“Feeling the Sensor Feeling you”: A Soma Design Exploration on Sensing Non-habitual Breathing

Vasiliki Tsaknaki
IT University of Copenhagen
Copenhagen, Denmark
vats@itu.dk

Kelsey Cotton
Estonian Academy of Music and Theatre
Tallinn, Estonia
kelseyicotton@gmail.com

Pavel Karpashevich
KTH Royal Institute of Technology
Stockholm, Sweden
pavelka@kth.se

Pedro Sanches
KTH Royal Institute of Technology
Stockholm, Sweden
sanches@kth.se

ABSTRACT

Though seemingly straightforward and habitual, breathing is a complex bodily function. Problematising the space of designing for breathing as a non-habitual act pertaining to different bodies or situations, we conducted a soma design exploration together with a classical singer. Reflecting on how sensors could capture the impact and somatic experience of being sensed led us to develop a new sensing mechanism using shape-change technologies integrated in the Breathing Shell: a wearable that evokes a reciprocal experience of “feeling the sensor feeling you” when breathing. We contribute with two design implications: 1) Enabling reflections of the somatic impact of being sensed in tandem with the type of data captured, 2) creating a tactile impact of the sensor data on the body. Both implications aim to deepen one’s understanding of how the whole soma relates *to* or *with* biosensors and ultimately leading to designing for symbiotic experiences between biosensors and bodies.

CCS CONCEPTS

• **Human-centered computing → Interaction design process and methods**.

KEYWORDS

sensing, actuation, soma design, autobiographical design, breathing, shape-change, non-habitual

ACM Reference Format:
Vasiliki Tsaknaki, Kelsey Cotton, Pavel Karpashevich, and Pedro Sanches. 2021. “Feeling the Sensor Feeling you”: A Soma Design Exploration on Sensing Non-habitual Breathing. In *CHI Conference on Human Factors in Computing Systems (CHI ’21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 16 pages. https://doi.org/10.1145/3411764.3445628

CHI ’21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05…$15.00
https://doi.org/10.1145/3411764.3445628

1 INTRODUCTION

We would like to start by inviting the reader to pay attention to their breathing for a moment. Breathing, for a lot of us, is often unremarkable. Much like we develop habits in how we sit or stand, we breathe in and we breathe out without giving it much thought. Yet our breathing habits affect how we feel and everything we do. For example, our habitual posture affects lung expansion capacity and how much air we get from each breath [35]. The depth and speed of our breath — when we breathe more shallowly and make more use of our diaphragm, for example — can affect our mood [46]. Many may attempt at times to consciously control their breathing, either by trying to pace their breath when doing sports, attempting mindfulness states by synchronising breathing with movement during a yoga practice, or simply breathing deeply to calm anxiety.

In this paper we report on a collaboration between a singer and interaction designers exploring how different breathing patterns can be sensed through muscle-movement occurring on the torso. Trained singers are experts in managing their air flow by engaging auxiliary muscles of the torso (e.g. rectus abdominis and intercostal muscles, depicted in Figure 1). Nuanced control of these muscles helps build physical stamina and is essential to perform classical repertoire and more experimental vocal works. The classically trained singer (Kelsey, 2nd author) had the ultimate goal of developing an artefact for "voiceless singing", i.e. singing through her body, as the movements her muscles produce when she breathes - as if she was singing - are mapped to sounds controlled and computed through software. The other authors were doing research in the area of soma design [24], with the goal of developing technologies that engage with the felt experience of breathing, connecting sensation, feeling, emotion, and subjective understandings of how breathing affects our somas – body and mind. In soma-based design work, it is important to train somatic designerly skills [63] by shaping not only the physical materials used to build our artefacts, but also our own movements and sensations as we learn to aesthetically appreciate, in this case, the act of breathing.

We therefore engaged with what we call *non-habitual breathing*. In the context of our research this refers firstly to the process of defamiliarising one’s breathing through soma design methods. But most importantly, non-habitual breathing refers to how somatic experiences of breathing are nuanced and cannot always be mapped to a breathing rate that biosensors are most often designed to capture. This reveals a gap that informs our main research question: *How to capture nuanced somatic experiences of breathing?* In this paper, we answer this question by proposing a design process that entails deeply engaging with the practice of breathing, which is the main contribution that we offer.

The main part of our work consists of a detailed articulation of the process of engaging with sensing technologies for capturing biodata from breathing, including the adaptations we made to off-the-shelf sensors for capturing nuanced aspects of the breathing experience. In total, we report on explorations with a wearable strain sensor, an electromyography sensor (EMG), and custom made shape-change pressure-actuator sensors. These explorations culminated in the Breathing Shell prototype, designed for a) capturing the wearer's breathing in the muscles shown in Figure 1, which are specific to classical singing techniques and Kelsey's experimental vocal practice, and b) giving the sensation of "tangibility" of the act of breathing. This is experienced as shape-change actuation evoked through the custom made shape-change sensors on top of the muscles that contract and retract while breathing.

Moving beyond the particular bodily function of breathing, our work offers a path for other researchers creatively engaging with biosensors, and suggests ways of opening the "black box" of how a particular sensing mechanism works. Specifically, we suggest that soma design is a fruitful path for engaging with estrangement of bodily functions and for approaching sensing technologies from a perspective that highlights the somatic experience of being sensed. We conclude with two implications for designing with biosensors from a soma design perspective, through a process that prioritises the primacy of diverse felt and sensed experiences when working with sensing mechanisms, aiming towards designing "symbiotic" experiences: 1) engage with biosensors through reflecting on the somatic experience of being sensed in tandem with the data captured, 2) use actuation for deepening one's understanding of how the soma relates *to* or *with* a biosensor, when engaged in complex bodily functions - in our case, breathing.

2 BACKGROUND: SENSING BREATHING IN HCI

A growing body of work in HCI has been looking at how to engage with biosensors creatively and designerly, including explorations on sensing technologies through collaborations with dancers and choreographers [16], surfacing the material properties of biosensors [1, 22], or studying how sensor data can be appropriated in everyday life [52]. Such approaches to working with sensing technologies are different compared to using biosensors in a lab or in stationary settings. In such settings, factors such as strictly following the suggested placement of a sensor on the body or keeping the body static by restricting movements, are crucial for capturing the type of biodata a particular sensor has been designed for [23]. But, in reality, design researchers and sometimes even end-users [5], often end up adapting biosensors to fit a particular design context and even different bodies that will be sensed.

Working with biosensors for sensing breathing in particular has been a subject of attention of many HCI projects. Prpa et. al. [49] summarised and classified existing research projects in HCI focused on breathing, based on four underlying theoretical frameworks in regard to attending to breathing: regulation, mindfulness, somaesthetics/soma design and social connection through breath. Breathing has been also of interest to artistic researchers including Khut [30], who developed somatic art installations that transform the viewers'/participants' biodata readings (including breathing and heartbeat) into video projections, accompanied by soundscapes. Additionally, many researchers looked at possible ways of working with breathing [7] or translating breathing signals into light output [60], sound [19, 47, 65], haptic feedback [6, 12, 17], or shape-change actuation [3, 31, 41]. In this paper, we are interested in the same domain, but we focus only on the sensing mechanisms. Therefore, we started by analysing the compiled corpus of Prpa et. al. [49] and complemented it with some additional work in the domain of breathing [30, 36, 55, 62, 68] with regards to the type of breathing being sensed, sensors used, and features extracted.

2.1 Normal Breathing?

In most of the related research in this context, breathing is sensed by stretch sensors in the thorax. The type of breathing is almost always unspecified and assumed to be "normal", also called "eupnea". There are however many ways of breathing. Clavicular occurs as a slight vertical movement of the clavicles (the collarbones), paired with a slight expansion of the thoracic/rib cage. Thoracic breathing can be observed as a greater expansion of the thoracic cage in inhalation, compared to the clavicular one. This is the most perceptible way of how our torso engages in breathing, i.e. the thorax expanding and shrinking when breathing in and out. Diaphragmatic breathing is the deepest and is achieved by engaging the intercostal muscles that run between the ribs, which help to move and expand the chest wall. These muscles push the lower ribs outwards and upwards, causing a contraction of the diaphragm when inhaling. This movement lowers the air pressure within the lungs whilst expanding the chest cavity and increasing the length of the diaphragm [21]. Diaphragmatic breathing can be observed as an outward expansion of the abdominal cavity, followed by the expansion of the thoracic cage and elevation of the clavicular muscles [14]. This is by no means an exhaustive list of how to breathe.

