Tuning In to Intangibility: Reflections from My First 3 Years of Theremin Learning

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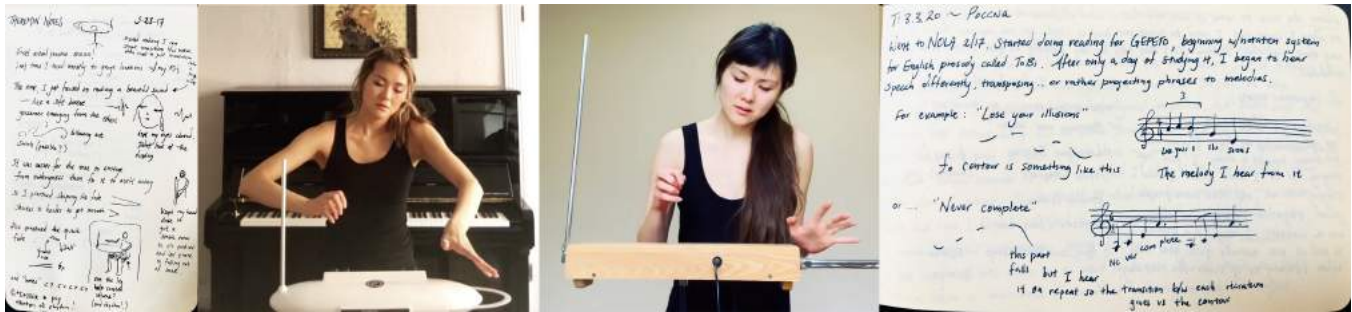Orsay, France

Figure 1: Excerpts of journal entries and videos from May 2017, October 2017, February 2020 and March 2020

ABSTRACT

This paper presents an autoethnography of 3 years of learning to play the theremin, an instrument lacking tangible feedback. While the theremin is typically invoked in HCI to emphasize the importance of the tactile modality, we interrogate how I, the player, attained musical proficiency without touch.

Through a thematic analysis of 235 journal entries, our study distills my strategies for navigating the instrument as well as my personal transformations along the way. We discover that without touch, accurate and musical playing on the theremin relies on continuous auditory feedback, proprioception, and imaginative processes. We discuss challenges and opportunities for embodied and tangible interaction in light of these findings.

CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models**; *Field studies.*

KEYWORDS

theremin, autoethnography, first-person methods, tangibility, embodiment, music, learning

1 INTRODUCTION

Invented in 1920 by Russian physicist Lev Sergeyevich Theremin, the theremin is one of the first electronic musical instruments, and is unique for being played without any physical touch [21]. Changes to the surrounding electrical field from the movements of a player's body are detected by a pair of antennas, which respectively modulate the pitch and volume of the output sound. Every nuance of the player's gesture is reflected in this sound, which evokes at once the familiar lilts of the human voice and something otherworldly.

The theremin has found its musical voice across a wide range of styles, from Clara Rockmore's classical renditions to the eerie sci-fi soundtracks of the 1950s and even pop hits of the Beach Boys and Led Zeppelin [7]. Despite its versatility, the theremin has not yet gained widespread popularity, largely due to its reputation for being notoriously difficult to play.

Within the field of HCI, the theremin has been a divisive subject. On the one hand, its interaction has been praised by the likes of Bill Buxton and Mark Billinghurst as "successful" due to the "direct mapping of hand motion to continuous feedback, enabling users to quickly build a mental model of how to use the device" [9]. It has also inspired the design of new musical instruments [38, 50, 54].

On the other hand, the theremin has been the prime example illustrating the necessity of tactility and haptics in interactive systems. One expression of such a view is Berdahl et al's "Theremin

Hypothesis," which asserts that "if a musical instrument does not provide any haptic feedback at all, it will probably be more difficult to play accurately" [4]. Various researchers have proposed modifications of theremins or theremin-like instruments to include haptic feedback [4, 44, 48, 49, 56]. An oft-cited example is O'Modhrain's doctoral thesis, which anecdotally describes the theremin being easier to play with the addition of a rubber band between the player's hand and the pitch antenna [44]. O'Modhrain also experimentally compared various modes of haptic feedback for playing classical melodies on a virtual theremin with only pitch control. "Marginal" improvements in note-finding were reported for the force feedback conditions over the no-force condition, but no statistical significance was provided.

