Suspended Circles: Soma Designing a Musical Instrument

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ABSTRACT

We present a soma design process of a digital musical instrument grounded in the designer's first-person perspective of practicing Dalcroze eurhythmics, a pedagogical approach to learning music through movement. Our goal is to design an instrument that invites musicians to experience music as movement. The designer engaged in the soma design process, by first sensitising her body through Dalcroze training. Subsequently, she articulated her bodily experiences into experiential design qualities that guided the making of the instrument. The process resulted in the design of a large suspended mobile played by touching it with bare skin. We shared our instrument with 7 professional musicians and observed how it inspires a variety of approaches to musical meaning-making, ranging from exploring sound, to choreographing the body. Finally, we discuss how engaging with Dalcroze eurhythmics can be generative to the design of music–movement interaction.

CCS CONCEPTS

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

KEYWORDS

Music–movement interaction, DMIs, Dalcroze eurhythmics, soma design, first-person perspectives

ACM Reference Format:
Tove Grimstad Bang and Sarah Fdili Alaoui. 2023. Suspended Circles: Soma Designing a Musical Instrument. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3544548.3581488

1 INTRODUCTION

Movement-based interaction and body-centered design are ever more present in the field of Human–Computer Interaction (HCI) [13, 21, 22, 47]. With the proliferation of technologies such as off-the-shelf IMUs (internal measurement units), smartphones and various movement analysis tools [7, 15, 28], designing movement-based interaction has become more accessible to interaction designers and researchers. With these novel designs come a variety of methods and theories for analysing, understanding and making use of movement in interactive systems [1, 21, 31, 47, 52].

At the intersection of musical practice and HCI, digital musical instruments (DMIs) are following a similar trend, with a growing range of body- and movement-centred designs for human–music interaction (e.g. [4, 8, 10, 38]). In the music domain, musicologists, music technologists, musicians and composers have for a long time been interested in music-related movements and gestures [6, 18, 23, 29, 48]. Centuries ago, the first examples of written music notation across different cultures, were mirroring gestures of the body, and today, analogies to movement are still present in western music notation [45, 49, 54].

According to Godøy and Leman, music can be understood as movement [18]. From a phenomenological perspective, how our bodies move in the world defines how we experience and act on the world [37]. Movement is central to musical performance, perception and experience [23, 35], and it is with the body that we interact with a musical instrument following the specific movements that it affords. Moreover, the way we move with an instrument, influences our experience of it and of the produced sound. Unlike acoustic musical instruments, with physically-bound affordances that create a fixed action–sound relationship, DMIs are coded with interactions that can be designed according to various users and contexts [32]. We as designers have the opportunity to create these interactions that invite new embodied experiences, based on the *action–sound mappings* [25] and material choices we make when building our DMIs [56].

In this paper, we present a design process, grounded in the theory of embodied music cognition, of a DMI called Suspended Circles. The goal of the DMI is to invite participants into a somato-musical experience, i.e. an experience of musicianship as a movement practice. Building upon previous works in HCI, on soma design (somaesthetic interaction design), and body-centred design of DMIs [34, 38], we followed a soma design process [21] to design the DMI based on the designer's (the first author's) engagement in a somato-musical practice called Dalcroze eurhythmics. It is a pedagogical method that cultivates musical sensitivities through embodied experiences. This method lets the designer broaden her sensory appreciation and performance of music while designing the DMI [19, 22, 50].

Concretely, we followed an iterative process where the first author attended Dalcroze eurhythmics classes and sensitised her body to music. During and following this sensitisation process, we articulated the first-person, musical, and somatic experiences involved in the practice as experiential design qualities. We then explored how different materials can evoke these experiential qualities and influence the somato-musical experience. Following these steps, we designed Suspended Circles with the goal to invite musicians to engage physically with a large-size tangible suspended mobile,

CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04…$15.00
https://doi.org/10.1145/3544548.3581488

made up of conductive materials in various shapes which they touch using their bare skin to trigger sound.

We invited 7 professional musicians, 4 of whom are practitioners of Dalcroze eurhythmics (including the first author), to play the instrument. We did this to investigate how they experience Suspended Circles and how they interact with it to produce music. We were also interested in gaining an understanding of how the experiential qualities in our design translated to other musicians. The results of this study revealed a variety of approaches to musical meaning-making ranging from attending to the sound, to attending to the body. We describe in our findings the observed differences in the movement patterns of musicians with different somato-musical backgrounds when interacting with the instrument. Finally, we discuss how applying the Dalcroze eurhythmics approach to soma design contributed to the cultivation of both the designer and the musicians' embodied sensitivities throughout the design process and the sharing of the instrument.

2 RELATED WORK

2.1 Embodied Interaction and Soma Design

Theories of embodiment are providing practitioners in HCI with theoretical frameworks and guidance for design, analysis and evaluation of interactive systems for the experiential body. Different theories present different emphasis on e.g. the body, context and point-of-view [20]. Some spurring out of phenomenology [11, 52] and others from cognitive science and its critique of dualism through embodied cognition [27].

We are particularly interested in soma design, an approach of designing with and through the body while paying attention to aesthetic sensitivities in all actors. It is proposed as a design approach to address the challenges of attending to the experiential body [21, 34]. With roots in the pragmatist philosophy of somaesthetics, soma design provides a method for designing, and a theory foregrounding lived experiences through a first-person perspective [21, 22]. According to Shusterman, somaesthetics is the "critical study and meliorative cultivation of the experience and use of the living body (or soma) as a site of sensory appreciation (aesthesis)" [46]. By joining the two words, soma (the living, sentient, purposive body), and aesthetics (sensory appreciation), somaesthetics opposes the traditions of mind–body dualism. Unlike most philosophy, somaesthetics is not only theory, but also includes practical exercises that allow to cultivate, attend to and ameliorate the soma.

Rooted in the interdisciplinary endeavours of somaesthetics, soma design is a method that includes estrangement, where one disrupts the habitual patterns and engages with the unfamiliar, through slowing down for instance, in order to access a larger repertoire of experiences [31, 53]. The first-person experience and the soma are at the core of the design decisions taken throughout the process, and provide the designer with critique and insights into their design [50]. Soma design also argues for inclusion of somatic connoisseurship through collaboration with experts in somatic practices, such as professional musicians or choreographers, or other somatic practitioners [21, 22]. Overall, inviting others into the design process is an important step in the soma design process, where the designer gets to see how other people experience their design, and whether their own first-person experiences translate to other people's experiences. Sharing and inviting others into the design process lets the designer and their collaborators critique, judge and validate their design decisions as they continue the design process [50].

Soma design and somaesthetics have been used on occasions in contexts of musical practice [3, 9, 16, 34], such as in the non-tangible interface DogDog by Bigoni and Erkut, where the first-person perspective is applied as a means to bridge musical improvisation and movement-interaction. Furthermore, without explicitly drawing from soma design, Alexander Refsum Jensenius, along with expert dancer-choreographer, Kari Anne Vadstensvik Bjerkestrand, engaged in a series of sessions of slowing down and standstill, taking notes of their subjective experiences, in order to explore micromovements. This research project started out with a foregrounding of bodily explorations to gain understanding of micromovement, as a first step to approach sonic interaction design within that scale [24].

We build on such previous works, and engage with a soma design approach applied to the realm of DMIs. While previous soma designs of DMIs use approaches that are either analytically oriented or engaging in non-musical somatic practices such as Feldenkrais, we chose, in contrast, to explore an already established somato-musical practice, namely Dalcroze eurhythmics. Our process consists of attuning to the designer's body and explicitly articulating their embodied experiences as we design the instrument. We do so to generate creative ideas and designs guided by and nested in the body.

2.2 Embodied Music Cognition

Extending from the phenomenological school of thought, and along the lines of the *embodied turn* in philosophy that spread into other disciplines over the past decades, Leman introduced the concept *embodied music cognition* to musicology [23, 25, 29]. The ideas of embodied music cognition suggests that the body acts as a mediator for musical meaning-making, and that there is a clear link between action and perception:

> *"It is assumed that human musical action and perception are reciprocal processes that fuel [an interactive] loop, and that action and prediction are co-determined by constraints of the musical environment, as well as by those of the (corporeal) organism that interacts within it. Music is something that the listener interacts with, using sensorimotor, cognitive, emotional, and energetic abilities that optimize the interaction; it can be seen as an expression of the embodied mind"*
>
> - Lesaffre et al. [30], (p. 1)

The process where the body acts as a mediator for musical meaning-making is influenced by the musician–instrument relationship. The instrument's interface shapes and determines the relationship with it, which in turn determines the musical experience, opening up for certain movements and aesthetic experiences, while limiting others. The form, interface, size and sonic qualities of musical instruments are essential to how musicians interact with them, and play a role in how they learn to play them [41].

We ground our soma design process in these ideas from embodied music cognition. With our design choices guided by the soma, we

foreground the body as a mediator for musical meaning-making and build an instrument that invites musician to experience music as movement.

2.3 Dalcroze Eurhythmics

Dalcroze eurhythmics is a pedagogical approach of teaching music through movement. The approach started with composer and music teacher Émile Jaques-Dalcroze around the beginning of the twentieth century, from him noticing how his students at the Geneva Conservatory were lacking musicality despite their solid theoretical knowledge [26, 43]. Dalcroze' approach to music pedagogy was a practical one, based on the idea that music is perceived, performed and understood through movement, opposing the tradition of body–mind separation, which was (and still is) the prevailing school of thought in score-based, Western music education [23].