Some of the reviewed work in HCI is concerned with detecting or even encouraging specific types of breathing (i.e. non-habitual). For example, Bingham and colleagues [4] have developed a game encouraging patients suffering from airway obstruction in cystic fibrosis to perform "huffing" [38] exercises, making use of a spirometer to detect airflow and feedback breathing data to the patient. Another example, is aimed at detecting and encouraging diaphragmatic breathing to promote relaxation, detected through a strap worn around the lower torso, aimed at children with anxiety disorders [64]. Another game, makes use of pursed lip breathing, i.e. exhaling through pursed lips while inhaling through the nose, by using a microphone specially designed for this breathing type [45]. Our work expands this design space by exploring breathing from a perspective of a classical singer, and we present both a detailed research process and an artefact specifically designed for this form of breathing. Classical singers practice non-habitual breathing exercises to build their physical strength and stamina in the rectus abdominis muscles, to control lateral expansion of the lower intercostal muscles, flatten the diaphragm and manipulate the internal air pressure in their lungs.Their engagement of these muscles is more deliberate and nuanced as opposed to other types of breathing.

2.2 Adapting Sensor Mechanisms

When it comes to sensors, there is a wide variety of technologies that can be used for capturing movements and bodily changes associated with the act of breathing [9]. As a broader categorisation, sensing mechanisms can be divided into *contact* and *non-contact* methods, based on whether or not a sensor used has direct contact with the skin [2]. Non-contact methods include motion capture systems for reading and analysing movements on the chest surface [57], microphones [8], and ultrasonic proximity sensors [40]. On the contrary, contact methods make use of sensors that come in contact with the skin. Examples include measuring airflow via flowmeters and hot wire anemometers. One can also detect breathing by capturing the modulation of the cardiac activity [37]. But the most common breathing sensing mechanism is done through an analysis of chest wall movements, using strain sensors, impedance sensors and movement sensors. The strain sensors are measuring expansion and contraction of the chest cavity and may take a form a wearable elastic belt. The most common off-the-shelf sensor systems used in HCI are the *Zephyr’s BioHarness* (e.g. used in [6, 18, 19, 44]), *Thought Technology* (e.g. used in [48, 50, 58, 65]), *Nexus 10* (e.g. used in [12, 36, 41, 55]) or *Plux* (e.g. used in [1, 11], who rely on chest straps for measuring chest volume. Notably, most of the reviewed work makes use of off-the-shelf sensors. Some designers, however, have had to adapt and/or create sensors in order to fit their specific design context. For example, during the design of *ChillFish*, a game for children with ADHD, researchers built their own breathing sensing mechanism based on LEGO and a thermistor in order to fulfil the requirements of an unobtrusive, cheap and easy-to-use controller adapted for children [59]. Tennent and colleagues [62] described the design of a custom-built respiration sensor for game control using a gas mask, which was chosen purposefully because of its striking aesthetic fitting to the type of games it was designed for. In our design process, we too started by using off-the-shelf sensors. However, we soon found that the nuanced bodily movements caused by breathing, in a manner characteristic to classical singing, were not captured by these sensors, which motivated the design process we describe here.

3 RESEARCH PROCESS AND METHOD: THREE SOMA DESIGN STRATEGIES

Soma design has been used in HCI contexts as a way of becoming more attentive to, and improving on our somas as designers, including not only movements but the whole self, body and mind as one [24]. By doing so, it is argued that one can approach the materials used in a design context, both physical and digital, from a perspective that places the whole soma at the core, and thus leading to designing better systems for end-users [26]. There is a variety of soma-based design strategies for engaging with the whole body, aiming to improve designers’ somaesthetic awareness and ultimately design rich experiences with technologies [63]. In our design process we followed three strategies.

The first strategy is working closely with a somatic connoisseur, in the context of non-habitual breathing in our case. Interaction designers are not always skilled in designing with movement or with holistic engagements with the body. For this reason, several methods and techniques have been used for engaging with the living body in HCI, including techniques inspired by Feldenkrais, theatre, dance, or other somatic practices [29, 34, 54]. The soma expert Schiphorst [53] suggests engaging with *somaesthetic connoisseurs*, to support a design team in engaging with their living body as part of a design research process. The author Kelsey, has a background in classical, experimental and contemporary music, as well as free vocal improvisation [51]. Kelsey’s experience and training as a singer meant she provided a very different perspective on how she breathes, how she feels her breathing, and the relationship between her breath and how her body engages in this bodily function.

Secondly, we engaged with our bodies as designers, by practising three non-habitual breathing exercises with the intent of defamiliarising breathing. Soma design methods in HCI often rely on ways of introducing change and maintaining interest [27], exploring the details of a desired experience one wants to achieve in interaction [32]. Subdividing experiences (be it bodily, emotional or social engagements) into more specific areas or functions and then engaging in activities that shift focus from one area to another and back, can be one path to providing a more nuanced and rich perception of fine-grained experiences [24]. We can, for example, slow down a movement in order to properly discern how it spurs emotions, thoughts, experiences or social responses [25]. Or we can make ‘strange’, disrupting the habitual ways we engage in movement or with one-another. The concept of *estrangement* describes the act of experiencing something that *"occurs in the moment of perception and that the further you confuse or otherwise prolong the moment of arriving at an understanding, the deeper or more detailed that understanding will be"* [66]. Kelsey, as a somatic connoisseur in non-habitual breathing for singing, provided us with exercises which are central to her vocal practice. The exercises, in combination with Kelsey’s experiences and explanations of how she developed her breathing practice, helped to shape our methodology and approach in learning (or re-learning): 1) How our bodies engage in this function, and 2) how we could use sensors to monitor (and possibly interact with) breathing.

Finally, we explored sensing mechanisms for breathing, towards sensitizing ourselves to the sociodigital material of our somas combined with computational and physical materials that form different sensing mechanisms and ways of capturing breathing. The research questions driving our explorations with sensing technologies were the following: What is the experience of being sensed through a particular sensor? What is interesting in each sensor exploration and why? What threads did we discard, or took forward in terms of sensor placement and type of data received?

3.1 Overview of Design Process: Autobiographical Soma Design

Soma design is characterised by using the designer’s soma and their first person experiences and reflections as a guide to judge, validate and iterate throughout a design process, with the ultimate goal

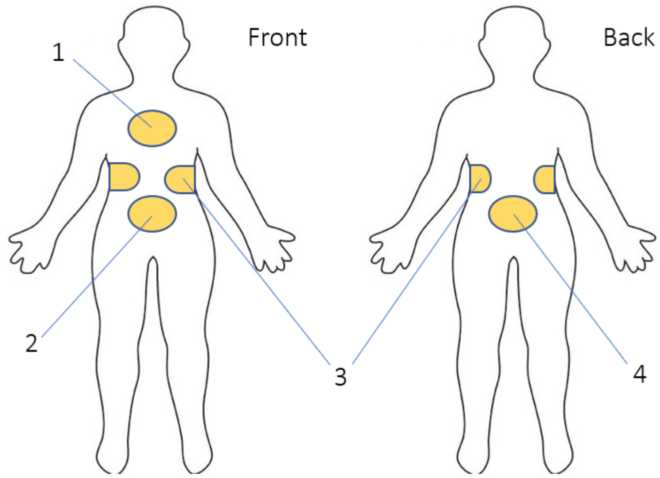


Figure 1: Muscles/areas involved in the exercises: 1 - sternum; 2 - rectus abdominis; 3 - intercostal muscles; 4 - thoracolumbar fascia.

to design for others [24]. Accounts of how soma design methods use first person experiences have been previously articulated in [24, 25, 32, 61, 67]. Similarly, in our design process we used first person perspectives in the form of autobiographical design [10, 43]. Autobiographical design and autobiographical research through design focus on using the experiences of the self as an explicit action, validation and critique within the design process, and has found value in the field of HCI as a method for studying complex situations with design and technology. Carmen Neustaedter and Phoebe Sengers introduce autobiographical design "*as a way of developing systematic understandings of a system's potential...that can provide detailed, nuanced, and experiential understanding of a design space*" [43]. They suggest that this experiential understanding of a design context or system should be done rather early in the design process to tinker with an idea over extended periods of time that can range from months to years. In their reflection of using autobiographical design, Audrey Desjarins and Aubree Ball also emphasise how the methodological innovation in autobiographical design supports situated, intimate, and long-term research which would be challenging to undertake using alternative methods [10]. Grounded on this research and methodological discourse in HCI, our research process evolved as follows.