Attempts to add haptic feedback to the theremin stem from a tendency within HCI to emphasize the intrinsic properties of an interface, such as its modalities or affordances, as determinants of successful design. Systems are typically compared in one-shot studies featuring simplified tasks, where small quantitative differences are often enough to declare one design as superior over another. We believe that such a reductionist approach is problematic when applied to musical instruments, where the design of the interface matters less than the practice of the player over time. Moreover, "success" in music playing is not only about what can be quantitatively measured but also includes expressive dimensions of performance.

The theremin is, after all, a musical instrument. Despite whatever impact the lack of touch may have on its inherent difficulty, players do manage to gain the skills to play in tune with consistency and expression (without carrying a rubber band on stage). Our research seeks to shed light on the embodied strategies that enable a player gain such proficiency over time.

This paper presents an autoethnographic study where we collected and analysed 235 journal entries documenting the first phase of the primary author's theremin learning experience from May 2017 to March 2020. Longitudinal, first-person methods allow us to consider the full range of embodied and artistic dimensions emerging from the learning process, including ways of thinking and perceiving that are difficult to observe from a third-person vantage point. Our analysis outlines operational strategies for learning to play and documents the transformations experienced by the first author as a result of theremin practice. Our key finding is that in the absence of a tangible interface to guide and constrain movements, gestures for theremin playing are led by several types of listening skills. Instead of "holding on," thereminists must "tune in," not only to audible sound but also the auditory imagination, as well as an internal sense for the body's position, movements, and emotional states.

By offering a nuanced understanding of what it takes to become a "skilled user" of an "intangible interface," this paper presents both challenges and opportunities for embodied and tangible interactions. It provides fresh insights into influential concepts from embodied cognition, where touch holds a central role in the body's interaction with objects. Such insights open new doors for design in under-explored modalities and for technologies to support human learning of embodied skills.

2 BACKGROUND

Our exploration of theremin playing aims to offer new perspectives to the understanding of embodied interactions and tangibility within HCI. To set the stage, we present an overview of foundational ideas of embodiment. We point out tacit assumptions of tangibility (i.e. direct physical interactions with objects) present within these ideas, and provide theoretical foundations for music as a sandbox for the study of embodied interactions.

2.1 Foundations of Embodied Interactions

According to Dourish, interaction is an embodied phenomena that happens in the world, which lends it form, substance and meaning [14]. In this view, the world is both a physical and social world. The link between the body's actions in the physical world and the creation of meaning can be traced to the philosophical tradition of Phenomenology.

Husserl, the founder of Phenomenology, sought to understand the lived experience of consciousness, and emphasized the relationship between perception, meaning and action [27]. Heidegger departed from Husserl's focus on consciousness to explore the nature of existence in the world, delving into the practical and embodied dimensions of everyday lives [22]. He introduced the notion of 'ready-to-hand' to describe the body's capacity to engage with an object, such as a hammer, emphasizing the active involvement of the body in using tools beyond mere theoretical comprehension. Merleau-Ponty further investigated the profound relationship between the body and objects, emphasizing the inseparability of perception and bodily movement in shaping our understanding of the world [40].

Drawing from research in contemporary neuroscience, Kirsch arrives at similar conclusions as the Phenomenologists [33]. He summarizes key principles describing how humans interact with tools in an embodied way that can serve as guidelines for HCI researchers designing embodied interactive systems:

- Interacting with tools changes the way we think and perceive.
- Tools, when manipulated, are absorbed into the body schema, and this absorption leads to fundamental changes in the way we perceive and conceive of our environments.
- We think with our bodies.
- We know more by doing than by seeing
- There are times when we think with things.

2.2 Embodiment and Tangibility

Tangible interactions are seen by Dourish as one manifestation of Embodied Interactions. Ishii frames the advantages of Tangibile User Interfaces in terms of a double feedback loop, with a first layer of haptic feedback from tangible representations (i.e. physical objects) controlling a second feedback loop of intangible (i.e. visual or auditory) representations [28]. Manipulating physical objects is said to take advantage of people's innate, embodied skills for sensing and manipulating their physical environments. The tactile feedback from physical objects is also said to be more immediate and responsive than the intangible feedback from visual or audio representations.

Beyond the domain of Tangible User Interfaces, the idea of tangibility, or the direct, tactile interaction with an object, is tacitly present in foundational theories of embodiment. In particular, interacting with physical tools is assumed to be a direct physical relationship. Thus Heidegger's notion of "ready-to-hand" as well as Kirsh's principles of tool manipuluation can be said to address tangible interactions.

Tangibility also holds significance in Gibson's theory of affordances [20], a concept that has been particularly generative in the field HCI. Although Gibson primarily focuses on the visual perception of a living organism and its environment, the action afforded by a specific object is grounded in the immediate, tactile connection between the body and the object.

