEMG and examine how this impacted their perception of their movement over time and revealed insights about their understanding. Rather than being focused on the technology itself, we conduct the interaction through a probe designed specifically for the expression of internal sensory experience in an external way. We use micro-phenomenology as the main focus for this investigation because the data provided by the interviewee is from a unique *second-person perspective*, which can be thought of as narration; the interviewer conveys the interviewee's experience offering balance to the first-person subjective and third-person objective components [77, 96]. Because the experience captured is pre-reflective, the discipline allows investigation of tacit knowledge; although elements of the experience may remain difficult to verbalise, the method can bring attention to fine details of experience which otherwise might have been overlooked. The discipline has been used within HCI and music interaction, more specifically, to focus interviewees on their experiences [73] and the explanation of *what* happened, rather than *why*. It also aids the development of a vocabulary for embodied dimensions of knowledge and has provided space for interviewees to re-live their experiences and gain new insight on their interactions [77].

4 APPARATUS

4.1 The VoxBox

We created the VoxBox as a probe to externalise an internal sensory experience: the control over the laryngeal muscles (Figure 1). Through providing a sonification of the laryngeal movements while singing and externalising this proprioception, we aimed to afford vocalists a novel context to experience their living bodies. The VoxBox collects the analog electrical signals of the muscle activations during singing and sonifies them, using the muscle contractions to generate sounds which can be interacted with in real-time by the vocalist. The VoxBox uses a VoxEMG board, a PCB implementation of the sEMG amplification circuit we previously developed for vocal sEMG interaction [75, 78] and a Bela Mini [57, 58] for processing the sEMG data and rendering the sonification (Figure 2). The VoxBox allowed the vocalists to easily set up an sEMG feedback system using their personal computers so that they could sing in their usual rehearsal spaces, disrupting the habitual in the vocal action but not in the practice environment itself (Figure 3). Included in the VoxBox kit are pre-gelled adhesive disposable electrodes (Kendall H124SG ECG electrodes, Cardinal Health), cabled electrode clips (CAB-12970 sensor cables, Sparkfun Electronics) for gathering sEMG signals, as well as kinesio tape (Kinesiologie-Tape, Altapharma) for securing the cables, if needed. The kit also included a pair of basic, wired in-ear headphones (Aurora, iFrogz) to ensure that the listening environment was the same for each participant; these are intentionally non-noise cancelling so that the participants would be able to hear themselves at the same time as the sonification played back from the Bela, effectively blending the external stimuli of the vocal audio with the sonification audio.

Participants also received a digital guide, *Working with the VoxBox*, detailing the components, how the box works, a tutorial for using the Bela browser IDE to run the sound design, and other setup and troubleshooting steps.[1]

4.2 Sonification

Using the VoxEMG board [75, 78], the VoxBox measures muscle movement and represents it as an external sound. The sound design used the incoming vocal sEMG signal voltage to provide a presence for the laryngeal muscles through auditory feedback. Sonification was done within Pure Data and, rather than manipulating the vocal signal itself, used the sEMG signal to control a soundscape in which a vocalist could explore their action and movement through an additional synthetic sound, independent of the sound of the voice.[2]

For the vocal feedback, the differential of the sEMG signal is calculated and mapped to the cutoff of a highpass filter applied to

[1] The full *Working with the VoxBox* guide can be found here: https://bit.ly/vox_box
[2] The PureData patch and examples of this sonification can be found here: https://github.com/courtcourtaney/voxEMG/tree/master/examples/VoxBox

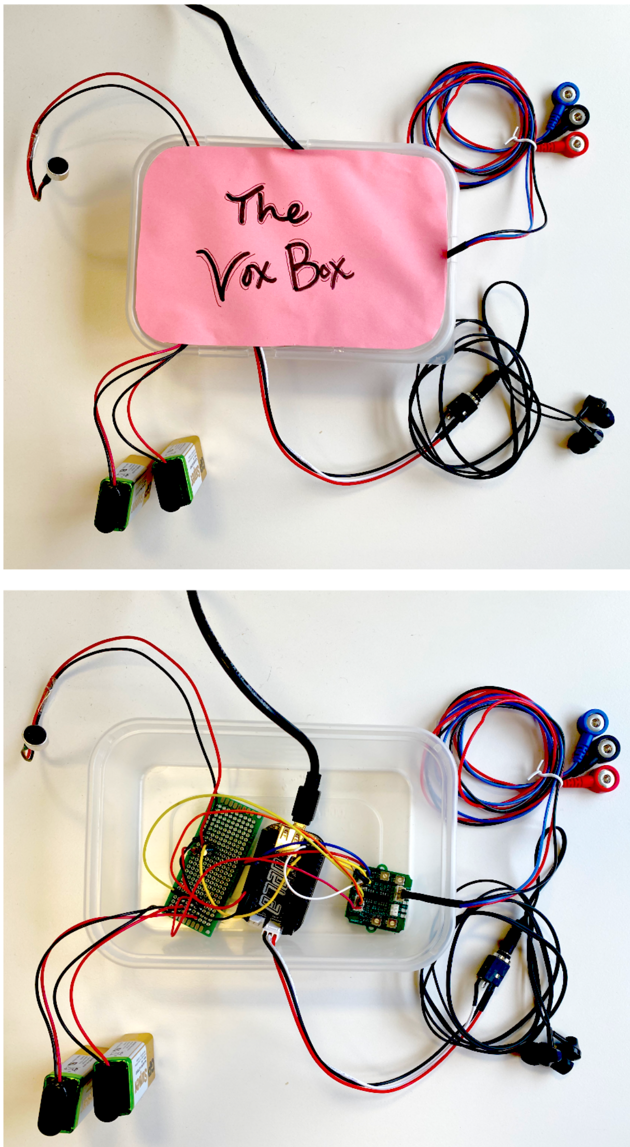

Figure 2: The VoxBox: external cables for electrodes, headphones, power supply (USB and 9 V batteries), and microphone (top), and inside a VoxEMG board, Bela Mini, and routing for power supply (bottom).