For a period that lasted about five months, the authors engaged in an autobiographical design process of exploring sensing non-habitual breathing through the 3 soma design strategies described earlier, meeting at least two times per week (see Figure 2 for an overview of the research process). A typical session included doing the breathing exercises guided by the connoisseur (author Kelsey), followed by individual reflections on body maps and sharing experiences in the group. After the breathing exercises, individual testing sessions with sensing mechanisms took place, for each person to become attuned to the sensor and develop an understanding of how it captures breathing data in relation to the different muscles in focus. There was no strict protocol followed for testing each sensor, as it was deemed more important to reflect on first person experiences at the meeting between technology and body, which is a common approach in soma design methods [61]. However, this process was grounded on the main research question driving our process (i.e. how to capture nuanced somatic experiences of breathing) and the research questions driving our explorations with the sensing technologies, mentioned above. Each author reflected on, and then documented their experiences, in the form of written text, body maps, and occasionally short video recordings and photos after each session. Throughout the design process, this data served as an anchor to drive design decisions forward, and to critique our process, while navigating this new design space. In autobiographical design methods rigour means careful and critical reflection on one's work, focused on being critical, explicit and thorough, rather than aiming at generalisability [10]. Additionally, as articulated in [25] design processes entail failures and successes along the way, which is the way such processes become validated, through "*the designer/user and their subjective attitude, aesthetic sensitivity, politics, taste, values and bodily experiences*" (p.9). In our research process, we were regularly returned to our data and using our research questions as lens, the goal was to find commonalities, new unexpected insights and disruptions. This process of reflection-in-action [56], central to design processes, served as a form of validation and critique for our design choices based on the autobiographical data gathered along the way. Our subjective review of our gathered data helped us to decide on how to proceed from one stage to the next, and consequently helped to open up the design space in this context.

Overall, the process of exploring sensors in the context of non-habitual breathing, evolved as described in Section 5, in terms of the sequence in which the different sensing mechanisms were tested. However, we often had to return to a sensor and experience it again, in light of our expanded understanding of this design space. The insights gathered from the sensor explorations informed the design decisions behind the Breathing Shell prototype, as they formed the basis for the choices we made on how many shape-change pillows

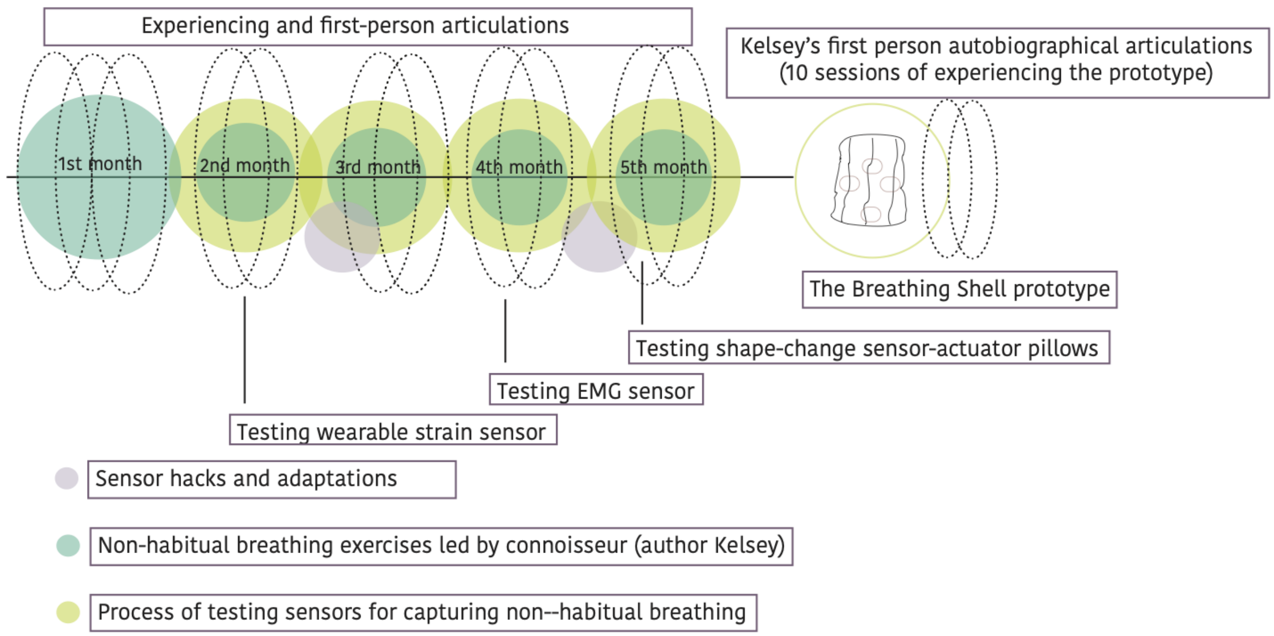


Figure 2: A diagrammatic overview of the soma design process followed: we practised 3 non-habitual breathing exercises led by the author Kelsey, followed by an autobiographical soma design exploration of three sensing mechanisms (wearable strain sensor, EMG sensor and custom made shape-change sensor-actuator pillows), including hacks and adaptations to the first two sensor mechanisms. This led to designing the Breathing Shell prototype, followed by 10 sessions in which Kelsey, as a somatic connoisseur in non-habitual breathing, reflected on first person experiences evoked when wearing and interacting with the wearable.

we should include in the prototype and choices of programming the shape-change pillows to respond to muscle pressure, as described in detail in Sections 5.3 and 6.

We identified two distinct approaches of how one could interact with the Breathing Shell, at the meeting between body and sensor-actuator material, influenced by the integration of the external shell with one's body: "total interaction/integration" and "total disruption". Those emerged from having all authors experiencing the garment. We present them in Section 6.1 through Kelsey's first person autobiographical articulations, as a connoisseur able to discern and verbalise a wider palette of somatic experiences while breathing non-habitually through the Breathing Shell. Kelsey conducted 10 sessions of wearing the garment for 30 minutes per session, while performing the sequence of the non-habitual breathing exercises. Each was in the form of an open-ended exploration aiming to feel the impact of the garment on her breathing, and observe nuances at the meeting between her body and the shape-change felt through the garment. Four sessions were conducted in the same room with the other authors, with Kelsey sharing her first person experiences aloud, and six sessions she conducted alone, documenting her first person experiences through video and text. All authors went through the transcribed material of these autobiographic experiential sessions in order to extract and summarise key felt experiences and evocative moments that Kelsey noted during her interactions with the garment (presented in 6.1.1 and 6.1.2). In particular, we looked for first person articulations highlighting the two experiences identified: "total interaction/integration" and "total disruption".

4 BECOMING ATTENTIVE TO NON-HABITUAL BREATHING: THE EXERCISES

When one starts formal classical voice training, learning (or re-learning) how to breathe is the first step. This re-learning process is centred around developing somatic awareness and conscious control of specific muscle groups responsible for inhalation and exhalation. A professional singer needs to know how to use and control these muscles, in order to a) facilitate diaphragmatic breathing, or "deep lower breathing"; b) to regulate the air flow as they phonate (sing); and c) to achieve the breath support necessary to maintain a sung note or pitch. In that way a singer can be trained to breathe into and using different parts of their body, and thus develop a whole-body engagement with breathing.

Adopted from singing training practice, the authors practiced three breathing exercises on a weekly basis, for a month: 1. Spinal roll with inhale, 2. Diaphragmatic inhale with sustained unvoiced fricative on exhale: "Sh" and "Ss", and 3. Quick Sh, Ss, He, Ft, Wsht (Appoggio Activation). A typical session included doing the three exercises one after the other, starting from the first one. After completing all three exercises, body maps [33] which are typically used in soma design processes, were used to reflect on the individual experiences, but also to share experiences with one another in the group.