2.3 Music as Sandbox for Embodied Cognition

Lemann introduced the concept of Embodied Music Cognition to musicology, suggesting that the body acts as a mediator for musical interactions [36]. In other words, the body is an active participant in both musical performance and perception [31]. For musical perception, Lesaffre observe that listening to music mobilizes sensorimotor, cognitive, emotional and energetic abilities [37].

For musical performance, Jensenius emphasizes the need to understand interactions between human bodies and musical instruments [31]. He observes that traditional acoustic instruments rely on a close, physical "action-sound coupling" between the performer's body and the instrument through the tactile modality. In contrast, electro-acoustic instruments express the actions-sound relationship through mappings that can be more or less "disembodied."

Nijs draws attention to a special state of "merging" between musician and musical instrument, giving the example of master cellist Mstislav Rostropovich and his cello [43]. In this state of merging, the musician no longer experiences a boundary between the self and the instrument, which becomes a natural extension of the body. Such a merging seems to be characteristic of optimal performance experiences, otherwise known as states of Flow [12].

While playing the cello features a clear tactile connection between the body and instrument, videos of expert theremin playing seem to exhibit a similar state of merging. Our research seeks to uncover the strategies that allow a thereminist to establish such a profound, embodied connection with the instrument without relying on the tactile modality.

3 METHODS

3.1 Autoethnography and First Person Methods

First-person methods have a long history in the humanities and social sciences and are now commonly used in HCI and Interaction Design [26]. Such methods in HCI include autoethnography, autobiographical design [13, 39], microphenomenology and soma design among others. We focus on autoethnography as a research method that uses personal accounts to describe and interpret cultural experiences, beliefs, and practices [15]. An early example of autoethnography is sociologist David Sudnow's account of learning to play jazz piano, first published in 1978 and rewritten in 2001 in collaboration with Phenomenologist Hubert Dreyfus [52, 53]. A first-person account of theremin playing experiences has been published by virtuosa Lydia Kavina, which focuses on her use of the instruments in compositions and performance and gives general advice for learning [32].

In HCI, autoethnography enables researchers to use themselves as the subject of the study in order to describe and analyse their own experience of a designed artifact from within. Unlike autobiographical design where designers use their personal experiences to design a system, autoethnography can be applied to studying an existing artifact, like our analysis in this paper of the first author's theremin learning experience.

A classic example of autoethnography from the HCI literature is Kristina Höök's accounts of her own horseback riding that she uses to show how to articulate intimate embodied experiences into design [25]. Other recent examples from HCI include Lucero's accounts of their experiences living without a mobile phone [39], Homewood et al's tracking of their own health data [24], Jain et al.'s study of their travel as a hard of hearing individual [29], Françoise et al.'s investigation of using a custom live-coding environment [17], Xiao's descriptions of her piano learning [58] and Grimstad Bang et al.'s design in conversation with her learning of Isadora Duncan's dance repertoire [3].

First-person methods have raised questions in HCI regarding their validity and generalizability. Zhang and Wakkary argue for recognizing the legitimacy of designers' experiences in interaction design, whether it concerns their observation of real-life events or their interaction with designed artifacts and systems [62]. Indeed, these first-person methods enable the explicit acknowledgment of researchers' and designers' personal experiences in the process of designing or living with interactive systems. They also allow the acquisition of comprehensive and long-term insights on the design and interaction with systems in real-world contexts. Their value, beyond generalizability, is the extent to which their insights resonate critically with the readers' personal experiences and understanding of interaction [15, 51].

Our work aligns with such methods. We present an autoethnographic account of the first author's practice of theremin and the lessons learned from it. In contrast to Kavina's accounts, our autoethnography gives more details on the specific practice strategies employed on a day to day basis, and details the first author's improvements and personal transformations over time. We believe that a thorough description of the author's learning journey sheds light not only on the process of learning theremin but also on the design of systems that promote human embodied learning capacites at large.

3.2 Who we are

The first author is an interaction design and music technology researcher with over 20 years experience in classical piano. She is the subject of the theremin learning autoethnography, and all passages written in the first person are from her point of view. The second author is an interaction design researcher and trained dance artist. Together with the first author, she participated in the data analysis and the framing of the paper. Our decision to co-write this paper was motivated by shared interests in embodied cognition, skill acquisition, first-person methods, and how artistic domains can serve as sources of insight for HCI.