The approach typically consists of rhythmics (regularly recurring patterns known as musical metre, pulse etc.), ear training (the ability to recognise musical characteristics such as pitch and melody), solfège (a music teaching method where syllables are added to notes on a musical scale often accompanied with hand gestures), improvisation and development of creative abilities, all while seeking to uncover musical knowledge which Dalcroze believed to already be there, present in the body. Today's teaching of Dalcroze eurhythmics is often accompanied by what is known as the three mottoes of eurhythmics: "show what you hear, show what you see, show what you imagine" [43], encouraging practitioners and students to continuously make use of their moving bodies in parallel with their musicianship.

Previous work has drawn from Dalcroze eurhythmics to design technology for musical education. Nijs designed a system that visualises the music student's movements, and applies it with Dalcroze-inspired educational exercises [42]. Xiao et al. drew inspiration from the Dalcroze method in the development of an interactive system for piano learning for children [55]. The system consists of a projection on the music stand and fallboard of the piano, showing animated figures moving across the piano keys. While Dalcroze eurhythmics, with its full-body engagement, serves as a theoretical backdrop of the project, the bodily engagement with the system is limited to the player imagining themselves moving the same way the projection moves on the piano.

In our work, we aim to design an instrument that offers a full-body experience of music, with the idea that music is movement. To do so, we chose to lay the foundation of our (soma) design process on bodily engagement with Dalcroze eurhythmics.

3 DESIGN METHOD

We followed a soma design process, where the designer's (the first author's) first-person experience and reflections of engaging in a somatic practice stands as a central holding point throughout the design process [21, 22, 50]. From the designer's bodily practice, experiential qualities are articulated and serve as a "red thread" to inform the design process and the aesthetics of the interaction with the DMI [50]. The designer participated in a total of 5 Dalcroze eurhythmics lessons, with the goal of sensitising her body to music-movement practice—of discovering and uncovering musical aesthetic sensitivities through movement. Concretely, the lessons took place at KMH Royal College of Music in Stockholm, with two different undergraduate classes and teachers (course codes FG8011 and FG8012). This was her first experience with Dalcroze eurhythmics. The students admitted to these classes had musical backgrounds and were knowledgeable in western music notation (sheet music) and played at least one instrument on a professional level.

The designer also followed a total of 8 sensitisation sessions with her personal musical practice on the flute, where she brought Dalcroze eurhythmics principles into her own musicianship and worked on improvisation techniques. These instrumental sessions were loosely organised and were based on what she learned during the Dalcroze eurhythmics lessons. The purpose of the sessions was to deepen her awareness of her moving soma, and also to slow down and defamiliarise herself with her own instrument [31, 53]. With her instrumental practice, in parallel with the Dalcroze lessons at the music college, she made space for reflections and deepened engagement with music and movement.

Throughout the design process, we documented and collected materials in the form of photos, sketches, audio memos and written texts. This collection of materials include detailed accounts of our (first-person) experiences from each session of sensitisation, material exploration [17, 44, 56] and sketching. All audio material was transcribed. In the material exploration, we engaged with digital and non-digital materials, first through low-fidelity prototyping. We slowly explored the aesthetics evoked in interaction with these materials, and continued the documentation of our first-person experience and bodily experience.

Our first-person accounts put the body at the core of our design process and ground our design decisions in the experiential body [50]. We emphasise the importance of the *first-person perspective* of the designer in the process [21, 22, 50], as it contributes to building up a repertoire of experiences that they leverage on in the design process, and in the sharing of the work.

3.1 Authors' Contributions

Both authors are interaction design researchers. The first author has an educational background in computer science, engineering, and sound and music computing, in addition to musical training. She is an intermediate-level flutist, and reads and writes western music notation. She also integrates music technologies in her instrumental practice, working with audio synthesis, music programming languages and digital audio workstations. She carried out the design process and invited other musicians to play the instrument. The second author is a trained dance artist and computer scientist, and contributed along with the first author to the data analysis and writing of this paper.

4 DESIGN PROCESS

In Section 4.1, we describe the designer's process of sensitising her body through Dalcroze eurhythmics training, and through applying its principles to her own instrument practice and improvisation. Then in Section 4.2, we show how we articulated the experiences from the sensitisation process as experiential qualities, guiding the design of the DMI. In Section 4.3 we describe our process of designing the instrument, starting with exploration of low-fidelity

materials, then moving on to exploring higher-fidelity materials. This material exploration and sketching was driven by our experiential qualities from our somato-musical practice. The process of probing into materials and interactions evoking our experiential qualities and embodied aesthetic sensitivities, led us to design our final prototype, named Suspended Circles.

4.1 Sensitising the Body

Our soma design process was driven by bodily practice, through Dalcroze eurhythmics. Engaging the body in somato-musical practice provided a space for the designer to attend to her musical, moving body. Her subjective, first-person accounts of bodily practice are reported below, hence the use of the first-person pronoun, throughout Sections 4.1-4.3.

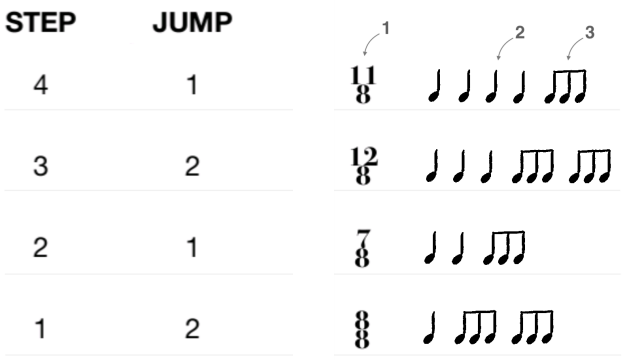
4.1.1 Getting to Know the Musical Body. The Dalcroze eurhythmics lessons followed some broad structures. The teacher would typically instruct us, students, to carry out an exercise, and afterwards ask us to reflect upon it in plenary. A focus in these reflections was placed on our subjective view of the experience, students often expressed their emotional and bodily sensations. Music theory was always introduced after bodily practice, and after sharing our bodily experience. This approach to teaching the Dalcroze method was the same with both of the teachers whose lessons I attended.

Walking as an Estrangement Method. Variations of walking were often used in the lessons, and became important sources of estrangement for me. In one exercise, we were walking freely around the room to the pulse of the music playing, and then started alternating between walking offbeat and onbeat. This was unsettling, and it was both physically and emotionally destabilising at first. I had a sense of losing control over something that I thought that I had mastered, and it disrupted the familiar and mundane act of walking. Walking offbeat was difficult, it felt unnatural, and from looking at my peers, I realised we resembled birds bobbing our heads, with forward tilting, heavy-looking upper bodies.

This type of rhythmic exercise was later explained to convey music theory related to *syncopation* (rhythmic variation disrupting a regular flow) and *musical metre and polyrhythms* (multiple, unequally spaced rhythmic patterns playing simultaneously). Elements of improvisation, collaboration and creativity were also recurrent in the exercises, through e.g. having us choose a walking direction or movement pattern while adjusting and making space for each other. Such collaborative aspects of the movement practice were alluding playing music with others.

Exploring Musical Rhythm With the Body. In one lesson, the teacher sat at the piano and gave us instructions for an exercise. The piano is an instrument often found in studios used for Dalcroze eurhythmics. We would also at time use other instrumental props, such as wooden sticks for rhythmic play. In this exercise, the teacher instructed us to step and jump according to a series of seemingly random numbers (see Figure 1a). So, first taking 4 steps, then jumping 1, then 3 steps, 2 jumps etc. This gave a strange sensation of the body moving off- and onbeat. The pulse of the musical rhythm started moving up into the chest from the legs, destabilising the body to the point of almost losing the rhythm in the movement, then regaining it when the pulse came back down into the legs again, where the musical pulse habitually resides. At times, when continuing these exercises on my own, I would get a strong sense of my upper body detaching from my legs and lower body.

After the exercise, the theory was introduced. The steps were crotchets (quarter notes) and the jumps were three quavers (eight notes) beamed together, with the metre changing every phrase, such that we were going off- and onbeat (see Figure 1b).



(a) Steps (left column) and jumps (right column).

(b) Musical metre, to the left (1), crochets (2), and quavers (3).

Figure 1: Instructions from a movement exercise, where students were instructed to move in a sequence of steps and jumps are seen in Figure 1a. The theory behind the exercise, in Figure 1b.

These types of **rhythmic exercises** could take form through a variety of different movements with the whole body, adding variations, and improvising with the lightness and weight of the body, and communicating with and attending to each other through movement. Theoretical parallels in such exercises were also drawn from dynamic musical terms and terminology, like *forte* (playing loudly), *legato* (notes articulated smoothly and connected), *ritardando* (gradually slowing down the tempo), *crescendo* (gradually playing louder) etc.

Broadening the Range of Bodily Expression. In more dance-like exercises, we were working with **repetition** and fine tuning of movement, as well as with *remembering* and *discovering* movement with the body. In one lesson, with a focus on working with the weight of the body, we were finding new ways to turn from one side of the body to the other, while laying down on the ground. Such an estrangement exercise is also used in other movement practises such as Feldenkreis in order to generate better awareness of one's movement patterns.

Entangling Movement and Sound. Some exercises were organised around *switching sensory modalities*. As reflected in the mottoes of eurhythmics, we would take an impression in one modality (e.g. music) and transform it into another one (e.g. movement). For example, one student sitting at the piano, improvising while the other students move with the sound, expressing or reflecting the sound through movement.