These exercises can sensitise a range of areas on the torso and muscles focal in training one's breathing for singing contexts and beyond, as depicted in Figure 1: the sternum (1), the rectus abdominis muscles (2) (lower-abdominal), the intercostal muscles (3) (left and right side of the torso) and the thoracolumbar fascia (4) (lower lumbar muscle). They also cover a range of fast and slow ones, which helped us to become attentive to breathing in different tempos, and thus offering a broader understanding of how the torso engages in non-habitual breathing patterns and sequences we do not involuntary engage in our everyday life. At this stage we did not include any actual sensing technologies, even though different sensor modalities that could capture breathing were discussed and considered in relation to the breathing exercises performed, which we integrated in the next stages of our process. During these later stages of exploring the sensors we were also doing the exercises regularly in order to become attuned to our bodies and to non-habitual breathing, as depicted in Figure 2. All three exercises are recorded and can be found in ACM, as supplementary material to our paper, in the form of audio files.

4.1 Reflections and Learnings from Practising the Exercises

The exercises gradually helped us to discern how different muscles on the torso contract and retract when breathing in different ways. Not being habitually attentive to breathing through the lower belly, back and side muscles, it was difficult to feel the exact placement of these muscles on our bodies, and even more to sense a change in these muscles while breathing, especially during the first weeks of practising the exercises.

Kelsey, as a connoisseur in non-habitual breathing, guided us (the other authors) to feel the muscles activated during each exercise, before we all became more confident in pinpointing the different muscles and discern changes. One particular tactic she adopted was to invite everyone to place their hands on the area on their body, where a muscle being focused on during an exercise was positioned. The hands were there while performing the breathing exercise, trying to feel the contraction and retraction of the muscle. This was inspired by her early years of training, when her teacher was guiding her to feel the impact of breathing on particular muscles, through a tactile sensation evoked by placing her palms on top of a muscle, touching the skin, while breathing. Kelsey also used the phrase of *breathing low and deep into a muscle*, guiding everyone verbally in feeling the somatic impact of each breathing exercise on our bodies.

Over time, by repeatedly engaging in these exercises, we started experiencing a more nuanced and detailed understanding of the different muscle structures on our torso. An interesting observation emerged when the conventional sequence of the exercises was altered: the fast-paced appoggio activation (3rd exercise) preceded the exercises with slower and deeper breathing patterns (1st and 2nd). Performing the fast breathing exercise first, raised our somatic awareness by activating and toning the rectus abdominis muscles, thus enabling us to "actually feel" the contraction and retraction of the muscles in the second set of exercises, which did not happen when the conventional sequence of performing the full set of the exercises.

Although changes in some regions were more difficult to detect during the exercises (such as the sternum and thoracolumbar fascia), overall, this became a pivotal phase in our process for two main reasons. Firstly, becoming attentive to non-habitual ways of breathing helped us to expand on our understanding of how nuanced breathing is as a function. Additionally, having sensitised our bodies on breathing we became more attentive to working with sensing mechanisms.

5 EXPLORING SENSING TECHNOLOGIES FOR CAPTURING NON-HABITUAL BREATHING

Aiming to understand first and then open up the design space of sensing non-habitual breathing, as a next step we delved into testing sensing mechanisms. All authors participated in the sessions hosted for testing each sensor. During each session, participants did a sequence of the breathing exercises to determine the suitability of the sensor for detecting muscle engagement in the muscle areas shown in Figure 1. We did not follow a strict protocol for testing each sensor, as it was deemed more important to reflect on first person experiences at the meeting between technology and body, which could vary from person to person. The participants, beyond following the sequence of the breathing exercises, were also invited to freely explore different sensor placement on their body. The sensors was connected to a circuit board and the data captured were shown live as a graph on a laptop screen, using visualisation software.

5.1 Wearable Strain Sensor

The first type of sensor we used was an off-the-shelf strain sensor in the form of an elastic belt worn around the torso (Figure 3). This was a natural choice considering that strain sensors in the form of elastic belts are the most common type of breathing sensor. The sensing element of this belt, which is a flexible piezoelectric thin film sensor, is embedded in the stretchable fabric. It can be worn around the thorax and/or around the abdomen area of the body. The sensing element is measuring thoracic or abdominal displacement in breathing cycles, i.e. the degree of contraction and retraction of the area of the body, where the belt is worn. Based on the impact the breathing exercises had on our bodies, we started by testing this sensor's potential for capturing aspects of breathing from the convex muscle regions during inhalation: the rectus abdominis and intercostals.

Initially we used a single sensor belt to measure and compare the volume shape-change of the rectus abdominis muscle and the intercostals. We found that the more curved regions around the intercostals had a stronger impact upon the biofeedback data reported from the sensor on the laptop screen. At the same time, the respiration data did not clearly map to the somatic experience of being sensed in these areas. Regions with greater curvature registered a 'higher' baseline respiration level (ie. low levels of body changing shape), which meant that the sensor struggled to capture the full range of expansion in this area because it was already flexed. But even in the area where the rectus abdominis is positioned, the muscle movement displaced the entire sensing bar, rather than flexing as this muscle expanded during inhalation.

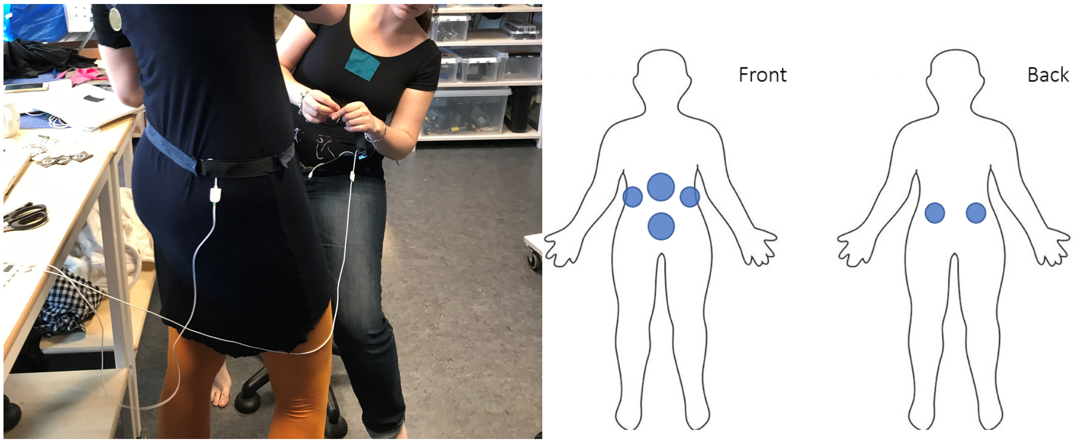


Figure 3: Left: One of the authors trying the hacked strain sensor belt. Right: Areas of interest for strain sensor.

We also considered how we could use this sensor most effectively to sense breathing through the type of movement, in the form of muscle expansion, occurring in these two areas. After repeated tests we noted that this sensor was not able to monitor this muscle movement occurring while breathing, as it provided information only on the amount of force exerted on the sensor, instead of direction, needed in this case. This posed a significant issue in measuring muscular engagement in the thoracolumbar fascia and sternum, as the movements in these areas is more directional (the sternum demonstrates more vertical displacement than expansion, whilst the thoracolumbar tilts and rises). It was concluded that the strain sensor was better suited to muscular regions which demonstrate expansion and contraction during breathing, rather than those which tilt or are vertically displaced.

When testing what data could be captured through this sensor on the rectus abdominis and intercostals when alternating between rapid and slow breathing (3rd exercise), or when maintaining a certain physical position for an extended time (2nd exercise), the sensor readings started to become unstable. The linear representation of the breathing rate viewed on the computer would progressively fall and drift. However, the sensor expressed high sensitivity in detecting the initial inhaling or exhaling stages of breathing. Another reflection pertained to the difficulty of keeping a consistent positioning of the strain sensor belt over the same muscle zones. Especially some of the more explosive and dynamic breathing exercises (e.g. 3rd one) would often cause the sensor belt to shift around the body as it was only fixed in place on a single horizontal plane.

The form-factor of the sensor also imposed constraints for capturing muscle contraction from both the left and right rectus abdominis muscles, at the same time. For achieving this we tried using two strain sensor straps, worn at the same time, with each strain sensor placed on top of each rectus abdominis muscle (left and right), in order to achieve a symmetrical placement of the sensor on the intercostal muscles. However, the strap of one belt always had to be overlapped on top of the other, which meant that the strain sensor placed closest to the skin was being affected by the force of the external/top one, as the body changed volume and shape beneath it.