3.3 How did I learn and document

This paper analyzes the first period of my (first author refered to as I) theremin learning journey, spanning from May 2017 until March 2020, documented through 235 journal entries. In this period, I primarily engaged in an autodidactic approach. While I did reference established resources, such as [41], and studied Youtube videos featuring expert thereminists, my primary focus was charting my own course by repurposing my existing knowledge from building interactive technologies and playing the piano. Although my learning was predominantly self-directed, I complemented it by participating in five in-person workshops organized by accomplished thereminists, where I received and observed both group and individual lessons.

My journal entries functioned like a lab notebook, where I notated observations about my playing. Often journal entries described problems I encountered and exercises I devised to address the problems as well as how well they worked. I also notated my hopes, dreams, frustrations, conceptual frameworks, as well as ideas for technological interventions. In October 2017, I began to supplement my journal entries with short videos of playing posted to an Instagram account[1] (figure 1).

3.4 Data analysis

The analysis of the data followed a thematic analysis [8]. The first author initially conducted a comprehensive review of all entries, engaging in discussions with the co-author to define the subsequent themes:

- **Embodied strategies:** Encompassing references to the body, including considerations of gestures, posture, and methods of movement.
- **Compositional strategies:** When an entry discusses the creation of original music
- **Personal transformation:** Noting new ways of thinking, perceiving, or moving observed within an entry
- **Metaphors:** Describing some element of theremin-playing through metaphor
- **Surprising features:** When something unexpected was documented
- **Bringing it to performance:** Accounts of public performances
- **Confronting ideas to the community:** Interactions with other musicians, including other theremin players

After reviewing several dozen entries, the first author added a second set of themes to more precisely characterize the daily work of practicing the theremin.

- **Listening:** Mentions of "listening" or "the ear," encompassing ways of listening to one's own playing or deriving inspiration from existing music.
- **Music theory:** References to music theory elements, such as intervals, scales, and harmonies.
- **Repertoire:** When an entry mentions work on specific musical pieces
- **Expression/Beauty:** Entries highlighting expressive aspects of playing

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[1]https://instagram.com/_xiaosquared_

- **Improvisation/Jam:** When improvisation was documented, including jam sessions with other musicians
- **Instrument Discovery:** When an entry described explorations of the instrument itself, such as tuning, timbre adjustments, or connection with other devices such as amplifiers and looper pedals
- **Frustrations:** When an entry expressed frustration or discouragement

All journal entries were thoroughly reviewed for both sets of themes by the first author, who assigned a set of coded to each entry based on the prominence of each theme. A theme received a code of 1 if mentioned in an entry and 2 if it constituted the central focus of the entry. A concise summary was crafted for each entry, and pertinent quotes were recorded.

4 FINDINGS

We present main findings in two broad categories: Operational Strategies and Personal Transformations. Operation Strategies describe "what I did" to navigate the instrument, build repertoire, and to create new music. Personal Transformations attempt to trace "how I changed" through the process of learning to play the theremin in terms of my embodied capabilities and ways of thinking. It also describes the push and pull in interactions with others in the theremin community.

4.1 Operational Strategies - "What I did"

4.1.1 Navigating the Instrument. From the beginning, deep listening was the central component to my explorations on the theremin. In my first documented practice session (figure 1), I "focused on making a beautiful sound" and experimented mostly with movements of the volume-control hand to shape the onset and fade of individual tones, listening closely to the result and adjusting my movements (5/23/17). Instead of immediately trying to play melodies, I began work on pitch-control with smaller, simpler "modules" such as intervals and scales, which were mentioned in 8 of the first 10 entries. When I did start working on melodies later on, I used my ear and my knowledge of music theory to help with accuracy of pitch, "cross-validating any tune with known intervals" (7/7/17).

Movement explorations were another main theme, especially in the early days of my practice. Drawings of hands and descriptions of movements were found in 8 of the first 10 journal entries (figure 2). I often experimented with different types of movements to express the same sonic goals (e.g. "noticed I'm no longer following the scale fingering gestures that I designed a few days ago" 5/30/17).