Exercises working with **rhythm** and **musical metre**, by providing a sense of *displacing the musical pulse around the body* made a big impression on me, as I was experiencing things that I had never felt before. The experience and discovery of moving the musical pulse around my body created a sensation of a strong push into the unfamiliar, where the musical pulse was in my upper body. Then, it strongly pulled me back to a habitual experience in which the musical pulse was again in my legs and lower body. After becoming more familiar with this musical experience, I felt much more supple in my ways of understanding music. I could listen to and experience "old" music that I had listened to many times before, but start hearing new things. I would also quickly experience and viscerally feel musical qualities as bodily sensations, such as tickling in the belly when hearing dissonance, or becoming emotional and feeling a strong flush or wave running through the body when hearing changing tonalities.

4.1.2 Bringing Movement Lessons Into My Own Musicianship. In the Dalcroze eurhythmics lessons I participated in, the students never brought their primary instrument into class. However, in my own musicianship, as a flutist and music technologist, I brought elements of what I learned in the lessons into my practice, as a means to *defamiliarise*, and *deepen my sensory appreciation* of my own instrumental music practice.

Aligning with the approach I learned in the Dalcroze eurhythmics lessons where we worked on slowly letting the body learn the movements before advancing further, I started out revisiting a classical music-education exercise involving repetition. When learning to play a new piece of music on an acoustic instrument, one of the tips you typically receive is to slow down, play it slowly until you get a hang of it, and then, when it has become readily available in your body and when your body has learnt it, you speed up again.

I decided to work on this exercise, while paying particular attention to my body while playing my instrument. I did so with a piece I enjoy, but find challenging to play, Debussy's "Prélude à l'après-midi d'un faune". Before playing and repeating the first four phrases of the score, I did the same repetitive exercise of the scale of the piece, the E-major scale. When *slowing down*, I started noticing my grip, the movement of my lips and mouth, head, back and shoulders. As a flutist I have, for as long as I can remember, been aware of how my breathing and posture affects the sound in my instrument, but in these exercises where I intentionally slowed down to bring my awareness to my body, I started noticing how much nuance and how much variety in sound I could get from adjusting the body alone, aside from basics of the grip around the flute and the embouchure (the action between my lips and the mouthpiece of the flute).

Now, when spending time and *exploring the nuances* of my instrument through attending to my body while playing, I found new possibilities and opportunities in the playing, beyond correcting or fine tuning sound. For example, with adjusting my head posture, and paying attention to my breathing pattern, I would start discovering interesting multiphonics (two or more notes sounding at once) in my monophonic instrument. When speeding up the scale repetitions I would also notice how, at times, my hands and fingers moved in jerky, staccato motions, and that I needed more time to familiarise myself with the gripping before speeding up.

I was repeating this exercise, going from scale to score, for about a week before I started approaching it from different angles, playing only parts of the scale, only parts of the score, or playing the scale with **rhythmic variations** and changing articulation, as we had been practising with body movement during the Dalcroze eurhythmics lessons, e.g. going from floating to more jerky movements.

Throughout these experiences of defamiliarisation by improvising with small **rhythmic and metric variations** I would easily lose myself and forget what I was doing, and then suddenly be pulled back when stumbling on a grip or note, or losing the rhythm. I continued with these types of **repetitions**, as these were exercises that would easily push me into improvisation and a sense of losing myself in the music. Thus, this sensitisation process created a space for me to (re)discover music, together with my instrument, through the body.

4.2 Bringing Movement Lessons Into Design

Attending the Dalcroze eurhythmics lessons gave me insights into the experience of music as movement, and provided me with language to articulate that experience, both musically and literally. The curious experience of feeling the *rhythm and musical pulse being displaced around the body* could now be articulated *1: as music theory*—syncopation or changing musical metre, depending on the exercise, and *2: as bodily knowledge*—moving and feeling complex musical rhythm. This sensitisation to such somato-musical experience was reflected in my experiences of now both playing and hearing music, having visceral reactions, and experiencing an embodied understanding of musical concepts, as described in Section 4.1.1.

The experience of rhythm and pulse being displaced around the body provided me with a reference experience for the idea of "music is movement", that is: *playing* music through movement, *feeling* music through movement and *understanding* music through movement. I call it a reference experience, in the sense that it was an experience that I could revisit and that each time I revisited it, it gave new meaning to my musical practice. I further articulated this reference experience as the experiential qualities of **rhythm** and **repetition**. I chose to work with **rhythm** and **repetition** because it provided higher-level, yet nuanced somato-musical qualities that are constructed by multiple specific experiences. As an example of how **rhythm** and **repetition** manifested in my body, when the musical pulse was moving through my body and I was on the brink of losing it, *repeatedly* moving with the *rhythmic structure* would help me pull back the sense of stability in the pulse. After *staying with the rhythm and repeating it* for a while, I was ready to experience the pulse being displaced around my body again.

In an attempt to further put words to this experience, I present the analogies of rowing and the elliptical trainer. When pushing the oars through the water, or stepping on the elliptical trainer while pushing the levers, there is resistance in the movement, and as you find a rhythm in the movement, the resistance feels softer and lighter. Now, if you lose the rhythm or stop abruptly, you will feel a strong push against your body, and will have to work on finding back the rhythm to be able to move again.

4.3 Designing the Instrument

Guided by the experiential qualities of **rhythm** and **repetition**, I engaged in a material exploration through movement and the body.

4.3.1 First Iteration: Material Exploration. I explored how various digital and non-digital materials influence the experience of somato-musical interactions. These explorations took place through Dalcroze-inspired, embodied engagement with a selection of materials, such that my design choices were informed by bodily sensitisation and through slow reflection with the soma.

I gathered a collection of everyday materials in varying shapes and sizes (see Figure 2). I started my material exploration with walking exercises, inspired by Dalcroze eurhythmics, to attune to my somato-musical sensitivities. Then, I carried out the exercise, evoking the reference experience of *moving the pulse around the body*, to revisit the experiential qualities of **rhythm** and **repetition**. I payed attention to how I felt the qualities moving throughout the body, and started crafting low-fidelity prototypes of DMIs that facilitated, produced or were built around these qualities. With the prototypes I imagined how I would play them, and then do so with the body. For example, with pieces of sponge-like material attached to a meter long piece of wood, I held the wood and squeezed, slapped and flicked the sponge while walking and at time placing the wood to the floor.

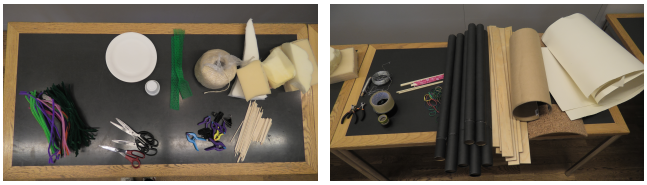


Figure 2: Mundane, everyday materials that the design used in the initial material explorations, and found a series of touch and movement qualities that she explore in relation to the experiential qualities.

At times, I felt the rhythmic quality residing in my limbs and extremities, and assembled a collection of touch and movement qualities that resonated with this sensation, namely : *patting, tapping, dabbing, holding, touching, stroking, gliding, floating, slapping, wringing, flicking, jabbing, punching, knocking, pressing, rubbing, crunching and kneading.*

4.3.2 Second Iteration: Prototyping Sensors. From these touch and movement qualities, I started crafting 'sensor' interfaces using combinations of conductive materials (conductive fabric, mesh, thread, yarn and paint) and varieties of surrounding shapes, structures and layers of non-conductive materials, such as wood, paper, plastic, yarn and fabric (see Figure 3). The 'sensors' were made from memory foam and synthetic pillow filling with conductive thread, sewn in crisscross patterns through the material, and patches of hand- and machine-knitted, conductive yarn and cotton with variations of an integration of conductive thread.

I continued revisiting my reference experience and experiential qualities of **rhythm** and **repetition** to get a sense of what experiences my 'sensor' materials facilitated. To digitise my 'sensor',

Figure 3: Drawing from the touch and movement qualities that resonated with the experiential qualities, the designer crafted a variety of 'sensor' materials from a mix of conductive and non-conductive materials, made from cotton, memory foam and pillow filling.

I created a fabric breakout board[1] for a capacitive touch-sensor. With the breakout, board I could then easily and non-permanently connect the conductive materials and render the sound of the interaction when prototyping (see Figure 4).

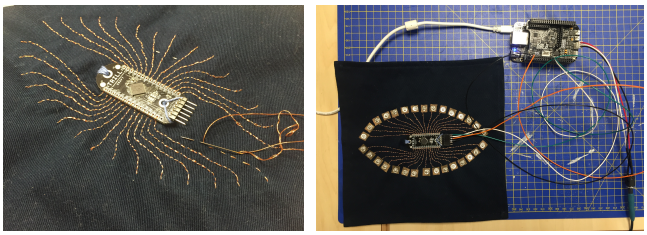


Figure 4: The designer made a fabric breakout board for a touch-sensor, for easy, non-permanent connections to 'sensor' materials during material exploration and prototyping.

To render sound of the interaction with the crafted 'sensors', I used a Bela board for audio processing together with the touch-sensor (Trill craft) that I connected to the conductive materials embedded into my sensor materials. I started out with one mapping where the sensor data mapped to the frequency and amplitude of a cosine wave audio synthesis in Pure Data (Pd). With this simple mapping, I explored the varying sonic outputs that would be generated when applying the different movement and touch qualities from the previous prototypes to the sensor. I first used my hands and fingers to impact the sensors. I then used larger contact surfaces like my arms, chest and legs, to engage my body in larger movements with the sensors.