5.1.1 *Adaptations and Hacks.*

Aiming to address the sensing and form-factor limitations encountered, we hacked the original form of the strain sensor. Firstly, we partially deconstructed the belt and added an additional sensor unit to it. In that way, we could monitor the intercostal muscles simultaneously, on the same horizontal plane. We also applied this dual sensing belt to the thoracolumbar fascia, but did not yield any improvements on sensing in this region. Implementing and testing this provided notable differences in both the type of data captured from the rectus abdominis and intercostals and the experience of breathing through this sensor. Due to the reduced amount of elastic strapping, there was a reduced tension on the sensor caused when breathing through or into a muscle, on top of which it was worn. Also, the visualisation of the breathing data on the screen reflected a "clearer" mapping between the felt experience of breathing and the data output produced. The felt experience of breathing was more accurately mapped to the data captured through the muscle movements.

We further expanded upon this modification by addressing the non-sensor material of the sensor belt. The question of whether the tightness of the elastic strap was affecting the data captured, led us to replace the elastic bands of the strap with a thicker neoprene material with less stretchability. This modification helped to reduce the physical displacement of the belt during more explosive movements of the muscles when breathing fast, or when changing suddenly the pace from slow to fast breathing.

In summary, we found that the combination of these two adaptations to the original strain sensor improved both the stability of the data captured when breathing through the intercostal muscles and the rectus abdominis (both independently and synchronously). Hacking the sensor had also implications in how we felt it measuring our breathing. In it’s original form factor, the more flexible elastic strapping made the strain sensing bar feel disconnected from the body. The only way to truly ’engage’ with the sensor was to significantly tighten the belt section, in turn ’forcing’ the sensor to bend and flex. We found that we couldn’t truly ’feel’ the sensing bar flexing with us as we breathed. Comparatively, using the sturdier material for the belt integrated the strain bar ’into’ the body better-it was more closely connected to the torso and one could palpably feel the sensing bar flexing during inhalation and returning to a 'relaxed' state during exhalation.

5.2 EMG Sensor for Capturing Rectus Abdominis Muscle Contraction

The second sensor we tested was an Electromyography (EMG) one, typically used for capturing muscle contraction, and which we explored for measuring data when breathing through the rectus abdominis muscle. We chose this sensor for this area, because there are not many bones around the lower belly which would interfere with the electrical signal. An EMG sensor measures electrical currents generated in muscles during their contraction and retraction. We used a sensor with three-lead electrodes, which is specifically designed for surface EMG acquisition. The positive and negative electrodes need to be attached to the muscle, while the neutral electrode need to be attached to an electrically neutral region (such as bone).

Engaging with this sensor for capturing non-habitual breathing data surfaced two challenges in regard to the somatic experience of breathing, in relation to the data captured. The first challenge had to do with trying to find the right placement of the electrodes over the focal muscle. Every time we would start a new session of testing, it was time consuming to find the exact placement of the electrodes on the skin that would render the best sensor readings. The explorations with this, compared to the strain sensor, surfaced more the expertise gap between Kelsey, being a professional singer and thus more attuned to locating and being able to control her muscles on the torso when breathing, and the rest of the authors. For Kelsey, it was very easy to find the spot where she could place the EMG electrodes for receiving data that would make sense to her felt and somatic experience of breathing through and with this muscle. On the contrary, the others struggled to find the right position for placing the EMG electrodes on top of the rectus abdominis muscle. The data signal was either not captured at all, or it was captured but was unstable and irregular. However, becoming slowly more attentive to muscle-movements through the non-habitual breathing exercises performed regularly, we started to become better at discerning the exact position of this muscle.

The second challenge we faced had to do with the robustness of the sticky electrodes on the skin. At this stage we were using the gel electrodes that one can stick to their body by placing the adhesive jelly surface on the skin. Soon we noticed that after trying the sensor a few times, breathing in and out, the surface of the electrodes started to disconnect from the skin and fall out. We also found that the connection would wear out during re-positioning of the electrodes, in case we needed to try another placement on the same muscle or continue our explorations the next day. And occasionally, even the body heat a person generated during some of the quicker paced exercises would cause the gel adhesive to become warm and less sticky.

The form factor of this particular sensor did not 'invite' the user to engage with it, nor to feel how the sensor was sensing the breath through muscular contraction. There was no means of actually feeling how the sensor could be directly engaged with, beyond viewing the electrical signal generated from the muscle on the screen visualisation and beyond contracting the muscle to make the signal spike.

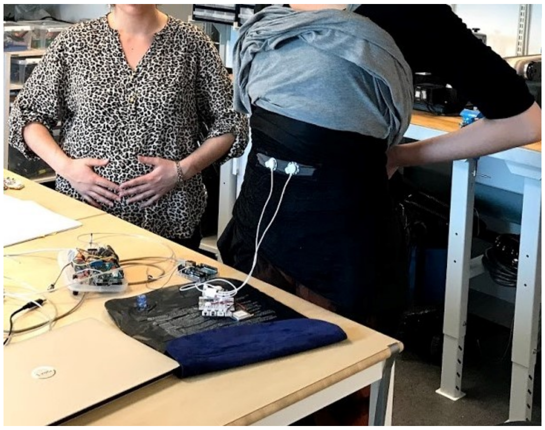
5.2.1 *Adaptations and Hacks.*

Our aim at this stage was firstly to establish a better connection between body and electrodes, and secondly to improve the signal connection on the neutral ("ground") electrode, placed over the bone. Additionally, we observed that pressure applied over the electrodes attached to the skin impacted greatly upon improving signal quality.

In order to address the first issue of electrode placement we incorporated the electrodes into a tight fitting leotard garment, which is an elastic full-body suit worn mainly by dancers. We found that the optimal place to put the electrodes for this context was on a horizontal line on the rectus abdominis (Figure 4). Due to the nature of the electrodes requiring a direct connection with the skin, we replaced the fabric of the lyotard with conductive textile panels, where the electrodes should be positioned, which would allow electrical signals from the muscle to be transmitted directly through the clip receiver of the EMG sensor. Creating permanent conductive panels on the lyotard, we succeeded in keeping the electrodes always on the same place, while at the same time securing a robust placement. We further found that the close fitting nature of the leotard helped greatly in ensuring a consistent gentle pressure of the electrodes over the rectus abdominis muscle, as the tightness of the garment provided a gentle compression and thereby would pull the electrode closer into the body. Due to the elasticity of this garment it fit all our different body shapes and sizes (of both gender), thus allowing us all to experiment with this new version of the EMG sensor.

Whilst the conductive panels and leotard fit helped to improve the quality of the signal received by the EMG, we explored how this design could be further improved by integrating the electrodes directly with the conductive fabric. We stitched metallic snaps onto the conductive textile using conductive thread, and then fastened each electrode directly on a metallic snap. This offered a more "wearable" solution of the electrodes, keeping them close to the body and in constant contact to the skin, through the conductive fabric. Additionally, the tension of the stretched fabric of the garment seemed to render better results on the signal captured. As observed, the neutral electrode, placed on the hip bone, really needed to be "pushed" into the body in order to ensure that the data collected would not receive signal interference from the muscle stretching to that particular bone. Experimenting with applying pressure to the neutral electrodes against the skin, we discovered that this reduced the noise of the muscles' electrical signal.

Overall, the EMG sensor incorporated into the leotard was able to capture robust data from the rectus abdominis when performing the breathing exercises, while successfully addressing the initial shortcomings including right and robust placement of the electrodes on the muscle, as well as keeping a constant connection between electrodes and skin. The tangibility of this hacked EMG sensor provided a means of interacting with both garment and sensor. As the wearer would breathe, the material of the leotard would shift, stretch and retract, drawing the wearer's attention to how the metallic snap was sitting on the body, sometimes becoming tighter or more present during inhalation. Through our experimentation



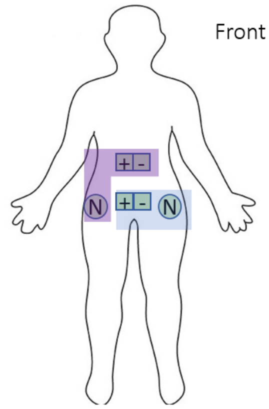


Figure 4: Left: The EMG sensor stitched on conductive textile panels. Right: Areas of interest for EMG sensor.

with the original gel electrodes and the hacked EMG electrodes in the leotard configuration, it became clear how important the role of touch and pressure was becoming in determining exactly where the muscles were contracting and releasing, and the level of engagement of each muscular region during breathing.