Sometimes, I took inspiration from videos of established thereminists but felt like I needed to make movements feel like "my technique," "even if I am not the first person to try them" (6/6/17). In making movements my own, I was always guided by my ears, "playing around in order to produce the sound that I wanted" (6/14/17). For instance, when working out the gesture to play a compelling vibrato,

> "I automatically came up with the technique required. I didn't even realize that I did for a long time, just heard it sounding better. And then examined my arm... because it felt different—tired from the elbow. And
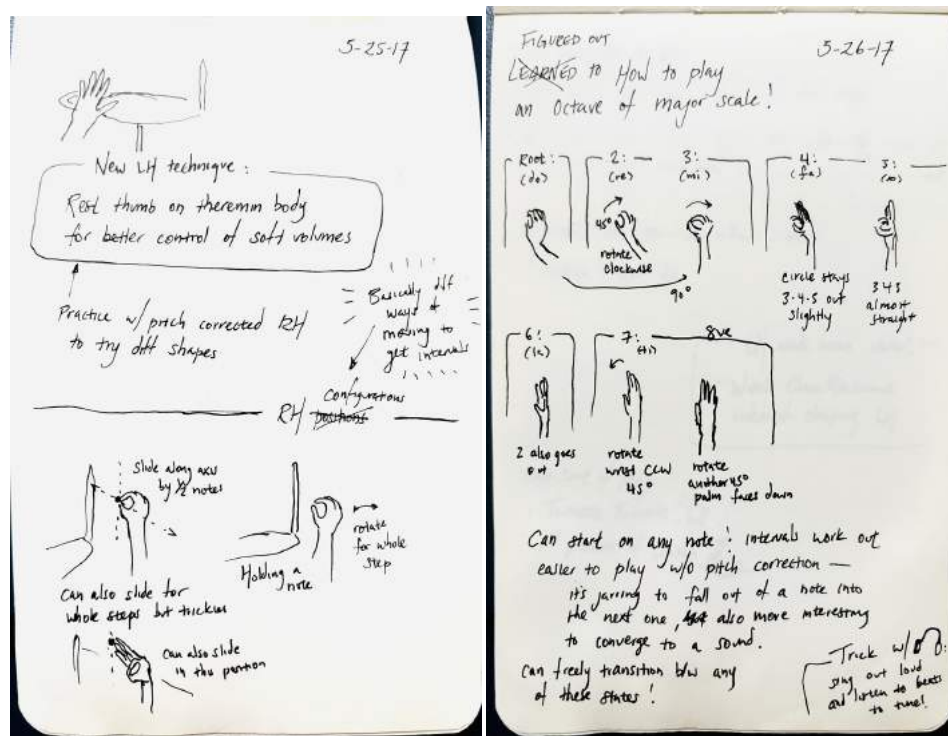
Figure 2: Sketches of hands documenting movement explorations from the early days of my theremin learning

then I realized I had been vibrating it side by side" (6/14/17).

Experiments in ways of moving went hand-in-hand with experiments on the capabilities of my instruments. During my second day of practice, I spent time "playing around with different settings of the instrument" (5/24/17). When I upgraded my theremin to a more sensitive model a few months later, I again experimented with its settings and experimented with different amplifiers. Every once in a while, I would purposely change the tuning of my theremin as an exercise in "adapting" my movements and my ears (7/2/17).

4.1.2 Building Repertoire. One of my goals on the theremin was to build a repertoire of melodic pieces. I employed two primary strategies to learn melodies on the theremin, the first, which I called "Modules/Debugging" is an approach I had learned from my piano mentor (7/17/17). It consists of dividing a new piece into sections, characterizing each section in terms of the music theory concepts and the physical techniques required, working on each section individually, and then putting them together. A few days after starting the theremin, I set myself the goal of learning to play the "The Swan" from *Carnival of the Animals* by Camille Saint-Saëns, a cello solo made famous on the theremin by Clara Rockmore. I first divided the piece into sections, and then examined each section to "figure out what it's about, for instance, section B1 is a sequence of minor 7th arpeggios, section C2 is a bunch of descending 5ths" (5/29/17). Breaking down a melody in terms of "basic vocabulary" based on music theory helped break down a long sequence of notes into smaller, more manageable, and reusable parts (1/2/19). When

practicing, I avoid mindless repetition but instead tried to identify and isolate problems, a process similar to "debugging" a computer program. Figure 3 gives an example of a difficult passage from a piece and exercises that I designed to target its different challenging aspects.

A second strategy for learning pieces is listening to and imitating recordings, which I described as a way to "get a shortcut into the music" (6/29/18). This approach served not only to learn the notes of a piece by ear but also to understand the feeling of different styles of music. For instance, I imitated Yo-Yo Ma's interpretation of the Bach/Gounod Ave Maria (7/4/17) as well as versions of "My Funny Valentine" by Chet Baker to study the characteristic phrasing of each performance (10/17/17, 12/19/18).

While I continued to employ both approaches to grow my repertoire, my priorities gradually shifted as my practice progressed. With regards to Modules/Debugging, I reflected in 2019:

> "Before I was mostly concerned with notes, identifying intervals, chords, scales, taking them apart and inventing exercises for them. Now I'm looking at phrasing at the same time" (4/12/19).