As I experimented with these crafted sensors, I found that a variety of touch input from small and large movements onto the sensors – tapping, holding, stroking and kneading – translated into nuanced sonic feedback, e.g. kneading or pulling resulting in a gradually increasing pitch. The harder you squeeze, the higher the pitch. I explored interactions with these materials by touching and moving them with my hands, fingers, arms and with larger body movements by spreading the sensor surfaces out over an area of about one cubic metre. That way, while continuously revisiting my experiential qualities, I continued sensing how the sonic output from the materials were supporting or evoking experiences as those I knew from my somato-musical practice.

[1] https://blog.bela.io/2020/09/29/e-textile-interfaces-trill-craft/

From my Dalcroze eurhythmics exercises and the experience of *displacing the pulse around the body*, I used conductive paint to sketch out syncopation patterns onto paper (see Figure 5) in an attempt to prototype an interface that would facilitate the experiential quality of **rhythm** in my design. When sliding my hands across the pattern, the produced sound generated the feeling of *displacing the pulse around the body*. This interaction evoked a sense of the pulse moving around in my chest and arms. My legs and lower body were not the point of departure for the pulse anymore, as they had been in the eurhythmics exercises.

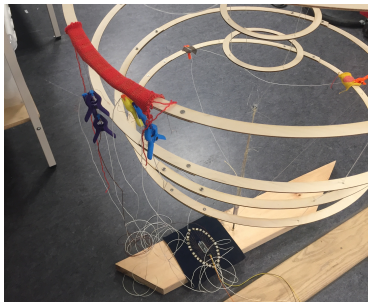
Figure 5: A prototyped interface with syncopation patterns drawn onto paper with conductive paint, aiming to facilitate the experiential quality of rhythm.

As I revisited my somato-musical practice, together with the interactions that I prototyped, I found the relationship to **rhythm** heavily symbolic, rather than embodied, when painted onto a sheet of paper. While the sonic output was rich and nuanced, and I clearly heard the syncopation, my bodily experience of the mobility of the musical pulse in my chest was less captivating than the ones from the full body exercises. The interfaces that I was prototyping were all controlled on a small scale even when I spread them out on larger surfaces, and going back to our somato-musical practice, I saw how the scale of the sensor interface was limiting the engagement of the whole body.

4.3.3 Second Iteration: Making Suspended Circles. In this iteration, I chose to focus on designing a large, stationary, tangible musical instrument, rather than a smaller, wearable or handheld instrument, or an intangible instrument using spatial or temporal sensors. Some of the interactions and action–sound mappings that I had developed were still relevant. Especially the synthetic pillow filling with conductive thread sown through it in crisscross patterns, and strings of knitted conductive yarn. These made up soft, fluffy 'sensors' which increased in pitch as I kneaded or pulled them. The immediate response to the sound from the touch gave me a feeling of not only being tightly linked to the material, but also that the material gave an appropriate sound to my feeling. However, as they were prototyped they did not fully evoke my experiential qualities. Precisely, they were not spatially distributed in a way that allowed me to engage the full body while interacting with them.

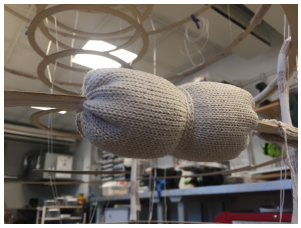
I continued exploring the experiential qualities in interaction with materials. Now, I went in with an idea of a large-size interface combined with elements of the crafted 'sensors' from the first iteration and with the goal of inviting both large, full-body movements, and small movements, making use of different spatial scales of interaction. I went on to design and build the musical instrument that I called Suspended Circles.

I kept going back to the experiential qualities of **rhythm** and **repetition** in Dalcroze exercises in order to tune into to my somato-musical sensitivities. As a way to facilitate these qualities, I embedded repetitive patterns in the design of the instrument. I created a repetitive structure made up of eight wooden rings, with the largest having a diameter of a 90cm, suspended from the roof as if floating in space above one another. I covered the wooden rings with sensors made up of machine-knitted fabric from cotton and conductive thread as well as synthetic pillow filling (see Figure 6). The sensing materials respond with nuanced sonic output from tapping, holding, stroking and kneading, as explored and refined during material explorations. The action-sound mappings and audio synthesis embedded in the instrument are the same as those prototyped during the first iteration, where kneading the sensor with pillow filling or pulling was mapped to an increasing pitch. Then, drawing from the importance of repetition and in Dalcroze eurhythmics exercises, I added a 4-channel looper pedal placed on the floor as another layer of repetition. The looper was controlled by stepping on the pedal-like boxes on the floor.



(a) Machine-knitted cotton with multiple different sensor areas with conductive thread connected to the touch-sensor.

(b) Pillow filling with conductive thread sewn into it.



(c) Cotton-covered pillow filling with conductive thread (from Figure 6b) sewn onto the instrument, and connected to the touch-sensor.

Figure 6: The instrument consisted of a large structure covered with multiple small-scale 'sensors' that the designer crafted from conductive materials and fabric as seen in Figures 6a-6c. The 'sensors' responded with nuanced sonic output from tapping, holding, stroking and kneading.

The varying distance between the conductive areas in the repetitive patterns in the fabric, drew upon the explorations of syncopation patterns from the first iteration. With these patterns, note sequences of changing musical metre gave the sonic feedback of syncopation, when sliding your bare skin over them at an even pace (see Figure 7). The input from these conductive areas were mapped to an increasing amplitude.

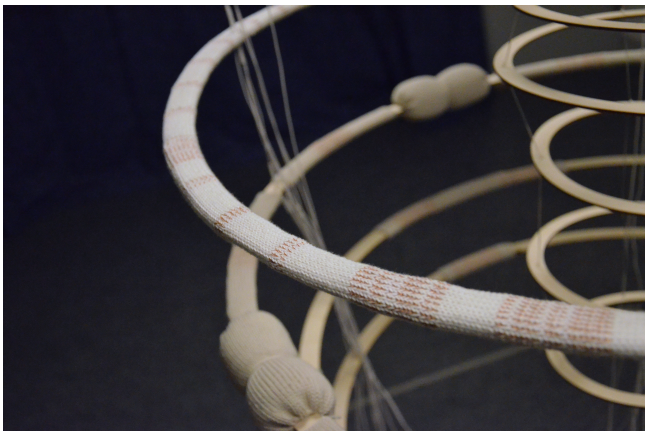


Figure 7: Some of the sensor areas of the instrument were made up of a sequence of conductive areas imitating syncopation patterns as inspired by Dalcroze exercises.

As in the first iteration, the conductive areas are connected to a touch-sensor breakout board, a Trill Craft. The sound is processed through a Bela board running a 4-channel looper and sound synthesis in Pd, with frequencies increasing across the height of the DMI, i.e. low pitch at the bottom and high pitch at the top (find code here[2]). The mapping of frequency going from high to low was chosen after I explored other spatial layouts. Going from high to low had direct parallels with the somato-musical practice from both eurhythmics training and instrumental improvisation, and was especially apparent in the Dalcroze exercises where students were "showing what they hear" with movement. Higher pitches were always associated with upwards movements, and lower pitches downwards. As I tried other mappings, it gave the interaction with the instrument a sense of being inconsistent with my bodily experience. I found a certain familiarity in the mapping, which together with qualities of repetition and rhythm facilitated by the conductive patterns and structure of the instrument, gave room to explore the music with the body in the Dalcroze fashion. More on how the DMI can be played is covered in Section 5, through accounts of sharing the instrument with other musicians.

5 INVITING OTHERS TO EXPERIENCE THE INSTRUMENT

After reaching this stage of the design of Suspended Circles (see Figure 8), we invited musicians to interact and experience it. We were interested in observing how they produced music with the instrument and what the instrument inspired them to do. Sharing the instrument with the chosen groups of people provided us with insights about the interaction, coming from experts with the embodied knowledge and language to express their experiences interacting with it.

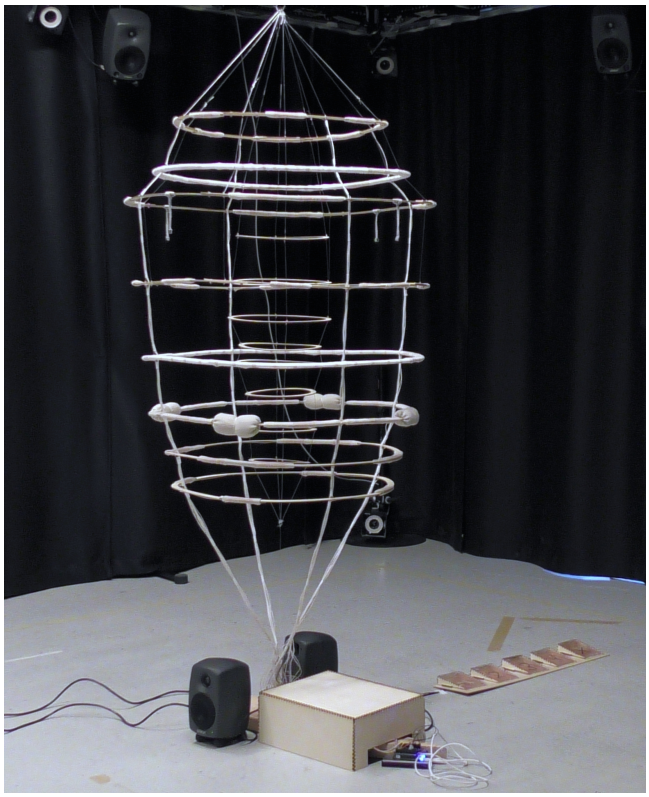


Figure 8: Through a soma design process, we designed the tangible musical instrument, Suspended Circles.