a white noise generator (Figure 4). This causes a sort of *whooshing* when the muscle contracts and there is a large change in the sEMG signal. With another noisy drone, the result is a non-musical soundscape where the body is heard as an ambient filtered noise, stimulating a sort of wind or breath with a slightly scratchy quality.

We intended that this would represent the tension within the muscles during contraction as an external, auditory presence, rather than an internal, kinaesthetic one. Where the muscular movement would largely be unconscious, the sonification aimed to move the awareness of the movement outside of the body. The goal was,

Figure 3: A participant uses self-palpation to secure the electrodes to her neck (left); the VoxBox being worn by a singer during their singing practice (right).

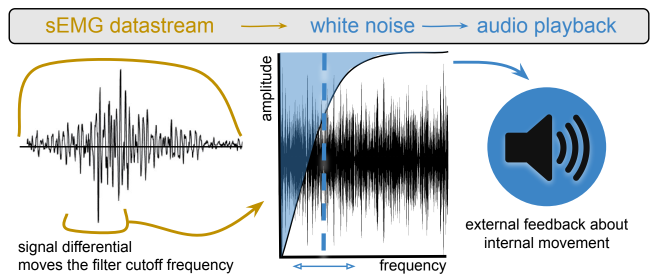

Figure 4: Translating the vocalist's sEMG signals to audio feedback: the differential of the sEMG signal is used to move the cutoff frequency of a filtered white noise. This audio is played back to the vocalist as an external feedback about their internal movement.

through the sEMG sonification, to pull the body's movement out of the existing action paths and make it distinct, so that a vocalist might be able to interact specifically with this movement, where normally it might be unconscious or understood at a higher level in their action. The sound design was intentionally non-vocal and non-tonal to ensure that it did not interfere with whatever the singer wanted to do, and also to provide a degree of separation between the muscles and the vocalist's high-level understanding of their practice. This ideally positions the body, expressed through the sEMG sonification, as a separate entity and a collaborator to highlight control aspects and understanding of lived experience [1, 12, 62].

5 STUDY

5.1 Participants

A call for participants was made through FA's personal network of performers, voice scientists, and vocal educators. We wanted to focus on extensive engagement, both in terms of time and content detail, with the participants to capture the particulars and emergent discoveries of each vocalist, as opposed to common elements in such a subjective experience [24]. Therefore two singers were selected for the study: both female, aged 29 and 31. The participants were from Brazil and Egypt, now working in Berlin and Barcelona, respectively. The vocalists were chosen based on their current engagement in regular vocal study and performance and interest in technological applications within vocal practices. Vocalist 1 (V1) is a singer-songwriter and vocal teacher who also works from time-to-time in audio production. She performs Hindustani music and is studying Indian classical vocal techniques with another teacher on a weekly basis. Vocalist 2 (V2) works in computational music research and is pursuing a PhD in music information retrieval. She performs regularly and rehearses weekly with a small jazz ensemble. She has also recently branched into generative electronic composition with an all-female computer music group in her city.

5.2 Procedure

5.2.1 Briefing. All communication with the vocalists was done over remote audio-video Zoom calls. I (FA) will refer to myself in first person from this point to describe my work with the vocalists. Together with the vocalists, we first identified the anatomy, using a self-palpation exercise to locate the hyoid bone and one of the laryngeal muscles, the geniohyoid, which helps to position the floor of the mouth [26, 86]. We continued this exercise together until the participants were able to recognise the muscle location with a little practice. The end- and mid-electrode sites, just above the hyoid and in the centre-middle of the flesh under the chin, respectively, were located with my guidance and the participants practiced placing the electrodes, feeling the movement while holding them in place and opening and closing their mouth, and listening to the sound design with this action.

5.2.2 Study Phases. The study consisted of two parts: 1) an Exploratory phase, and 2) a Targeted Technique phase. Each phase lasted two weeks. For the Exploratory phase, the vocalists were asked to incorporate the VoxBox into their usual routine. The goal was to establish a connection with the sonification and provide a free-form exploration. The Targeted Technique phase involved singing a set of targeted vocalises (exercises for vocal warmup), which focused on four vocal fundamentals: supported breathing, posture, sound production, and sound shaping. The specific exercises chosen (see Appendix A) were intended to cause noticeable audible movement. After, the vocalists were free to continue exploring the sonification as they pleased. They were also tasked to record themselves with audio-video, for instance on their computer or phone, for later review and to keep a basic journal of anything they had found notable in their perception or feeling about the interaction. The data collected were aimed to balance the pre-reflective, in-the-moment experiences of the sonification, with further reflection after each use [82].