5.3 Custom made Shape-change Sensor-actuator Pillows

At this stage we were curious about how the tangibility of the sensor, experienced as pressure applied against the skin, could potentially offer new insights in regard to capturing non-habitual breathing data through muscle contraction, in addition to creating a tactile somatic experience of the sensor on the body. In order to explore further the aspect of pressure surfaced with during the tests with the strain and EMG sensors, we developed a new type of shape-change sensor-actuator mechanism for this context (Figure 5). Inspired by the shape-change actuator of the Soma Bits toolkit [67], we developed an actuator consisting of an electronics unit with an Arduino microcontroller, solenoid valves, an air pump and a barometric pressure sensor. The electronics are connected, through transparent tubes, to shape-change pillows of different sizes that we designed, made of Thermoplastic Polyurethane (TPU)-coated nylon. This device connects wirelessly to a laptop in which a Processing software program is running that communicates to the Arduino board.

One can program the device to inflate and deflate the shape-change pillows, and monitor the required pressure-level in each pillow. For our explorations we programmed each shape in a way that can deflate when pressure is applied on it, and consequently inflate when there is no pressure applied to its surface. This feature, even if not being actually "interactive", was chosen for exploring the sensing of non-habitual breathing in our context aiming to work with the level of contraction and retraction of the different muscles on the torso, which, can create or take space as they contract and retract. By applying pressure to a sensor-actuator shape-change pillow placed on top of a muscle, it is possible create a "mirrored" effect of the degree of inhalation/exhalation to the shape-change on the sensor-actuator material.

Aiming to measure breathing from different muscles simultaneously, we tested a combination of five pillows that we attached, through elastic straps, on top of the sternum, the rectus abdominis, the thoracolumbar fascia and the intercostal muscles (Figure 5), in order to capture the rate of expansion and pulsation during non-habitual breathing. As we observed, the feeling of the gradual inflation of each pillow against the body in exhalation, instantly drew attention to that area as we felt it expand. This was because the muscles were shrinking in each region during exhalation, causing each pillow to inflate and "fill" the cavities on top of each muscle. The shape the pillows took on, once inflated, rendered it quite separate from the wearer’s own body, rather than inhabiting the same physical space, mainly due to their acquired stiffness and their bubble-like shape. When inflated they also established an intense focus as to what that part of the body was doing beneath the pillow, when breathing. This felt experience at the meeting between pillow and body was verbalised as "the pillow ’growing’ out of the body". Overall, we found the placement of the sensor-actuator pillows on top of each muscle to be successful for measuring how these muscles work synchronously during habitual respiration, but also how they function independently during non-habitual respiration.

Wearing this new type of sensing mechanism close to the body evoked a different somatic experience compared to the strain sensor with its closeness around the body or the EMG sensor with its direct skin contact. Additionally, the expansion of the body causing a change of volume instantly when breathing, elicited the sensation of being able to interact with this sensor-actuator material: to push against each pillow and to immediately feel their reaction against your body, as they compressed and collapsed in response. There was also a feeling of slight re-expansion as your body collapsed during exhalation, and a feeling of receiving information from an external consequence caused by breathing.

The shape-change pillows provided a distinct somatic experience of non-habitual breathing that could be also felt externally, compared to the other sensors we tried. By "felt externally" here we mean that this sensing mechanism had a tactile and tangible impact on the body. Breathing then became an event not exclusively residing within a body, but an experience with a tactile consequence that could be ’felt’ by the shape-changing pillows. By applying pressure

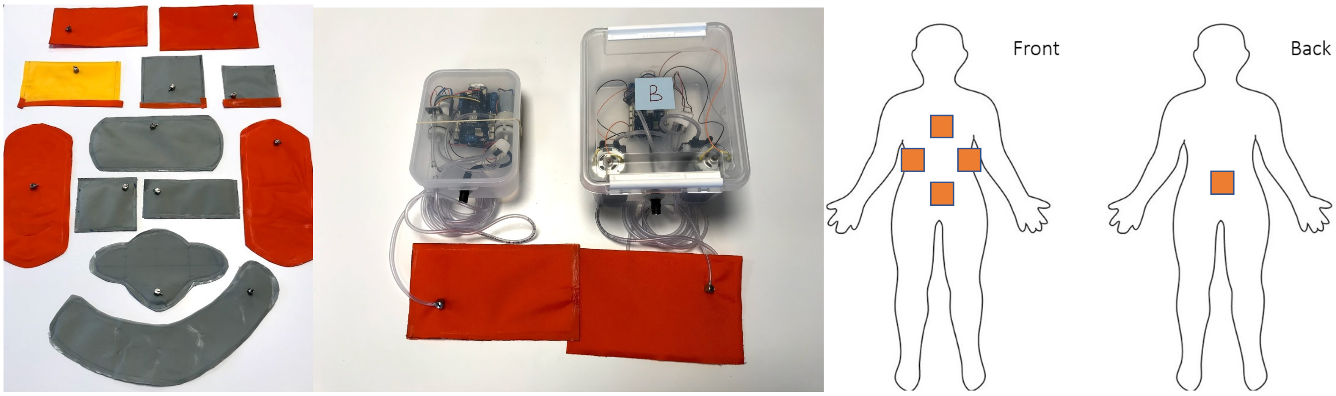


Figure 5: Left: Inflatable pillows. Center: Shape-change sensor-actuators. Right: Areas of interest for shape-change pillows

against the skin, similar to a hand touching and slightly pushing one's flesh, and through that tactile feedback create awareness on this bodily area, the inflated pillows provided a felt sensation of breathing. This happened due to filling with air the negative space (external curvature) on an area on the body where inhalation caused a retraction on a muscle.

As a next step we took the distinct tactile somatic experience of breathing, offered by this shape-change sensor-actuator material one step further, and we "packaged" it into the form of a prototype.

6 THE BREATHING SHELL PROTOTYPE

We developed this artefact for facilitating non-habitual breathing exercises and for providing a tactile, somatic experience of being sensed in tandem with the data captured from muscle-movement on the torso while breathing (Figure 6). It consists of three main parts: 1) The leotard with the embedded EMG sensor presented earlier, which captures breathing through movements on the rectus abdominis muscle, 2) four shape-change sensor-actuator pillows, placed on the muscles depicted in Figure 5 (without the pillow on the thoracolumbar fascia), and 3) an external rigid wearable structure that hosts the pillows close to the body.

During the phase of making and testing the shape-change pillows, we found that a shell container was required to provide an external limit for the pillows to be pressed against when inflating, mimicking the internal environment of the rib cage within which the lungs inflate and deflate. Our design for a housing unit for the sensor-actuators drew inspiration from conventional steel-boned corset designs. But rather than shaped fabric panels interspersed with rigid bones to 'shape' the body of the wearer, in this artefact the bones, which are plastic stripes of 3cm width, were placed to provide vertical rigidity only. The shell is made of thick fabric and worn over the leotard. Large pockets were stitched to the inside of the shell to accommodate the shape-changing pillows on the corresponding areas. We chose to design a wearable shell that resembles a corset garment, as adjustability to fit different bodies and body sizes was very important to us, and the adjustable lacing of the shell fulfils this purpose.

Having an external compact and rigid shell was important for keeping the sensor-actuator pillows in a stable position and in close contact with the body. But at the same time, maintaining a slight external pressure source against the pillow sensors in contact with the skin was important, since they are assessing the depth of respiration. The degree of external pressure felt against the body, and thus the sensitivity of the sensor readings (of each one) can be further controlled by tightening the ribbon of the shell. Finally, the rigidity and tight fit of the shell are necessary properties for maintaining a constant connection of the neutral-bone electrode of the EMG sensor of the leotard, which is placed on the hip bone.