5.1 Participants

We invited two groups of musicians with different practices to interact with and experience the instrument, in training contexts true to their own practice.

5.1.1 Context 1: Dalcroze Practitioners. In the first context, we invited the musicians and music pedagogy teachers from the Dalcroze eurhythmics classes that the first author participated in to explore the instrument collectively as in a typical eurhythmics lesson. Three musicians (including the first author) with extensive Dalcroze eurhythmics training, explored the instrument together. The first author participated as a musician and the group was accompanied by one of their teachers.

5.1.2 Context 2: Non-Dalcroze Musicians. In the second context, we invited three musicians without Dalcroze eurhythmics training (a vocalist, a pianist and a pianist/composer) to explore the instrument individually in separate sessions. We invited these musicians

[2]https://github.com/togrba/suspended-circles

to individual sessions with the instrument as this is usually the case in instrumental training.

Our decision to invite these two groups of musicians separately was taken with the intent of staying faithful to their real-life practices when probing their interaction with the instrument, as the Dalcroze practitioners train collectively in a group and the non-Dalcroze musicians train individually.

5.2 Procedure

Suspended Circles was installed in a studio (as seen in Figure 8) where the 7 participants were invited to explore the instrument in a total of 7 sessions, all in the same studio and with the same instrument setup and mapping. In context 1 with the Dalcroze practitioners, the 4 sharing sessions took place in a collaborative exploration, as it is also the case in Dalcroze eurhythmics training. The sessions were facilitated by the teacher. As for context 2, the 3 sessions with the non-Dalcroze musicians, were held as individual sessions with each of the three musicians. No directions were given, and the sharing took place as a free individual exploration.

5.3 Data Collection and Analysis

The sessions were video recorded. We also recorded moments where the participants explained their experience with the instrument. Additionally, the first author observed and took notes during and/or after these sharing sessions. All observation notes and video recordings were done with the consent of the participants. The videos together with the observation notes were transcribed and analysed by the authors through thematic analysis [5]. In doing so, we first coded the data, and then defined themes that capture participants common patterns of interacting with and experiencing the instrument. Each participant was given a code name based on their role and the session that they participated in (musician with Dalcroze training—DM, non-Dalcroze musician—M, followed by a number for each participant): DM1 (teacher), DM2, DM3, DM4 (first author), and non-Dalcroze musicians: M1, M2, M3.

5.4 Findings

Our findings illustrated different attitudes towards the instrument between the two groups, the Dalcroze and the non-Dalcroze musicians, and their respective contexts. We observed the Dalcroze musicians focused on choreographing the body and their interactions with the instrument, treating it as a sacred object that they performatively touched together. The non-Dalcroze musicians focused on moulding the sound and their bodies to the instrument, and treated the instrument as a medium that they manipulated primarily to produce sound.

5.4.1 Context 1: The Instrument as a Temple for Dalcroze Practitioners. Our findings show that the Dalcroze practitioners engaged in collaborative, choreographed bodily explorations of the instrument. They collectively invented performative ritualistic mise-en-scènes where the instrument seemed like an object of devotion or a temple. They were primarily attentive to their bodies and choreographed movements, more so than the sound they produced.

Rituals, Narratives and Mise-En-Scène. In the sessions with the Dalcroze practitioners, DM1 played the role of guiding and structuring the explorations without interacting with the instrument and by solely observing what the musicians did. DM1 first explained an exercise to DM2, DM3 and DM4 and asked them to perform it. Then DM1 asked each of the 3 Dalcroze practitioners to come up with their own exercises to share and perform together.

In the exercise led by DM3, a narrative unfolded with a complete mise-en-scène that they invented. The participants started by jumping on two feet into the room at an irregular pace, one behind the other. At first, they pretended not to see the instrument. Then they discovered it, and approached it with curiosity and apprehension, not yet touching it. After some time of curiously looking at it, exploring it and touching the structure and peripherals with their hands, they all retreated, but later returned as if they were "too curious to let it go", as expressed by DM3 in their explanation of the exercise. When returning to the instrument, the participants slowly started touching the instrument with their hands to create sound, kneading, stroking and tapping it. DM3 and DM4 were slowly stroking and holding the instrument, and DM2 was rapidly tapping it. Eventually, they stopped playing the instrument simultaneously, and slowly retreated, jumping back out of the room on two feet. The exercise panned out as a theatrical bodily exploration. We observed that the musicians payed less attention to the sound itself than they did to the narratives and the rituals that produced the sound.

The 'otherness' of the instrument played a central role in inspiring ritualistic narratives invented by DM1, DM2 and DM3, as explained above. In the exercise proposed by DM1, the participants started by entering the room, one after the other, and slowly pacing around the instrument, as if they were discovering, exploring and moving around an unknown creature. Furthermore, in the exercise proposed by DM1, the participants were performing a pulsing movement with their upper bodies and arms out towards the instrument, before moving on to touching it lightly. These movement seemed like ritualistic prayers around an object of devotion, perhaps a temple.

This suggest that the musician's Dalcroze background incited them to have a performative relationship to the instrument, emphasising the central role of movement expression in musical meaning-making. Their mise-en-scène and performative bodily rituals that took place around the instrument, suggests that they explored it in their Dalcroze exercise embracing the idea that there is more to music than simply producing sound.

The Instrument Choreographing the Body. From the sharing sessions with Dalcroze musicians, we observed how the movements performed by the participants were inspired and guided by the instrument, inviting small scale movements of nuanced touch, as well as full-body engagement around the instrument.

The participants were often moving around the instrument, in the circular space delimited around it, and building exercises that took advantage of that circularity. The instrument stood insular, in the middle, with the participants moving around it in a way that suggested it being another separate body, as expressed through the 'otherness' or mysteriousness brought up by the participants that we describe above.

Figure 9: We observed the Dalcroze musicians choreographing their interactions with the instrument, here playing the instrument with their feet.

As the participants started touching the instrument, it began as slow and careful explorations of the affordances of the instrument, adapting and adjusting to its response. The participants were touching the areas closest to themselves, and oftentimes giving more time and attention to the sensor areas that responded with a changing pitch from kneading or pulling. At one point, DM2 pulled a string, making a high pitch distorted noise, and responded with surprise quickly moving their hand away from it. They then repeated it again right after, with the same reaction of pulling the hand away.

As the playing evolved, the participants went on to kneading, pulling, holding and touching everywhere with both hands, exploring the complexity of the instrument, using big, full body movements to reach all areas, as the instrument is larger than human scale. The flexibility of the wooden structure allowed for a variety of touch qualities, even bending and turning the structure itself. The participants were also touching the instrument with other parts of the body, in particular, all 3 of them lied down around the instrument and started touching the circles with their feet (see Figure 9).

The Dalcroze method of "showing what you hear" was used in the exercises led by DM2 and DM4. Here, when DM2 was "showing" what they heard from DM4 playing the instrument, they interpreted the low pitch sounds through leg and lower body movements. High pitch sounds they interpreted with toe movements as well as upper body movements, i.e. lifting their chest and arms up in the air. They interpreted pitch bends as a wave through the body, and they moved to distorted sounds in a jerky manner, losing balance and falling to the floor at one point. They interpreted higher volume as larger body movements. When DM3 was "showing" what they heard from the music played by DM2 and DM4, their movements were more fluid than DM2's movements, through which they were not imitating the sound but rather feeling the sound in their body.

Emerging Collaboration. Collaboration between participants was observed as a spontaneously emerging component that was central to all the exercises proposed during the sharing with the Dalcroze practitioners.

In the exercises where the practitioners were "showing what they hear" by imitating the sound with movement (see Figure 10), the roles evolved and participants went from "being the music", to joining in to play the instrument together.

In the exercise proposed by DM2, both DM2 and DM3 had to enter the room "being the music", make one round around the instrument, then all three participants had to collaborate on playing the instrument. They first played across only three circles at the time, moving from bottom to top, structuring their movements from low to high and the sound going from low pitch to high pitch.

In the exercise led by DM4, the participants had to collaborate on recording loops. As they paced in circles around the instrument, one participant would start recording a loop by stepping on the looper pedal when passing it. to start recording a loop. Then, the participants could play the instrument, and finally, as they continued pacing around the instrument, another participant passing the pedal would stop the recording by again stepping on the pedal. During this process, the participants were instructed by DM4 to "show what they hear", spurring repetitive movement with the repetitive sound from the recorded loops.

Participants were slowly building up layers of sound together while continuously analysing and making decisions about what to add next. Thus, collaboration emerged from every exercise that was invented. Their exercises were challenging, as it included moving—"being the music"—, recording, playing the instrument, and attending to each other all at the same time.

Following the four sessions, the Dalcroze participants mentioned how they lost track of time and were absorbed by the interaction with the instrument and each other. They also discussed the possibilities of continuing their practice with the instrument, or installing it in their own facilities, as they found it suitable for their eurhythmics training. For the teacher, the instrument provided additional inspiration for choreographing the body and inventing movement exercises.