5.2.3 Debriefing. In between each phase (end of Week 2 and Week 4), we conducted a debrief which lasted approximately 45 minutes. For Week 2, this consisted of a short semi-structured interview about initial impressions and feelings about working with the sound. The vocalists also chose a moment of interest, either a connection or a disconnection with the sonification, that they wished to explore in detail through a micro-phenomenological interview with me. The same was done for the Week 4 debrief, with the addition of the vocal fundamentals. The vocalists were asked to describe the vocalises as they noticed them with the sonification and answer a few questions on their expectations of the auditory feedback they received. In a follow-up micro-phenomenological interview, the vocalists were asked to recall a moment similar to the previous exploration (e.g., if the vocalist felt a sense of connection while doing a particular behaviour, another instance of this connection from the most recent two-week period was explored). The full sets of interview questions for the two debriefing sessions can be found in Appendix B.

5.3 Analysis

Interviews with the participants were transcribed at the level of utterances. For the micro-phenomenological interviews, satellite dimensions — that is, moments in the micro-phenomenological interview where the interviewee slipped away from their evocation of the specific experience and spoke more generally or about other, similar experiences [95] — were marked and omitted from analysis. The remaining evocation was structured into a diachronic and synchronic timeline. A bottom-up, inductive, reflexive thematic analysis was then conducted to organise the vocalists' communication of their interaction, both during the micro-phenomenological interview and semi-structured interview [7, 8].

6 RESULTS

Overall, the vocalists reported spending about 6 hours (V1 = 5.25, V2 = 6.5 hours) working with the kit during the course of the month. I will narrate the vocalists' experiences in present tense, as they would have described the evocation during the micro-phenomenological inspired interview. Each specific experience is noted in **bold**. The structure of each experience is outlined and presented in a figure, where the x-axis depicts the diachronic succession of the experience. The y-axis depicts the synchronic depth of the sensory perception in a singular moment. I have used arrows to show how these small perception details form the larger overarching moment in the experience. As well, I have depicted these details by their modality: tangible sensations in red, auditory in yellow, and emotional characteristics in blue. There were no visual details uncovered when the vocalists and I inquired further about what they noted during the experience. If the vocalist was able to identify the location of these sensations somewhere in the body, this is also noted in a bubble placed above their description.

It is important to note that, if we had explored a different moment or other aspects of the chosen experiences, the details revealed would likely have been different. However, we expect to see that the overall structure of repeated experiences to be similar or reveal consistent stages and aspects of interaction [68, 71].

6.1 Vocalist 1

Initially, V1 was able to connect her movement and the resulting sound and indicated that it influenced her movements during her practice. This was mostly related to movement of her neck and head while not singing; she often sits at her piano while practicing and noted that she would hear responses more clearly in her body sway while playing. This made her more aware of her position while getting ready to practice and in ancillary gestures while warming up. She noted that, although she usually sits to play, she had not

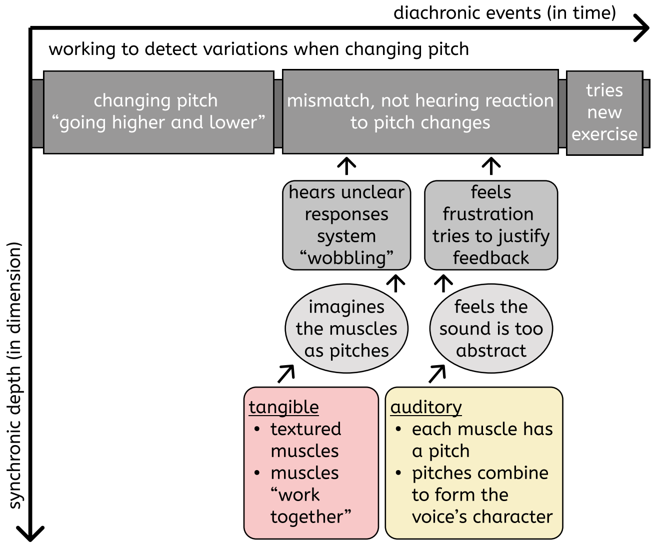

Figure 5: Vocalist 1, Experience 1: V1's sensory perception while experiencing mismatch and feeling "useless" in her interaction, while exploring feedback for her register switches.

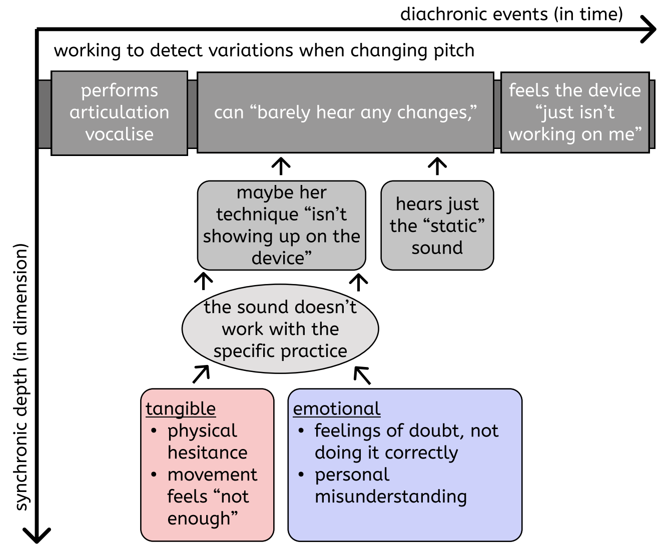

Figure 6: Vocalist 1, Experience 2: V1's sensory perception during an experience discerning the sEMG activation during her breath before a long phrase.

thought too much about how this was happening, focusing primarily on being relaxed above all else. Over time, she was able to connect these movements, which were otherwise unconscious, to the response of the sound design. Other non-sung vocalisations also produced a noticeable reaction in the sound — something was different when she spoke in a lower register while wearing the electrodes, but she elaborated that she could not pin down exactly what was happening. However, when singing, she most often felt disconnected from and out of control of the sonification; this appears to be due to a mismatch between V1's perception of her body and her singing and the system's behaviour, which meant she struggled to negotiate the system's reaction and her expectations for it.