6.1 Wearing and Experiencing the Breathing Shell

Reflecting on our first person experiences of wearing and interacting with it (Figure 7), the Breathing Shell facilitates the wearer to become attentive to the muscle-movement occurring during non-habitual breathing, by feeling the compression of the pillows as they breathe in. The tight fitting of the garment also draws attention to how the sternum and thoracolumbar fascia assist in, and engage in non-habitual breathing, through an increase of pressure felt in these areas.

Another observation arising from wearing and experiencing the garment, pertains to the importance of being able to accommodate the maximum expansion of one's body, in regard to the overall tightness of the shell structure. This has the effect of making the wearer feel the internal movements of their breathing outside of their body, and the feeling of encasement establishes an expanded awareness of one's body. Specifically, during deep inhalation one can externally feel the change of volume and dimension of their torso. The gentle pressure from the inflated pillows draws more attention to the type, the depth of movement occurring in the targeted zones when breathing. Additionally, the gentle collapse of the pillows as the air is forced out of them during inhalation, makes one more conscious of the amount of air being taken into the body across different muscle regions (i.e. air goes into the lungs and the same volume of air is felt being pushed out of the pillows).

Slowly discovering more aspects of the experience provided through the Breathing Shell, we identified two distinct approaches of how one could interact with it, at the meeting between body and sensor-actuator material, influenced by the integration of the external shell with one's body: "total interaction/integration" and "total

Figure 6: The external rigid shell of the Breathing Shell prototype

disruption". As outlined in Section 3.1, we present them through Kelsey’s first person reflections, as a connoisseur able to discern and verbalise a wider palette of somatic experiences while breathing non-habitually through the Breathing Shell.

6.1.1 Experience of "total interaction/integration".

The experience of a tactile, external representation of her internal body and its movements as she breathed, was a significant component of how she interacted with this artefact. Because of the design of the shell to conform to the body, the constant contact of the inflated pillows with her body and the size customisation afforded by the shell, she found the wearable to feel like an extension of her own body. Feeling her own body through the shell, meant that Kelsey could experiment and feel the immediate consequence of utilising different muscles on her torso to move her breath and air around her body. This allowed a "total interaction/integration" with the immediate consequence of her bodily changes during breathing, as felt through, and with the sensor-actuator pillows, as well as the back of the shell.

The responsiveness and interaction with the pillows added to this somatic experience of feeling like "a body within a body" when wearing the Shell. During her explorations, Kelsey learnt how she had to adapt the inflation rate and volume of the pillows to ensure that they could interact with her movements, as desired. She had to test how much air the pillows needed during inflation in order for her breathing to not be significantly constricted, but also to test how the volume of the inflated pillows impacted upon the subsequent ease of compression during her use of the garment. Through testing varying inflation speeds she was able to create an external bodily environment that mirrored hers, but as an inverse, or complementary operation to her own. As she would inhale, the pillows would respond to this exertion of force by compressing or collapsing at a rate quite equal to that of her muscle movements.

6.1.2 Experience of "total disruption".

The close physical connection between the shell and the body is a factor that contributed to an experience of "total disruption" between the soma and the sensor-actuator material. As articulated by Kelsey, as the pillows inflate to their maximum volume, they create the sensation of being trapped within her own body, or within someone else’s body, while the shell is moulded to the body like a second skin. Kelsey remembered experiencing a similar sensation of ’fighting against her own body’, during her early singing training when she was learning how to control and move her muscles and bones to support her voice. She described this as “*her brain understanding what it had to do, but being unable to get the muscles to move the way she knew they had to*." She felt as if her body was betraying her, or as if she was separated into two different bodies, which were not communicating with each other. This had the effect of Kelsey changing her breathing and adapting her body to this experience; she used her breath as a tool for engaging, fighting and playing with the pillows rather than solely as a means to engage with the muscles she used for singing. Kelsey observed how she moved air throughout her body to take up as much physical volume and space in her torso as possible, experimenting with trying to overwhelm or crush the pillows into submission.

The combination of the experience of "total disruption" and Kelsey’s altered relationship to her breathing, led to a secondary observation. Kelsey’s interaction with this environment of "total disruption" to her normal use of non-habitual breathing led to her using deliberately bodily movements, separate from her breathing practice, that would cause the pillows to compress. She would consciously and deliberately move and bend whilst wearing the shell, trying to force the pillows to find ways of controlling the degree of pressure applied to them, through her body and its movements. Kelsey would utilise these physical movements in addition to her breathing ’for maximum impact’: Moving air around her body and moving the muscles of her torso to take up as much physical space as she could within the shell, and thus force the pillows to reduce in size and volume.

Kelsey’s explorations with the Breathing Shell illustrate its potential usage as a wearable platform for engaging directly with the non-habitual breathing action of one’s body, or to be ’disrupted’ or prevented from engaging with it, as a way of defamiliarising an already familiar experience for expert singers.

7 DISCUSSION

An important finding from our process was that the meeting between sensor and body, from being independent to one another (i.e.

Figure 7: Wearing the Breathing Shell and testing the somatic impact of non-habitual breathing, through the shape-change sensor-actuator pillows. The tubes lead to the areas where the pillows are placed.

the sensor being perceived as an "attachment" on the surface of the body), started to evolve to a type of a *symbiotic experience* between sensor body, highlighting the "soma", as a combination of the fleshy and muscular body, mind, emotions, and subjective values and experiences, as considered and approached in soma design methods [24]. HCI has a long history designing interactions through metaphors such as the concepts of "instrument" in Merleau-Ponty [39], or tools in Heidegger [20], where objects can become extensions of the sensory apparatus and incorporated into one's body schema. In fact, the experience of the Breathing Shell as integration and disruption shows how it can shift from being perceived as part of our own body to being perceived as an external tool [20], and vice versa. Our work shows a pathway for achieving integration with technology through re-imagining sensing mechanisms as instruments purposefully designed to engage with the felt experience of the embodied phenomenon of breathing.

Reaching this symbiotic experience in our case was a result of engaging deeply with sensors, in tandem with engaging deeply with breathing as a bodily function. Becoming attentive to the affordances of the sensing technologies used, but also becoming attentive to breathing as a non-habitual experience both for the individual and between different people, allowed us to zoom into the meeting between sensor and body. The design process we propose here can be used to address some of the grand challenges in how to achieve human-computer-integration [42], particularly when it comes to how to design implicit interactions, occurring under the users' awareness and possibly based on biodata from autonomic processes, such as breathing, and how to considerately design how we perceive ourselves when tightly coupled with machines [15], by focusing on the somatic meeting between the person and the technology.

Even though our research focus was on non-habitual breathing, our explorations and research findings contribute to broader contexts of working with biosensing technologies in HCI beyond this context– including for example heart rate or sweat activity biodata– expanding on work already done in this field [1]. Taking the learnings from our design process further, we are offering two concrete suggestions in the form of design implications for helping others navigate the space of working with biosensors, with a focus on the somatic and felt experience of having one's body being sensed: 1) Enabling reflections of the somatic impact of being sensed in tandem with the type of data captured, and 2) creating a tactile impact of the sensor data on the body. The approach we suggest for working with biosensors through these design implications, highlights first person somatic and subjective experiences pertaining to different capabilities of people, past experiences, and anatomical construction of different bodies. Additionally, they can be applied to the design phase of initial explorations of sensors as a material to work with, or to later stages of a design process. Following these design implications, a designer will aim to gain a deep and nuanced understanding of a particular bodily function being in focus, and of sensor capabilities for capturing bodily data.

7.1 1st Design Implication: Enabling Reflections of the Somatic Impact of Being Sensed in Tandem with the Type of Data Captured

In our design process, we moved on a trajectory of testing and reflecting on the data different sensor placements produced and how different sensor placements affected the experience of breathing through particular muscles or body parts. As a consequence, these reflections and observations led us to re-think and re-construct our initial views on the observed phenomena pertaining to muscle contraction happening on the torso when breathing, including breathing sideways, deep diaphragmatic breathing, or breathing lower on the thoracolumbar fascia. They also led us to shift our attention from focusing solely on capturing breathing data to capturing the *experience* of breathing through sensors. We observed that in order to gain a better understanding of how to "collaborate" with a sensor and design for a symbiotic experience between sensor and soma, one has to slowly learn how to discern the exact location of a muscle on their torso, in addition to how that muscle moves in inhalation and exhalation, and how such movements alter when breathing faster or slower, among other factors. And beyond becoming attentive to the fleshy body, a similar detailed reflective and learning process needs to take place in regard to sensor affordances. In our case, slowly learning how breathing affects and impacts different muscles on the torso progressed in tandem with becoming more attentive to the type of data captured through each sensor tested, which led us to making adaptations to the actual sensors for bringing body and sensors closer.