5.4.2 Context 2: The Instrument as a Manipulated Sonic Object for Non-Dalcroze Musicians. Our findings show how the musicians without Dalcroze training payed active attention to the sound produced when interacting with the instrument, more so than their bodies. We observed the musicians moulding and stretching their

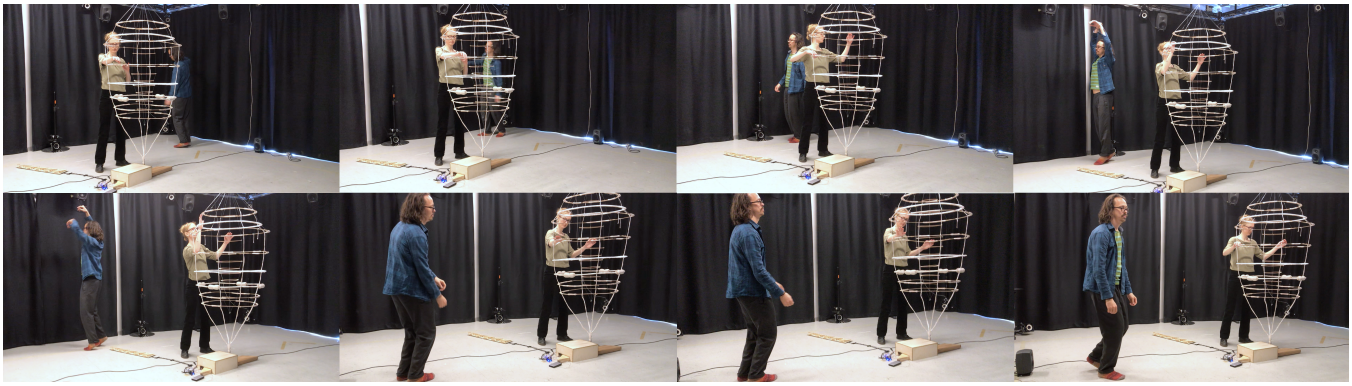


Figure 10: Collaboration between the Dalcroze musicians was central to how they played and interacted with the instrument. Here, one participant is playing the instrument and another is "showing what they hear" while *"being the music"*.

bodies to create sounds and explore the sonic possibilities of the instrument, their bodies serving as a vessel for playing music.

Attending to and Crafting the Sound. We observed how the participants systematically approached the instrument with the goal of sound production, searching for new sounds and learning to play the instrument with methodological precision. The participants were actively attending to the sound more so than the body. Touching the instrument itself was an exploration of sound, and as the participants found a sound they enjoyed, they would record it with the looper, which led them to grab it or hold on to it for a while.

M1 in particular was methodologically layering the sound, using the looper, to create complex soundscapes. They were exploring different ways of touching the instrument and creating thick, nuanced soundscapes. The soundscapes quickly sounded saturated, but even then, it continued evolving, as they continued layering while exploring new ways of touching the instrument.

M3 was methodologically trying to learn the scale and mapping of the instrument, in order to play musical pieces from their repertoire. M2 and M3, both pianists, were often touching the instrument as if they were playing chords on a piano. This suggests the impact of the musicians' backgrounds in shaping their imagination of the scenarios they invent to interact with new instruments.

In order to explore the instrument to the fullest, the participants started playing it with their hands, and as the sensor areas on the instrument are conductive, they would partly uncover parts of their dressed body, such as the arms, to have more areas of skin available. They would also play with other parts of the body, like the face and neck, to be able to touch and play multiple sensor areas at the same time, in search of new sounds.

The Instrument Moulding the Body. During these individual sessions with the non-Dalcroze musicians, we observed the instrument moulding the musicians' bodies, and that in turn the musicians moulded the instrument to their creative ideas.

While playing the instrument, the musicians' bodies, and M1's in particular, moulded to the instrument. They were actively searching for ways to create and discover new sounds through bending and moulding their body, *moving with, through and across* the instrument. We observed them as they took uncomfortable positions to reach specific parts of the instrument, stretching their arms to reach the upper and lowers parts of the instrument, or even tilting their heads in uncanny ways to touch the farther conductive part of the circles (see Figure 11).

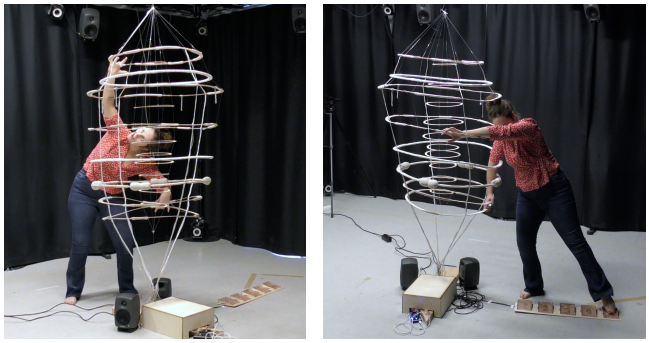


Figure 11: We observed the non-Dalcroze musicians moving "through" the instrument and moulding their bodies to it.

The musicians also moulded the instrument to their will in order to achieve their creative ideas. For example, M1 was making significant use of the looper, and would move the instrument in ways to reach the looper pedals, grabbing onto it and twisting it around, as if bringing it with them to reach the pedals and record the sound that they had discovered. We also observed them as they twisted the circles rigorously to make several circles touch each other to create additional layers of sound.

Thus, in the sessions with the musicians without Dalcroze training, they adopted a "manipulative" relationship to the instrument: as an object that they moved around and moved with in order to primarily craft the sound in a musical way. There was no scripted narratives nor mise-en-scène around how the body needed to perform with the instrument. The sound always came first, in the musicians' search for layers of sound, through loops of repetition and rhythm.

6 DISCUSSION

6.1 Attending to the Sound or Attending to the Body

Our results show that the Dalcroze musicians attended primarily to the body while the non-Dalcroze musicians attended primarily to the sound, as they interacted with the instrument.

The Dalcroze trained musicians choreographed their interactions with the instrument, inventing narratives that were a theatrical mise-en-scène of the body around it. They treated the instrument as a temple and performed ritualistic movements to come in contact with it. Thus, they used more ancillary or semiotic movements and gestures than sound producing movements when playing the instrument. These ancillary movements are well known in musicology [6, 18]. They usually serve to expressively accompany the music production rather than to produce music per se. Dalcroze practitioners used such ancillary movements that were unnecessary to produce sound, but instead served as a vessel for them to collaboratively express themselves while exploring the instrument. Collaboration was also a central aspect that held the scenarios together. Surely, the practitioners were invited to explore the instrument in group, as during their regular classes. However, the essence of how they approached the instrument, beyond the instructions that they received, consisted of building and layering the meanings on top of each other, making up a collective story of playing the instrument.

The non-Dalcroze context, on the other hand, revealed how the musicians used movements that serve almost exclusively to search for sounds, manipulating the instrument and adjusting their body to it. They were attending to the sound and moving with the instrument as a means to discover new sounds. The large-size interface of the instrument allowed for discovery of sound through small scale touch, as well as through large scale, full-body movement. This has been brought up as an important design quality in large DMIs in previous work by Mice and McPherson [36, 38]. We described in our results the physically challenging ways by which the musicians moved, touching multiple parts of the instrument simultaneously, all in an attempt to familiarise themselves with the instrument, learning how to play it and ultimately discovering new musical possibilities with it. These explorations were made individually, just like an instrumentalist trains alone with their instrument to refine their craft.

Observing the differences in the interaction pattern across people with different somatic training and backgrounds, suggests that our soma design process, even while being built upon subjective narratives of the designer, led to the design of an instrument that accommodates different bodies and different somatic experiences. As discussed by Ståhl et al., sharing our design with others provides a way to critique and judge the work beyond the critique from our own body, and to observe how and if the design resonates with other people [50] with various sensitivities and expertise.

Along our observations that showed that the Dalcroze practitioners focused more on the body, and the non-Dalcroze musicians focused more on the sound, we wish to emphasise that we do not present these differences as outcomes of a comparative study. We rather see these as revealing two distinct approaches to music-making with a new and unfamiliar interface, of people coming from different traditions of musical practice. We see the value in how the Dalcroze practitioners were digging into the body and musical embodiment, and in how the musicians were digging into sound qualities and the nuances in the soundscapes they produced. From observing these different approaches to our instrument design we find value in both, and recognise that one is not better than the other. Instead, observing these differences serves as a way for us to learn how our design can be accommodated by others with different practices and different bodies than our own.

6.2 Staying With the Body

For the first author, this design process with the unfamiliar experiences related to music and movement, led to a widening of musical sensitivities and a deepening of sensory perception of music, both as a practitioner and a listener. Following a process grounded in somato-musical practice (Dalcroze eurhythmics and instrumental practice) provided several examples of *movement as reference experiences for the design work*. These movements provided us with design material, generative to the design of the instrument [21, 50].

Throughout the design process, the first author found herself reflecting on how the sensitisation process was provoking strong musical experiences in her. She soon became convinced that such musical sensitivity might be required in the designer to be able to follow through an embodied soma design process of a musical instrument, since without the sensitivity towards the experiences, they would perhaps not stand out at all. The reflections on the need of a sensitisation process and the resulting experiential qualities, were mostly stemming from the designer struggling to 'let go' of the experiential qualities after sharing the instrument with other musicians. The experiential qualities were guiding the design process, but after sharing the instrument with others, the experiences were expanding, and became something new and different when experiences in other bodies. We had to learn to let the new experiential opportunities arise. This speaks to the generative nature of soma design, in terms of providing space for new experiences to emerge in the design, and the sharing with others [21, 50].