6.1.1 V1: Micro-phenomenological Perspectives.

Experience 1: We explored some of V1's feelings of frustration and disconnect (Figure 5) in a moment where she was not able to find a notable response from the VoxBox when she was changing her pitch and moving between different vocal registers: "**I didn't feel like I was interacting with the sound while I was doing something, which made it a little bit like useless to me. I felt useless for the device,** let's put it like that way."

V1 begins an exercise where she moves between her chest and head registers to capture the greatest changes in her range and explore the VoxBox's reaction. After a few alternations, she feels a sense of mismatch and notices no clear reactions in the pitch of the sonification, although she notes a "wobbling" in the audio feedback. She feels a sense of frustration and tries to consider why she is not hearing anything. When I ask her *When you are feeling this mismatch, what do you feel?*, she imagines her muscles as different pitches, where the muscles have different textures and layer over each other. They combine to make the tone of her voice; she hears them as separate tones which work together to form a whole sound. She wants the sound design to behave similarly, where there would be an indication of each muscle's movement (she imagines multiple muscles, even though only one is being measured) and similar layering to create a harmony. In the end, she hears only small changes in the sonification and feels frustration that the sound is too abstract. This is difficult for her to explain, but she remarks that she feels nothing happens when she expects it to. In the end, she moves on to try another exercise.

Experience 2: V1 and I again explore a moment of doubt. V1 questioned her technique while practicing the sound production vocalise and **wondered if really that she was not moving her muscles, because of her own fault in her technique.** We uncovered some tangible sensations and as well explored her emotional experience while this moment unfolded (Figure 6).

The moment begins with V1 singing the first phrase of the articulation given for the sound production vocalise (singing descended from sol to do on *ta*). As she repeats the phrase, she becomes more and more frustrated that she cannot hear anything notable from the VoxBox in response. She hears only the "static" noise generated by the sonification. In this moment, she thinks that maybe there is something about her technique which does not register or cannot be picked up by the voice. She worries that, based on the tension needed to belt and use her chest register most of the time in Hindustani music, that her muscles are not moving properly: "if they [the sounds] are not moving, that means that my muscle is not moving... I'm either hesitant to think that perhaps my technique is not great. That's why nothing's happening... Or, it's just that the muscle is moving always in the same way. So therefore, also everything sounds the same." When we explore *What does it feel like when you feel the sound is not working with your technique specifically?* she tells me that she feels a physical hesitance or that her movement is

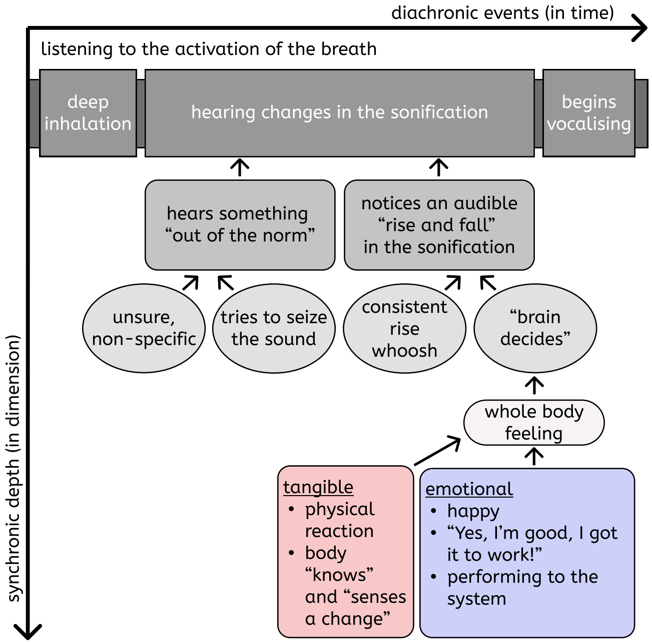

Figure 7: Vocalist 2, Experience 1: V2's sensory perception during an experience discerning the sEMG activation during her breath before a long phrase.

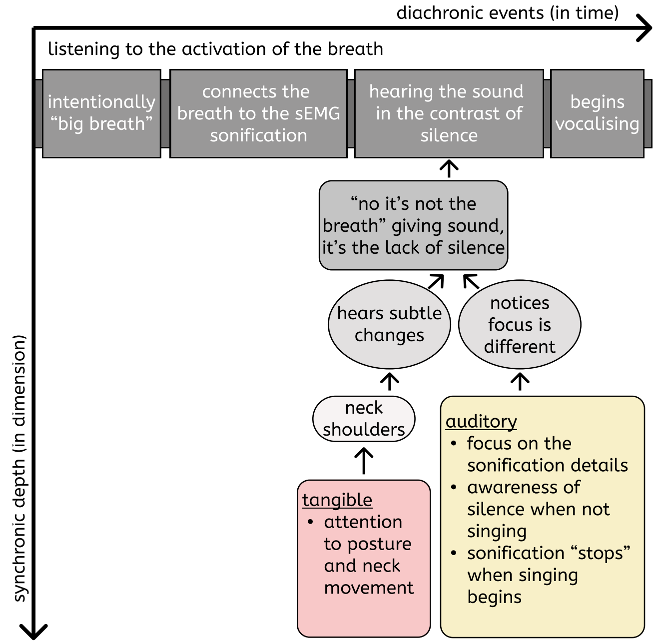

Figure 8: Vocalist 2, Experience 2: V2's sensory perception during an experience where she feels her changing focus while breathing.

smaller or less active than it should be. Emotionally, this is paired with a sense of doubt and of personal misunderstanding of how the box is meant to work. In the end, the moment finishes with her conclusion that the VoxBox must not work with her specific vocal practices.