While I continued to imitate recordings as a starting point for new pieces, I increasingly tried "to make each song my own rather than trying to copy what I hear on the recording" (3/1/19).

Though my journal entries often focused on the learning strategies I utilized, I still acknowledged the role of traditional repetition to make movements fluid and automatic. This can be seen in the question I posed myself "how many days of practice does it take to make something more or less automatic" (5/19/19). When repeating,
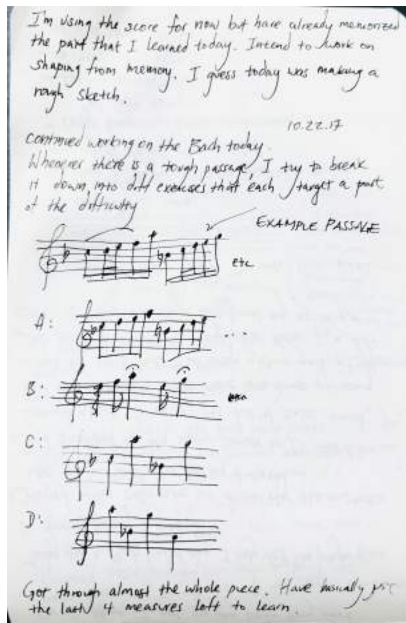
Figure 3: An example of a difficult passage in a piece and four exercises that I invented to practice different aspects of it. Exercise A highlights the scale present in the passage while exercises B, C, and D work on leaps of different sizes.

I sometimes engaged in a sort of "sketch" practice where I played something very softly instead at full volume because I found it easier to achive accuracy (11/6/17).

4.1.3 Creating Music. The theremin provided ample opportunities to engage in the creative aspects of music-making, such as improvisation, composition, and performances. As often as I could, I organized jam sessions with musician friends. These sessions allowed me to immerse myself in different styles of music, ranging from jazz to contemporary classical to industrial noise music. It required me to listen carefully to the soundscapes made by my collaborators and to experiment with "different ways the theremin can fit" (11/24/17). Improvisation was also an integral part of my private practice to prevent mindless repetition:

> "When I get bored with interval exercises, I try to make up some random stuff, usually melodies that prominently feature the intervals I've been working on" (5/29/17).

Thanks to the theremin's unique reputation, I had many more opportunities to compose and perform, even as a beginner thereminist, than I ever had as an advanced amateur pianist. On several occasions, I was asked by friends and colleagues to compose theremin tracks for their projects, including art installations and dance performances. Here, I also used improvisation as a strategy to generate content, "following the narrative" provided by my collaborators to search for interesting sounds (11/21/17).

Public performances on the theremin gave me valuable insights that could not have emerged from practice alone. In my first performance, with a band playing original pop-style songs, I "came up

with ideas of solos that had not occurred to me before" (10/3/17). Subsequent performances taught me the importance to thoroughly sound-check the stage (12/9/17) and to "not let glitches get to you, to stay calm, accept the unexpected and just go with it."

4.2 Personal Transformations - "How I Changed"

4.2.1 Superpowers. A few months into my theremin practice, I started noticing changes in how I perceived music and sounds in general, not only the repertoire that I was learning. One day, I was meditating to the sound of a cello drone, and "I started to hear overtones much more clearly. It was as if my mind can snap to different frequencies and those come to the foreground. I could even hear 'tunes' hidden within the drone by focusing on different frequencies" (1/28/18). Later, I began hearing hidden melodies in speech (4/17/20) and in surprising places such as the creaking of our bathroom door.

These phenomena highlight the role of the imagination in perception, like a child "seeing" animals in the clouds. One hypothesis for the theremin being particularly conducive for developing this type of auditory imagination is that playing accurately requires "pre-imagining the next note" before it is played (3/30/19). After spending time analyzing each piece in terms of music theory modules, I observed that "the theremin forces me to form a clear mental image of musical building blocks" (9/1/18).

The auditory imagination developed by the theremin is not always triggered by real music and sounds. While improvising on the theremin I felt like "all the music that I have ever heard reverberates in my ears" (1/5/18). Later, I gained the capability to improvise music clearly in my mind away from any instrument. For example, while riding public transport one day, I was surprised to start "hearing Bach-like improvised sequences very clearly in my mind. It felt like a 'sequence generator'" that "I could direct somewhat" and I could later play it on the piano (9/1/18).