In a bodily driven design process such as this one, staying with the body and its experiential qualities that we design for, remains a challenge. One way forward could be to steer clear of theoretical or symbolic fast lanes when designing for the experience, to take the time to design reflectively and to accept that the experience is likely to never be felt the same in everyone. Our study made a concrete example of the challenge of developing interactive computing systems (which are symbolic in nature) for diverse experiences, which may be in conflict with the symbolism and representational nature of the system. This gap has been previously discussed by Fdili Alaoui et al. in their study of the challenges of embodied interaction design [14]. Including symbolic notation in a system like this is perhaps not a problem in and of itself, as the design invites bodily engagement and the symbolism does not have a functional quality in the interaction per se, but it rather plays a role in the design process. As an example, none of the participants playing the instrument, apart from the first author, interacted with the syncopation patterns that were built into the circles and that came from musical theory, but that did not take away from their musical experiences playing the instrument.

6.3 Traces of Musicians' Practices

The instrument built throughout this paper unfolded as a trace of their designer's artistry. The designer built an instrument that had no obvious links, nor drew from traditional instruments, and spurred a diversity of movements in the musicians playing it. Most importantly, this illustrates how the instrument trace the designer's musical imagination, skills and practice.

The instrument represents the first author's musicianship and is a mirror of the experiences lived throughout the design process. Through the Dalcroze eurhythmics lessons, "music is movement" took on new meaning for the first author, as she was learning to assimilate a movement repertoire where her musical experiences were allowed to evolve. Based on the Dalcrozian idea that musical terms are naturally there within our bodies, the first author went through a process of learning to express and make use of movement in musical terms. Prior to entering this process, e.g. syncopation in music was for the first author articulated as rhythmic variation, and did not have any particular movement associated with it. During the design process and movement exercises, she learned to articulate the same syncopation as "destabilising the body". And later on, in addition to being "destabilising", she also felt the syncopation viscerally travelling through her body. As demonstrated with this example of gaining a deeper understanding of syncopation, the process of designing, building and playing the Suspended Circles not only traces the first author's experience of *music as movement*, but goes as far as changing it radically.

The movements and articulations acquired from the Dalcroze training sometimes felt unnatural and estranging, but provided a push to discover something new. In the same way as the first author's experiences of feeling syncopation in music "touching" her body, she felt rhythm and the movements initiated by the instrument as she interacted with it. This aligns with Nijs who argues for combining music technologies with Dalcroze eurhythmics to open new possibilities of musical meaning-making [42]. The process of designing, building and playing Suspended Circles not only traces the first authors' understanding and experience of music as movement, but also went as far as changing and shifting it radically.

The first author and Dalcroze practitioners discussed the possibility to continue using the instrument in their training, but quickly encountered the constraints of a DMI built in an experimental research context. Indeed these systems tend to be difficultly manageable by other people than their designer due to their insufficient robustness [2, 12, 33, 39, 51]. Eventually, the Dalcroze practitioners did not adopt the instrument, as they did not have the resources to maintain it in their daily practice, and neither did we.

Thus, a step further for this work would be to facilitate the long-term use of Suspended Circles in the day-to-day practice of Dalcroze eurhythmics and other musicians. This would demand to further develop the instrument to meet the robustness required for musicians to use it in their daily practice. Deployment of the instrument over a longer period of time in the wild, would give rise to new insights into the musicians' interaction with it that are perhaps not available through lab experiments or short term studies, such as the one we present in this paper.

In summary, this work provides an account of the exploratory and transformative design process behind our instrument creation, and as stated by Morreale et al.: "...most [new instruments for musical expression] are viewed as exploratory tools created by and for performers, and that they are constantly in development and almost in no occasions in a finite state" [40].

7 CONCLUSION

We followed a soma design process centered around the idea that *music is movement*. The design process was grounded in a somato-musical practice, where the first author engaged with Dalcroze eurhythmics. Based on a sensitisation process, we articulated experiential qualities that serve as a red thread throughout our design process, namely *rhythm* and *repetition*. Guided by these experiential qualities, we explored design materials in order to generate a variety of possible movement–sound interactions. We then refined our interactions through continued engagement with the body and built a large, tangible musical instrument that we called Suspended Circles.

From sharing the instrument with musicians, one group with Dalcroze eurhythmics experience and another without, we observed that the Dalcroze musicians primarily paid attention to the body and choreographed their interactions with the instrument, while the non-Dalcroze musicians were moving "through" the instrument and moulding their bodies to the it, primarily attending to the sound.

Finally, we discussed these differences and also how engaging with Dalcroze eurhythmics as a defamiliarisation practice provided for a generative and reflexive design resource for music–movement interactions in a soma design process.

ACKNOWLEDGMENTS

We thank all the musicians and Dalcroze practitioners for taking part in this study, and the teachers at KMH who welcomed Tove into their classes. Tove would also like to thank Kjetil Falkenberg and Kristina Höök for guidance and critique during the design process, and everyone else at MID KTH Royal Institute of Technology, making it a wonderful place for a curious student and young researcher to explore the world of HCI.

This work was partially supported by the Agence National de la Recherche (ANR) grant ANR-20-CE33-0006- "LivingArchive: Interactive Documentation of Dance".

REFERENCES

[1] Sarah Fdili Alaoui, Baptiste Caramiaux, Marcos Serrano, and Frédéric Bevilacqua. 2012. Movement Qualities as Interaction Modality. In *Proceedings of the Designing Interactive Systems Conference* (Newcastle Upon Tyne, United Kingdom) *(DIS '12)*. Association for Computing Machinery, New York, NY, USA, 761–769. https://doi.org/10.1145/2317956.2318071

[2] Edgar Berdahl, Spencer Salazar, and Myles Borins. 2013. Embedded Networking And Hardware-Accelerated Graphics With Satellite Ccrma. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Daejeon, Republic of Korea, 325–330. https://doi.org/10.5281/ZENODO.1178476 Publisher: Zenodo.

[3] Francesco Bigoni and Cumhur Erkut. 2020. DogDog: Soma-Based Interface Design for an Improvising Musician. In *Proceedings of the 7th International Conference on Movement and Computing* (Jersey City/Virtual, NJ, USA) *(MOCO '20)*. Association for Computing Machinery, New York, NY, USA, Article 23, 4 pages. https://doi.org/10.1145/3401956.3404242

[4] Maros Suran Bomba and Palle Dahlstedt. 2019. Somacoustics: Interactive Body-as-Instrument. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Marcelo Queiroz and Anna Xambó Sedó (Eds.). UFRGS, Porto Alegre, Brazil, 95–100. https://doi.org/10.5281/zenodo.3672880

[5] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Jan. 2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[6] Claude Cadoz and Marcelo Mortensen Wanderley. 2000. Gesture - Music. In *Trends in Gestural Control of Music*, Ircam-Centre Pompidou Marcelo Wanderley et Marc Battier (Ed.). https://hal.archives-ouvertes.fr/hal-01105543 cote interne IRCAM: Cadoz00a.

[7] Baptiste Caramiaux, Alessandro Altavilla, Scott G. Pobiner, and Atau Tanaka. 2015. Form Follows Sound: Designing Interactions from Sonic Memories. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3943–3952. https://doi.org/10.1145/2702123.2702515

[8] Doga Cavdir. 2021. Movement-based Music Making: An Aesthetics-based Evaluation. In *Creativity and Cognition*. ACM, Virtual Event Italy, 1–5. https://doi.org/10.1145/3450741.3467461

[9] Kelsey Cotton, Pedro Sanches, Vasiliki Tsaknaki, and Pavel Karpashevich. 2021. The Body Electric: A NIME designed through and with the somatic experience of singing. *NIME 2021*. https://doi.org/10.21428/92fbeb44.ec9f8fdd https://nime.pubpub.org/pub/ntm5kbux.

[10] Marco Donnarumma. 2012. Music for Flesh II: informing interactive music performance with the viscerality of the body system. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. University of Michigan, Ann Arbor, Michigan. https://doi.org/10.5281/zenodo.1178245

[11] Paul Dourish. 2004. *Where the action is : the foundations of embodied interaction.*

[12] Sarah Fdili Alaoui. 2019. Making an Interactive Dance Piece: Tensions in Integrating Technology in Art. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. ACM, San Diego CA USA, 1195–1208. https://doi.org/10.1145/3322276.3322289

[13] Sarah Fdili Alaoui, Jules Françoise, Thecla Schiphorst, Karen Studd, and Frederic Bevilacqua. 2017. Seeing, Sensing and Recognizing Laban Movement Qualities. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 4009–4020. https://doi.org/10.1145/3025453.3025530

[14] Sarah Fdili Alaoui, Thecla Schiphorst, Shannon Cuykendall, Kristin Carlson, Karen Studd, and Karen Bradley. 2015. Strategies for Embodied Design: The Value and Challenges of Observing Movement. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition* (Glasgow, United Kingdom). Association for Computing Machinery, New York, NY, USA, 121–130. https://doi.org/10.1145/2757226.2757238

[15] IRCAM Forum. 2021. *MuBu.* https://forum.ircam.fr/projects/detail/mubu/

[16] Jules Françoise, Yves Candau, Sarah Fdili Alaoui, and Thecla Schiphorst. 2017. *Designing for Kinesthetic Awareness: Revealing User Experiences through Second-Person Inquiry.* Association for Computing Machinery, New York, NY, USA, 5171–5183. https://doi.org/10.1145/3025453.3025714

[17] Elisa Giaccardi and Elvin Karana. 2015. Foundations of Materials Experience: An Approach for HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 2447–2456. https://doi.org/10.1145/2702123.2702337

[18] Rolf Inge Godøy and Marc Leman. 2010. *Musical gestures: Sound, movement, and meaning.* Routledge.