6.2 Vocalist 2

V2 felt more connected in some moments than others, but overall more in control; additionally, the sound design felt natural and she was able to make more connections between her movement and the sound over time. She was able to make connections with activity in her body when she was engaged and preparing to sing; specifically, she attributed what she could hear as a tension, for instance in deep breathing and the resistance of holding long notes for varying time lengths. This was also associated with a relaxation or movement in timekeeping or acting as a "metronome" with the body, wherein the looseness and tension "would help in also these muscles moving." However, similar to V1's experience, V2 struggled to multitask between the auditory feedback from the VoxBox and her own voice. Because of the spontaneity of the sound design, often she would be able to hear a response in the auditory feedback but unable to determine quickly enough in the moment what she had done to influence the system. She struggled to give attention to the sound design while she was singing. When trying to go back and find that activation again, V2 noticed her consciousness and efforts to recreate the behaviour removed the natural approach she originally had, making it hard to receive the same interaction from the system — the awareness subverted the instinctive behaviour.

6.2.1 *V2: Micro-phenomenological Perspectives.*

Experience 1: V2 explores a connection and awareness she had to her breath. She remarked that, when she sang longer notes, **she noticed a change in the sound but she couldn't quite pin down what was happening.**. We further explored the sensory interactions that made up the moment of her noticing this interaction — what was going on at the time of her realisation (Figure 7).

First, V2 prepares her breath to sing a longer phrase. She notices that there is a change in the sonification, but this dies away as she begins vocalising. When I asked her *How do you feel that something has changed?*, she says that she hears something "out of the norm." She is unsure initially of what that is, but notices the departure from the constant noise and "tries to seize" the cause of the sound, but is unable. She determines that there is a change and hears an audible "rise and fall" in the sonification. Interestingly, she remarks that "my brain decides, not me." When I ask her *What do you feel when your brain makes this decision?*, she replies that her body responds — the decision of her brain is felt in her body, again reiterating that this is a more physical response than a cognisant auditory understanding. We further explored this sensation in the body as having a physical reaction, albeit not an easy-to-describe one, and that there is a "knowing" in her body as it "senses a change." As well, this change is felt with a notable emotion of happiness and V2 thinks to herself "I got it to work!" She does something that the VoxBox has picked up on and feels a satisfaction as she receives the response from the sonification. The experience ends as she notices the response dies away after she begins to sing.

Experience 2: V2 has begun to uncover her connection to her breath being a result of her changing focus while singing. In moments where she sings, it becomes harder to focus on the sonification as she "tunes out" other feedback besides her voice. We explore a moment where **she realises her shifting focus when she is breathing before beginning to sing, and "that's when I can hear [the sonification]"** (Figure 8).

V2 knows that her breath is something which the VoxBox responds to. She is working on one of the breathing vocalises to test this interaction in repetition. She begins and takes an intentionally "big breath." She hears the sonification and again connects this to her movement. She then feels a sense of contrast, going from a relatively silent and continuous sonification to changes in the sound design. She realises this contrast is obvious without the sound from her voice; this silence and focuses her attention to the sound design. In this moment, she notices more subtle changes in the sound design. When asked *What do you feel when you notice these subtle changes?*, she is aware of her posture and small movements in her body. The awareness centers in her neck and shoulders. She comments as well that she knows these small adjustments to her posture provide easy-to-hear responses from the VoxBox, although it appears this comment was a more general satellite dimension — rather than being specific to this experience, it is a justification she makes based on her previous encounters. Her focus feels different than normal. She concentrates on the details of the sonification becoming clear. When I ask her to explore *What do you feel when this sonification becomes clear?* she feels that her attention shifts as she breathes and then just again before she begins to sing. The experience ends when she begins to sing and the sound of the VoxBox is removed or "tuned out."

6.3 Reflexive Thematic Analysis

Thematic analysis of the two vocalists' interviews revealed three main themes pertaining to vocal embodiment: 1) *The voice is its audio*, 2) *The necessity of assurance and correctness*, and 3) *The infallible technology and the body and self to blame*. These themes capture many of the individual points in the analysis highlighted above, and reveal further detail about similarities between the two experiences for discussion:

7 DISCUSSION

We here discuss the thematic analysis in conjunction with the micro-phenomenology inspired structural analysis of the vocalists' experiences working with the VoxBox.