The capability to hear detailed, expressive music in my mind also affected my movements when playing. Being able to follow a clear auditory image is a key component of a state that I referred to as being "inside the sound":

> "When I am inside the sound, my precision gets a lot better, as well as my ability to stay in tune for long sustained notes. Also there's a natural sense of musicality and a sense of ease. It's almost as if I can do no wrong. I can experiment with how I shape phrases, and there's just an utter lack of effort. I feel grounded on my feet yet lighter than air. If I am not inside the music, everything is more effortful, and my body is way more tense. I can still play pieces, but I always feel like I'm on the precipice of falling out of a note or falling out of tune, and sometimes, often I do." - 4/18/18

I also describe the state of being inside an emotion when playing:

> "There were moments when I was completely inside an emotion. It was as if I was speaking, though my voice was silent. Yet I was speaking in a language beyond the tangle of words... My hands traced the
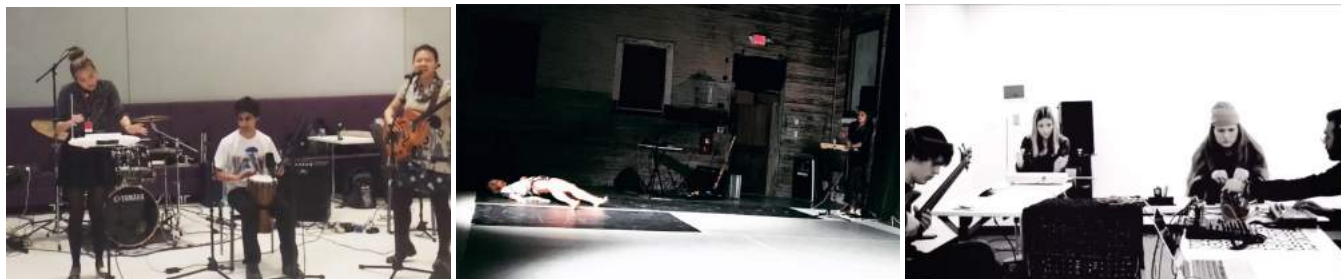
Figure 4: Collaborations with other musicians and artists. (Left) Performance with a pop/rock group. (Middle) Performance with a dancer. (Right) Jam session with musician friends.

gestures that were a product of the emotions I projected" (2/25/19).

As I progressed on the theremin, I became more interested in the conditions to achieve such states that allow me to play more accurately and expressively. Journal entries began reminding myself to "Relax everything" because "I seem to be more in tune when I'm totally relaxed" (2/9/19). The difference in relaxation between my playing posture of 2017 and 2020 can be seen in figure 1.

Another surprise were the improvements in other modalities of music-making that I had not explicitly practiced, especially singing. Several months into my theremin practice, I naturally began to sing with more vibrato in my voice, and my piano teacher observed that "my singing sounded much more expressive" (11/9/17). Later, I was "magically" able to sightread a piano part and sing a melody at the same time despite always having trouble with it before (9/20/19).

4.2.2 Metaphors & Ways of Thinking. I employed recurring metaphors to describe the act of playing theremin. One such metaphor is that of writing or drawing. Within a month of starting to play, I observed that "I almost see a line in my mind's eye" as if "I'm drawing or writing" (6/14/17). Later, I elaborated on the connection between music theory exercises and learning to write:

> "Children practice writing letters in isolation. They also practice writing sentences and dictation. In a sense, my scale exercises are like practicing the letters. Building up different ways of writing a vocabulary of little movement motifs, and playing a piece is stringing them together. Playing along to a recording is like dictation. Just practice turning sound into gesture, because in the end I want to write what's inside my own head." (4/12/19)

I also invoked the comparison with drawing to describe the feeling of improvising with other music "as if I'm tracing nature. sketching lines, shading, bringing out what's there, following the natural curves of sounds in the environment" (2/12/18).

The idea of landscapes and maps were another recurring metaphor in my notes. After another improvisation session with a friend playing beats and textures on a synthesizer, I reflected that "he is the environment, the landscape, and I am the animal that roams the land" (3/3/18). Metaphors of landscapes and maps were also employed to conceptualize more analytical aspects of learning. For instance, when approaching new repertoire, I wrote that "for relationships between different parts of the piece, we need a global

sense of the landscape, like making a mental map by surveying the streets and how they connect (6/29/18, figure 5).
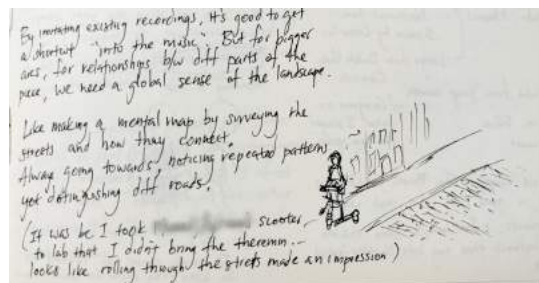