[19] Kristina Höök, Steve Benford, Paul Tennent, Vasiliki Tsaknaki, Miquel Alfaras, Juan Martinez Avila, Christine Li, Joseph Marshall, Claudia Daudén Roquet, Pedro Sanches, Anna Ståhl, Muhammad Umair, Charles Windlin, and Feng Zhou. 2021. Unpacking Non-Dualistic Design: The Soma Design Case. *ACM Trans. Comput.-Hum. Interact.* 28, 6, Article 40 (nov 2021), 36 pages. https://doi.org/10.1145/3462448

[20] Eva Hornecker, Paul Marshall, and Jörn Hurtienne. 2017. Locating theories of embodiment along three axes: 1st–3d person, body-context, practice-cognition. In *Proceedings of the Workshop Position Paper for CHI 2017 Workshop on Soma-Based Design Theory, Denver, CO, USA*. 6–11.

[21] Kristina Höök. 2018. *Designing with the Body: Somaesthetic Interaction Design.* MIT Press, Cambridge.

[22] Kristina Höök, Baptiste Caramiaux, Cumhur Erkut, Jodi Forlizzi, Nassrin Hajinejad, Michael Haller, Caroline Hummels, Katherine Isbister, Martin Jonsson, George Khut, Lian Loke, Danielle Lottridge, Patrizia Marti, Edward Melcer, Florian Müller, Marianne Petersen, Thecla Schiphorst, Elena Segura, Anna Ståhl, Dag Svanæs, Jakob Tholander, and Helena Tobiasson. 2018. Embracing First-Person Perspectives in Soma-Based Design. *Informatics (Basel)* 5, 1 (2018), 8.

[23] Alexander Refsum Jensenius. 2007. *Action-sound : developing methods and tools to study music-related body movement.* Ph.D. Dissertation. University of Oslo. https://www.duo.uio.no/handle/10852/27149

[24] Alexander Refsum Jensenius. 2017. Sonic Microinteraction in "the Air". In *The Routledge Companion to Embodied Music Interaction* (1 ed.). Routledge, 429–437.

[25] Alexander Refsum Jensenius. 2022. *Sound actions: conceptualizing musical instruments.* The MIT Press, Cambridge.

[26] Marja-Leena Juntunen and Heidi Westerlund. 2001. Digging Dalcroze, or, Dissolving the Mind-Body Dualism: Philosophical and practical remarks on the musical body in action. *Music Education Research* 3, 2 (2001), 203–214. https://doi.org/10.1080/14613800120089250 arXiv:https://doi.org/10.1080/14613800120089250

[27] David Kirsh. 2013. Embodied Cognition and the Magical Future of Interaction Design. *ACM Trans. Comput.-Hum. Interact.* 20, 1, Article 3 (apr 2013), 30 pages. https://doi.org/10.1145/2442106.2442109

[28] B. Laczkó and A. R. Jensenius. 2021. Reflections on the Development of the Musical Gestures Toolbox for Python. In *Proceedings of the Nordic Sound and Music Computing Conference.*

[29] Marc Leman. 2007. *Embodied Music Cognition and Mediation Technology.* MIT press. https://doi.org/10.7551/mitpress/7476.001.0001

[30] Micheline Lesaffre, Pieter-Jan Maes, and Marc Leman. 2017. *The Routledge companion to embodied music interaction.* Routledge, Chapter Introduction, 1.

[31] Lian Loke and Toni Robertson. 2013. Moving and Making Strange: An Embodied Approach to Movement-Based Interaction Design. *ACM Trans. Comput.-Hum. Interact.* 20, 1, Article 7 (April 2013), 25 pages. https://doi.org/10.1145/2442106.2442113

[32] Thor Magnusson. 2009. Of Epistemic Tools: musical instruments as cognitive extensions. *Organised Sound* 14, 2 (2009), 168–176. https://doi.org/10.1017/S1355771809000272

[33] Adnan Marquez-Borbon and Juan Pablo Martinez-Avila. 2018. The Problem Of Dmi Adoption And Longevity: Envisioning A Nime Performance Pedagogy. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Blacksburg, Virginia, USA, 190–195. https://doi.org/10.5281/ZENODO.1302541 Publisher: Zenodo.

[34] Juan P Martinez Avila, Vasiliki Tsaknaki, Pavel Karpashevich, Charles Windlin, Niklas Valenti, Kristina Höök, Andrew McPherson, and Steve Benford. 2020. Soma Design for NIME. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Romain Michon and Franziska Schroeder (Eds.). Birmingham City University, Birmingham, UK, 489–494. https://www.nime.org/proceedings/2020/nime2020_paper93.pdf

[35] Fred Everett Maus. 2010. Somaesthetics of Music. *Action, criticism, and theory for music education* 9, 1 (2010), 9–25.

[36] Andrew P McPherson et al. 2019. Embodied Cognition in Performers of Large Acoustic Instruments as a Method of Designing New Large Digital Musical Instruments. International Symposium on Computer Music Multidisciplinary Research.

[37] Maurice Merleau-Ponty. 1962. *Phenomenology of perception.* Routledge, London ; New York.

[38] Lia Mice and Andrew P. McPherson. 2022. Super Size Me: Interface Size, Identity and Embodiment in Digital Musical Instrument Design. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 221, 15 pages. https://doi.org/10.1145/3491102.3517626

[39] Fabio Morreale and Andrew McPherson. 2017. Design For Longevity: Ongoing Use Of Instruments From Nime 2010-14. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. Copenhagen, Denmark, 192–197. https://doi.org/10.5281/ZENODO.1176218 Publisher: Zenodo.

[40] Fabio Morreale, Andrew P. McPherson, and Marcelo Wanderley. 2018. NIME Identity from the Performer's Perspective. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Thomas Martin Luke Dahl, Douglas Bowman (Ed.). Virginia Tech, Blacksburg, Virginia, USA, 168–173. https://doi.org/10.5281/zenodo.1302533

[41] Luc Nijs. 2017. The merging of musician and musical instrument: Incorporation, presence, and levels of embodiment. In *The Routledge companion to embodied music interaction.* Routledge, 49–57.

[42] Luc Nijs. 2018. Dalcroze meets technology: integrating music, movement and visuals with the Music Paint Machine. *Music Education Research* 20, 2 (2018), 163–183.

[43] Eva Nivbrant Wedin. 2015. *Playing Music With The Whole Body - eurhythmics and motor development.* Gehrmans Musikförlag AB. 13–15 pages.

[44] Charlotte Nordmoen, Jack Armitage, Fabio Morreale, Rebecca Stewart, and Andrew McPherson. 2019. Making Sense of Sensors: Discovery Through Craft Practice With an Open-Ended Sensor Material. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19)*. Association for Computing Machinery, New York, NY, USA, 135–146. https://doi.org/10.1145/3322276.3322368

[45] Walter J Ong. 2013. *Orality and literacy.* Routledge.

[46] Richard Shusterman. [n.d.]. *The Encyclopedia of Human-Computer Interaction* (2 ed.). Chapter Somaesthetics.

[47] Diego Silang Maranan, Sarah Fdili Alaoui, Thecla Schiphorst, Philippe Pasquier, Pattarawut Subyen, and Lyn Bartram. 2014. Designing for Movement: Evaluating Computational Models Using LMA Effort Qualities. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 991–1000. https://doi.org/10.1145/2556288.2557251

[48] Karlheinz Stockhausen. Premiered in 1981. Donnerstag aus Licht.

[49] Hope R Strayer. 2013. From neumes to notes: The evolution of music notation. (2013).

[50] Anna Ståhl, Vasiliki Tsaknaki, and Madeline Balaam. 2021. Validity and Rigour in Soma Design-Sketching with the Soma. *ACM Transactions on Computer-Human Interaction* 28, 6 (Dec. 2021), 1–36. https://doi.org/10.1145/3470132

[51] John Sullivan and Marcelo M. Wanderley. 2018. Stability, Reliability, Compatibility: Reviewing 40 Years Of Dmi Design. Limassol, Cyprus. https://doi.org/10.5281/ZENODO.1422595 ISBN: 9789963697304 Publisher: Zenodo.

[52] Dag Svanæs and Louise Barkhuus. 2020. The Designer's Body as Resource in Design: Exploring Combinations of Point-of-View and Tense. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376430

[53] Danielle Wilde, Anna Vallgårda, and Oscar Tomico. 2017. Embodied Design Ideation Methods: Analysing the Power of Estrangement. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 5158–5170. https://doi.org/10.1145/3025453.3025873

[54] Craig Wright. [n.d.]. Quantification in Medieval Paris and How It Changed Western Music. *City, Chant, and the Topography of Early Music: In Honor of Thomas Forrest Kelly* ([n. d.]), 3–26.

[55] Xiao Xiao, Pablo Puentes, Edith Ackermann, and Hiroshi Ishii. 2016. Andantino: Teaching Children Piano with Projected Animated Characters. In *Proceedings of the The 15th International Conference on Interaction Design and Children* (Manchester, United Kingdom) *(IDC '16)*. Association for Computing Machinery, New York, NY, USA, 37–45. https://doi.org/10.1145/2930674.2930689

[56] Jianing Zheng, Nick Bryan-Kinns, and Andrew P. McPherson. 2022. Material Matters: Exploring Materiality in Digital Musical Instruments Design. In *Designing Interactive Systems Conference*. ACM, Virtual Event Australia, 976–986. https://doi.org/10.1145/3532106.3533523