7.1 *The voice is its audio.*

Feedback about internal movements was delivered through sound; however, this created a barrier to understanding at times because, as indicated by both of the vocalists, it occupied the same sensory channel they were already focusing on — the auditory feedback of their voice. As we see from the micro-phenomenological analysis, V1 had an existing image of her voice and how her physiology worked. Based on the images of her muscles combining to create the timbre and characteristic of her voice, V1 effectively understands her body *as a sound*. This auditory reference allows her to explain this understanding, even though she does not have a concrete understanding of the action itself:

> "Muscle is very complex... the combination of all of them creates this kind of sound that I hear. I try to picture it like this: so that you have three textures. And then they are all constantly mixing up with each other while I'm using my muscles, but because they are my muscles and it's the technique I have, I'm always getting the same sound."

She explains further that, in comparison to the sonification used in the study, she might have preferred having a representation similar to this existing image for the interaction with the VoxBox:

> "Obviously, in the practice, the most important thing is that you really hear your voice and what you're doing in order for understanding what you're doing with your muscles... If those three muscles had their own particular pitch, then I would know exactly which muscle is working."

V2 expresses a similar feeling of distraction and inevitably tunes out the sonification while singing. We see that she was able to connect to the sonification well when she was not actively vocalising, for instance in her breathing exercises and when working on posture and alignment:

> "I think remember what last time, I was telling you that when I take a big breath, this is when I hear some change. It's because, when I'm taking a breath, that's when I'm not singing. And that's when I can hear... In the beginning, I was saying, 'I'm not hearing any changes,' no, there are subtle things happening [while singing]... I think I have a good ability to drown out sounds, which is something I do if I'm concentrating."

Similarly, V2 also expresses that the sonification interfered with her existing attention. She remarked that the feedback should be given in another "channel," separate from the audio feedback she was already listening to:

> "What's the best form of feedback? I think if it's the same channel as the other thing that you're actually doing it becomes really hard. Yeah, it's like if someone is doing something visual, don't give them visual feedback, give them other feedback."

This suggests that the vocalists already rely on a mapping to what they hear and know how to react physically, even if they cannot describe verbally what that reaction is. The intention in externalising the internal kinaesthetic feedback through sound was to play with the existing external feedback the vocalists were relying on. However, the existing vocal audio feedback is, in these cases, being used as an explanation for and is entangled with the physical action. This seems to be a sort of sensory translation process: aspects of the sound utilise a tacit understanding of what is going on internally, as if through synaesthesia [17, 101]. Competition for attention appears to disrupt this sensory translation for understanding. In moments where there was no active vocalisation, using audio feedback might not have been so disruptive because there was no pre-existing connection or active attention to sound; instead, the focus was able to be turned to the sonification as an externalisation of the kinaesthetic feedback within the body, allowing the vocalists to uncover details about their posture, breathing, and other non-vocal activity.

This may also explain why V1 wanted the feedback to behave as her voice did, perhaps to then match the existing way she understood her practice. For V2, she did not give attention to the sonified feedback, similar to what she does with other sound sources while focusing on her own singing as the critical point of understanding her control. The voice and control over vocal musculature seems to then be understood inseparably from its audio; although the singers were very cognisant of their bodies when describing their practice, they struggled to work with the separation of the laryngeal movement and the disruption from the sonification. The audio is heavily responsible for the innate understanding of the voice, almost to the point of exclusivity. When describing the voice in her micro-phenomenological interaction, V1 relates the movement of her muscles to tones and pitches; V2 describes her awareness as a change she can hear based on something her "brain decides." The link between movement and fine-tuned motor control is determined on sound, linking the awareness and sensory experience of the body to its sound is a very fuzzy, overlapping way. This reliance on audio feedback for motor control and understanding of physical interaction is a sort of translation between the senses; this is not a sensory experience which has been previously found in other places in the body and is perhaps unique to the voice.

7.2 *The necessity of assurance and correctness.*

The vocalists express a need for reassurance and correctness in their exploration. V1 expressed that guidance on what specifically she should be hearing or training to know "what to pay attention to" would have helped her focus:

> "Perhaps I needed help recognizing different pitches that the device could produce, so I could have paid more attention to all the sounds. I think I would have needed you to show me. This is how this it should sound."

Interestingly, V1 again is focused on the pitch of the device, expecting it to mirror her interpretation of her voice. In using the probe, there was no expectation that it should sound any way in particular, as outlined in the initial briefing. Likewise, although she knew it would inevitably shape her interaction, V2 wondered if working with others and reviewing their interaction might be helpful as reassurance during her interaction:

> "I don't think that our bodies are alike so I don't think it's possible because of different references and other things, but... to sort of see and understand what happened with other people, what other people are saying, and then sort of to build my expectation a bit would be helpful. Even though that might bias the way I think... it's nice to grab onto something."

"Correctness," is a difficult aspect of vocal pedagogy to assess. Vocal teachers focus more on what is healthy and comfortable for the individual singer. Further, the individual physiology, musical careers, and lives of these two vocalists would have shaped very different approaches and lived experiences to drive the interaction. In the same manner, embodiment has no consistency amongst the diverse lived experience [85]: different bodies move in different ways and the experience is unique to each person. Despite the study being explained as a chance to explore their relationships with their body and being reassured that there was no expected behaviour or outcome, both V1 and V2 expected and wanted to have some kind of affirmation that what they were doing was correct. This might suggest some kind of participant bias, where the openness of the study directive left the vocalists wanting to make sure they were hitting the mark with their participation [37], but might also suggest that, especially when learning a new interaction method or practice, the reassurance or confirmation that what they were doing was more important than how connected they felt with their own body. Without a reference and consistently working independently, both felt it was hard to tell what should be expected of them and their behaviour.