Soma design proved to be a fruitful method to achieve this, as it provided us with a set of theories around the body, but also with concrete tools for facilitating our endeavour to engage with the bodily function of breathing through performing breathing exercises and through estranging and de-familiarising breathing. But most importantly, soma design showed us a path towards engaging with the actual technologies for sensing breathing from a perspective that was constantly reminding us to stay in the experience of breathing, in addition to articulating and reflecting on that experience, by sharing first person accounts among our research group. We argue that staying close to the experience of being sensed is also crucial for reminding one of the importance of working with sensing technologies with a curiosity and with a reflective lens on the phenomena being sensed, and the actual bodily function being in focus. Our process showed that by having the whole soma as a starting point, including its muscles, movements, felt sensations and subjective experiences when delving into explorations with sensors, it becomes possible to take a step back, deconstruct and then re-construct and re-articulate what this function does to the whole body, which muscles does it engage or which other bodily areas does it affect. This process helped us move away from treating breathing- or any other physiological bodily function in other cases- as "a given" and unified bodily function that can be measured in predetermined ways with off-the-shelf sensors.

(Re)discovering the somatic experience of the act of breathing and its impact on the upper part of the body (muscles on the torso), led us to adapting our sensing mechanisms to match our intended goals. This emerged as a need for exploring more closely the intersection between sensor and soma as a new material, instead of adapting the material affordances of the off-the-shelf sensors to the soma, or the soma to the off-the-shelf sensors. This became a crucial path in our process and the adaptations made to the sensing mechanisms deemed necessary in order to be able to capture our experiences of how different muscles and areas of the torso participate in breathing. And later, it led us to innovate in this design space by developing our own sensor mechanism (shape-change sensor-actuator pillows).

More broadly, we argue that this design implication can help designers working in this space to achieve a match between: a) what bodies experience when being sensed, b) how different bodily areas/parts (e.g. muscles in this case) are affected and/or participate in the bodily function being sensed (breathing here), and c) what sensors are able to capture in a particular context, in relation to the felt experience of being sensed.

7.2 2nd Design Implication: Aim for a Tactile Impact of the Sensor Data on the Body

With the first design implication we argued that a designer should stay close to the somatic and felt experiences arising when placing sensors on bodies for capturing data. However, while exploring the design space of breathing, we also saw the need the need to develop ways of experiencing the sensor data on the body, as a way of bringing closer sensors to the experience of being sensed. We found that one concrete path for achieving this was to use kinaesthetic actuation in the form of shape-change, materialised as pressure applied to the skin.

Therefore, a design implication arising from our process is to aim for an experience of *feeling the sensor feeling your body*. We argue that this is important for a) evoking a tactile and felt experience of being sensed, while at the same time b) making sense of what is happening at the meeting between sensor and body, in addition to c) providing a tactile physical experience of the internal workings of one's own body, providing guidance for exploring the design space of novel sensing mechanisms. In our design process this became a pivotal aspect for understanding how the soma relates *to* or *with* a sensor, when embracing and engaging with the full complexity of a bodily function- in our case with breathing. Engaging with breathing exercises initially, and integrating sensing technologies as part of the exercises at a later stage, revealed that pressure applied against the body (the skin), is very important for sensing breathing through the muscles we focused on. We explored this quality with the practice of touching oneself, then with pressure applied on the EMG sensor, with the shape-change pillows and then with the Breathing Shell. Sensing breathing started having an experiential component, and moved from being just about getting the correct signal from a sensor.

The process of questioning and deconstructing what a sensor measures on one's body and how the body responds or acts to the sensor, led us to another reflection regarding the boundaries between sensor and soma. The experience of breathing inside the Shell evoked a somatic experience of "someone else placing their hands on top of a particular muscle", where each shape-change pillow was positioned. Thus, the sensing shape-change pillows took almost the role of being one's hands, or one's body part, instead of being just a sensor added to someone's body for capturing biodata. Feeling the "foreign body" of the sensor became important as it kept on reminding to the wearer that it is a "body" to breathe against and into. This was materialised as a type tactile sensation, a type of "touch" applied against the skin, through the deformation of the pillows as the wearer's body changed shape as they breathed, and it was observed to be an immediate physical response to the changes produced on the body while breathing. The external experience of feeling one's internal breathing processes, provided a heightened experience: it drew greater attention to the velocity and degree of the change of the body's shape, since the deformation of the pillows is in fact the sensing mechanism that causes the pressure changes. This can also result in the experience of 'total disruption' described earlier, where the wearer attempts at controlling and effecting this foreign body wrapped around theirs. Our work is aligned with previous research exploring how wearable artefacts can be designed to evoke particular ways of moving. For example, Karpashevich and colleagues [28] explored *restriction* as a quality that can contribute to new creative engagements with one's body, encouraging particular ways of moving. Also Tsaknaki and Elblaus [13] designed the Nebula garment for investigating how bodily movements, expressed both explicitly and implicitly, can be translated into a subtle and intricate soundscape surrounding the wearer, encouraging wearers to explore the range of sounds that can be achieved in collaboration with the garment.

We argued that when designing with biosensing technologies one needs to take into account the overall experience of sensing, and design for that. But what does the overall experience of sensing mean, and what is the actual experience being sensed? A core reflection from our process was that the experience of the phenomena being in focus shifts as the design process goes on. Both by exploring different sensing mechanisms and also with exploring data outputs. For example, revealing the signal about a process happening in the body can reinforce or change the ways we breathe. In our process our focus shifted toward exploring ways of designing for the broader experience and practice of sensing breathing, instead of focusing solely on capturing and visualising breathing data. Consequently, our research is opening a design space on working with biosensing technologies from a somatic first person perspective that can expand from breathing to other bodily functions. Our implications lay the groundwork for others to delve deeper into this space and explore further the somatic impact of being sensed. In terms of future work, we have already started to engage in follow-up research on how these implications can inform designing with other forms of biodata, and we are expanding our user studies with the Breathing Shell aiming to explore more in depth and elaborate on the spectrum of the felt touch qualities of breathing it evokes.

8 CONCLUSION

In this paper we offered a detailed and rich account of our explorations on sensing non-habitual breathing, aiming to reveal and capture the complexity of this bodily function. With our process we opened a new design space for navigating contexts of designing with biodata more broadly, through problematising both the act of breathing and the overall approach towards sensing breathing. By adopting soma design and autobiographical design methods, we prioritised the somatic experience of being sensed while breathing through different muscles on the torso: the rectus abdominis (lower-abdominal), the intercostal (left and right side of the torso, front and back) and the thoracolumbar fascia (lower lumbar muscle). We tested a strain sensor belt and an EMG sensor for capturing muscle contraction when inhaling and exhaling. We also developed a new type of a shape-change sensor-actuator mechanism for capturing aspects of the somatic experience of non-habitual breathing. The findings from this process led to designing the Breathing Shell, a wearable that provides a sensation of "tangibility" of the act of breathing, since the felt experience of breathing, sensed as changes in different muscles on the torso, is actuated back to the wearer as pressure applied against their body, through the custom made shape-change sensors in the wearable shell. With our distinct approach to this research space we emphasised the collaboration between soma and sensing mechanisms. We suggest aiming for symbiotic experiences of sensors and bodies by offering two design implications: 1) engage with biosensors through reflecting on the somatic experience of being sensed in tandem with the data captured, 2) use actuation for deepening one's understanding of how the soma relates *to* or *with* a biosensor, when engaged in complex bodily functions - in our case, breathing. Both prioritise the primacy of diverse felt and somatic experiences when working with sensing mechanisms, over focusing solely on the data captured through sensors.

ACKNOWLEDGMENTS

This work has been supported by AffecTech: Personal Technologies for Affective Health, Innovative Training Network funded by the H2020 People Programme under Marie Skłodowska-Curie grant agreement No 722022 and the Swedish Foundation for Strategic Research project RIT15-0046.

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