However, the need for this reassurance and indeed the community aspects are very intertwined with learning and technology use in unfamiliar contexts: we learn from watching and mirroring others' behaviour, which forms a good deal of our own practice. V1 usually measures her performance with a tuner or against the piano, while V2 relies often on her ensemble to gauge her practice. In this sense, we are biased towards what we are taught or what others are doing; perhaps by providing the singers with a specific reference or example, they might have been taught to listen for particular sounds and learn the sonification from a third-person observational perspective, as a data source [100]. This highlights how the feedback and information provided in the learning process influences perception of individual, personal parts of our lives, and indeed our bodies themselves [32]. If it is important and natural to seek confirmation from others about individual experiences, particularly those involving the body, it is important to make sure information is shared in a way where the depictions of the body do not *dictate* one's own body [72]. In an ideal situation, we might present an interaction context where there is no such interpretation, but humans naturally seek patterns in understanding the world, making the desire for structure an important factor which must be negotiated, even when there is no ground truth. The use of the VoxBox and similar technology then shares a similar risk with other instances of "quantified self" [10, 47, 74], even when designing in opposition to quantifying the body.

7.3 *The infallible technology and the body and self to blame.*

There was a personal association to the interaction seen with the both vocalists: getting a clear reaction and connection from the VoxBox was reassuring and encouraging. For the moments where there was a disconnect between the expectation and the sonification, it was generally viewed as the fault of the self and body, rather than the technology. Neither vocalist commented that they thought the VoxBox was broken or was poorly designed. If there were such feelings, perhaps they were not conveyed to avoid sharing negative feedback. On the other hand, the vocalists shared many worries that, somehow, their actions or techniques were to blame. V1 worried her technique was somehow incompatible or that she just did not understand the device as a fault of her own. V2 doubted her practice routine and wondered if her practice was too "lazy," resulting in underdeveloped muscular movements. Although this encouraged her a bit to spend more time "challenging herself" in the future, we see the negativity that can be placed on one's own perspective of themselves by technology.

There is a feeling that bodies must adapt to technology, rather than the other way around [60], or that technology is somehow "infallible" and knows best. When something goes wrong, the vocalists jumped to blame themselves, rather than considering that maybe the device was at fault. We see how then technology can shape perception and the body itself [32, 85]. Reiterating again the previous theme, using technology, whether intentionally or not, as the source of ground truth or "typical" qualities about the body can neglect the individuality in experience [85]. With a restrictive view, we may fall into the trap of the quantified and influence thinking about our bodies by conveying "ideal" or "normal" response in biodata feedback [48, 72, 85]. There are any number of reasons that the sEMG might have been difficult to use in this study. Perhaps, in a way interesting to design research, it was because the feedback disrupted an existing audio-motor pathway, as discussed above. There is a mismatch between the design goal, to create a probe which allowed for exploration of the vocal technique through novel feedback, and the vocalists' expectations of the technology. Both vocalists had an expectation of the VoxBox *to tell them* something about their body and practice, rather than for it to be used as a channel for them *to explore their action*. Most of the technology we interact with in a daily basis tells us something about the world; it is very rare for technology to be oriented towards exploration, leaving participants of somatic studies looking for an answer [37]. The vocalists placed some kind of trust in the technology. When it did not work the way they expected it, this was interpreted as a personal fault.

7.4 Motivations in Externalising the Body

The major affordance of sEMG is that we are able to capture aspects of internal movement, which is normally perceived through proprioceptive sensing, as external feedback. The technology could function within the quantified self paradigm, providing a marker against which vocalists measure how much laryngeal tension they should have or judging the control over their muscles as being sufficient or not. Whether such a device is possible is unclear, but probably unlikely given differences in physiology. Philosophically, the VoxBox comes from the opposite direction, intending to provide a backdrop and context for exploring lived experience by externalising sensory experiences which are not normally conscious and providing new insights into individual interaction. This suggests that other sensing methods can also be used in the design of interactions for exploration with the internal, particularly through biofeedback.

However, considering the above theme, it is important to acknowledge the role that this interaction has on our perception of self and ability from an ethical consideration. In this study, it is clear that connection to the data through embodied understanding is also dependent on the design of the technology itself and our entanglement with it [60]: by providing a context which was too open-ended or exploratory in nature, participants did not have enough confirmation of their actions or the ability to gauge whether their expectations were appropriate. This can also create feelings of being lost or uncertain. Individual interpretation and perception should be acknowledged to avoid over generalising experience; yet, guidance with reflection on that could be used to create encouraging environments for difficult tasks such as exploring movement or learning new skills. Although there was no direct quantification of the self, as one might see on a fitness tracker, and the interaction was designed specifically as a probe to explore embodiment, the inability to connect with the feedback provided resulted in misinterpretation of action and ability [20, 47, 72]. This can be seen in related work, wherein participants attempt to fit themselves and their bodies to an interface [60], rather than believing the interaction should be adjusted to their needs. This highlights that "quantification" of the self is not just a numbers game, and these expectations of performing to a system, rather than the system performing to you, are entrenched in the way we view and interact with technology [32, 60].

7.5 Limitations and Future Work

Continuing with the attention to bodies and diversity of experience, it is worth noting that working with other participants would have likely yielded different results and interactions. Future work would benefit from the exploration of similar internal-to-external sensory translation, either within the vocal context outlined here or through the development of further probes for internal sensory experiences. For instance, sports sciences and other movement-based artistic practices would be key areas for further iterations of this type of study. In this vein, it would likewise be beneficial to further explore vocalists' perceptions of their bodies as instruments and their interaction with their physical experiences in singing, aside from technological mediated activities; adding to previous research on singer identity [67], this type of introspection will provide a "baseline" of how vocalists view this relationship with their body-instrument and highlight individual perspectives going into further studies with biofeedback.

Additionally, the use case presented in this paper deals with a month-long exploration in an isolated, remote study. Conducting the study in person or with a longer time frame might have shaped the experiences differently, providing better support contexts to work through frustration during the interaction and ample time for learning the internal-to-external translation as it evolved over different lengths of use. As suggested by V2, it might be worthwhile to conduct this type of study by comparing explorations of such lived experiences in a group setting to a solo activity.

Finally, we see in this specific case that the auditory channel of interaction revealed an understanding about vocal embodiment *because* it disrupted the existing interaction. Perhaps using tangible or visual externalisations might be more useful for some singers who rely more on this existing audio connection; future work might incorporate flexible rendering of this externalisation through different modalities to allow for more reactive exploration of lived experience through sensory domains which better match individual embodiment. In these cases, frustration and connection may be linked to different modalities for different people. It will be worthwhile to work on bespoke designs and mappings for individual users, for instance through a co-design strategy or workshop environment where vocalists are able to explore different modalities of biofeedback, mappings between their biodata and the feedback, or even other sensors beyond sEMG.

8 CONCLUSION

This work exploring vocal embodiment, in both the body and with a technological extension of it, revealed the intertwined representations and understanding of the body as multi-sensory experiences. Through a design probe which allowed vocalists to explore their physical movement through laryngeal sEMG sonification, we uncovered that vocalists understand their bodies and actions through the vocal sound. Auditory mappings provide a translation for kinaesthetic experience and understanding of movement, rather than awareness of the muscular actions themselves. This work contributes to the understanding that embodiment does not refer only to the physical body; humans understand their bodies and actions through diverse sensory representations. To acknowledge only the physicality of experience in the design of technology focused on movement limits connection to the existing embodiment in practice. This work further demonstrates how the addition of biofeedback can create awareness of movement and provide attention to previously unconscious movement; however, this work also shows how disruption of existing embodied understanding lead to doubt and personal blame for the inability to connect with the technology. The use of this design probe demonstrated how technology is viewed as infallible and dictating what is correct. This understanding further highlights the need to focus on individuality in design and maintain awareness of the role and expectations of technology on the way we view our bodies and selves.

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A VOCALISES

The vocalises tasked to the vocalists for the Targeted Technique phase for each vocal fundamental examined. The exercises were sung to the vocalists during the Week 2 debriefing, which was recorded and offered back to the vocalists for reference. It was also offered to provide a transcription but all three vocalists declined this, working with the auditory reference.

1. Comfortable and flexible posture during singing.
At the start of the practice, stand or sit comfortably and align your posture to eliminate tension and create flexibility in the neck. Focus on release of tension. Keep the shoulders back, neck long and relaxed, chin tucked slightly down. Take as long as you need to feel comfortable.

2. Sustained and controlled breathing.
First work on a hissing vocalise to warm up and get the breath going. This should use a sustained *Sss* hiss sound, to move the air without pitch. Exhale on the hiss starting with four counts, then move to eight, and further if you wish. You can slow or speed up the tempo. Try to focus on sustaining the breath for longer and longer each time. Feel the tension in your abdomen but not in your neck and back as you control the breath.

3. Sound production with articulation.
Use a descending pattern on *Ta ta ta ta ta* (sol to do) to begin to create sound. Use the articulation to get the breath going and focus the sound. You can start as high or as low as you like and end where you choose. Focus on each pulse and the feeling of the articulation as you sing.

4. Vowel formation.
Use a sustained pitch to go through different vowel sounds *Aa Eh Ee Oh Oo*, ascending after each group. Again, start as high or as low as you like and end where you choose. Focus on the quality of the sound and creating clear, distinct sounds.

After completing these exercises, sing again as you please - whatever you want to try or focus on. This can be from your normal repertoire if you are working on something in particular, or explore new vocalises or exercises as you like.

B INTERVIEW SCRIPT & PROMPTS

Vocalists answered a series of semi-structured interview questions during each debriefing session:

B.1 Exploratory (Week 2)

1. General.

- How are things going with the interaction experience?
- Are there any [initial] impressions you want to share?

2. Micro-phenomenological Interview.
Vocalists are asked to choose a specific moment of connect between movement and sound they noticed to explore in a micro-phenomenological interview.

3. Controllability and Working with the Sound.

- What are your overall impressions of the quality of the sound?
- Do you find the sound pleasing to work with?
- What would you wish to change about the sound?
- Can you describe the connections between your movement and the resulting sound?

Targeted Technique (Week 4)

The second debriefing used the same components as above:

1. General.
As in Week 2.

2. Micro-phenomenological Interview.
As in Week 2.

3. Vocal Fundamentals.
This was the only section added to the interview script, to address the vocalises added:
For each vocalise (*go through each one-by-one*):

- Did you notice anything in particular about the sound while you performed the exercise?
- Did this change over time (noticing anything more or less, different impressions)?
- What was surprising? What was not?
- If you were to teach someone else (a beginner student), how might you explain this technique?
- What would you say about the sound while performing this? What would you tell that student to listen for?

4. Controllability and Working with the Sound.
As in Week 2.