Figure 5: Metaphor of a map for understanding the structure of a piece

Finally, diverse metaphors were employed to describe the emotional dimension of playing. In the same entry from December 2017, I used two very different images to describe my emotions. First, "feeling like I'm a body of water. If I stop and zone out, I feel waves coursing through me" and second "it's as if I've constructed a room somewhere inside me, and filled it with my feelings… but I have to find my way to it" (12/18/17). Another image was one of speaking through my hands:

> "I felt like I was telling stories, but abstract stories about emotions. It was as if I was speaking but I was mute" (2/13/18).

4.2.3 Confronting the Community. Interactions with musicians in general, both friends and new acquaintances, have been overwhelmingly positive, opening doors to interesting discussions and fruitful collaborations (See section 4.1.3). Engaging with the theremin community, however, resulted in mixed experiences.

Some professional thereminists have been very open and encouraging about my progress as well as my "learning by discovery" approach. These tend to be players who do not adhere to a standardized technique. Their feedback for my playing tended to point out areas where I can pay more attention or what I am doing that differ from what most players do, without labeling what I am doing as "wrong."

Other professional thereminists sought to establish a standard theremin technique and desired learners to emulate their approach.

Interactions with these individuals often left me feeling discouraged. After observing a private lesson and a lecture from one such thereminist, I noted that the thereminist "seemed to be all about exploring and figuring out tricks for her own practice. But when she teaches, it's all about getting people to copy what she figured out, rather than encouraging exploration" (5/10/18). Later, when I took a lesson myself from another professional thereminist, I expressed my disappointment at being told to "follow all the people who have mastered the instrument" when "I had hoped for more mentorship on forging my own path from someone who had evidently done so" (5/13/19).

After recovering from my initial disappointment for the lack of encouragement in my exploration-centered approach, I did take more lessons from more experienced thereminists to better understand the merits of their ways, reflecting

> "I'm fine with throwing out 'my technique' if another way works better. It's not about having my name attached to the technique. I'm trying to advocate for having people figure things out for themselves" (6/30/19).

In particular, during the covid-19 pandemic, I became a regular participant in weekly online theremin workshops hosted by a prominent figure in the theremin community and took several online private lessons with her. Many points discussed during these workshops resonated with my own discoveries, such as the idea that "the theremin is played with the ear" (3/22/20), interval exercises that she offered to participants, and the advice to imagine the next note before playing it. The start of my involvement in these workshops marks the end of the first chapter in my theremin learning experiment.

5 DISCUSSION

Conventional narratives in HCI about the theremin focus on the difficulties arising from the lack of direct tactile feedback. To address this "problem," researchers have explored incorporating a haptic dimension into the theremin to enhance its playability.

Our work calls into question this narrative, arguing that the theremin's lack of touch is not a problem to be solved, but rather an invitation to look beyond the typical emphasis on intrinsic properties of an interface as central to success in task performance. Our findings unveil the existence of rich, embodied strategies, as well as ways in which practicing these strategies over time transforms the player.

The following sections summarize these embodied strategies, processes and transformations. We connect the dots to previous work and point out promising, underexplored areas in HCI. Finally, we reconsider influential ideas about embodiment through the lens of the theremin's intangibility.

5.1 Embodied Strategies

Accurate and expressive playing of the theremin without tactile feedback seem to rely on the convergence of different ways of what we call "tuning in"—to auditory feedback, proprioception, as well as various types of mental imagery.

Within HCI, attuning to sound and its connection with movement has previously been explored by the movement computing community as well as the emerging field of sonic interaction design [5, 18, 19]. Applications include dance pedagogy, rehabilitation, and the improvement of bodily awareness for general audiences. The field of movement computing has also explored the existence of different types of imaginatative processes such as visual and kinesthetic imagery for dance learning [47].

However, in HCI research about music learning, these inner processes are often eclipsed by the more visible external gestures on a physical instrument. Music learning is often reduced to the reptition of a correct set of movements to achieve muscle memory [58]. While in certain cases, novices can accurate play pieces depending solely on muscle memory, such as plucking a sequence of guitar chords or tapping a simple melody on the piano, the movements of elite musicians depend on other, less visible embodied skills [23].

According to Lehmann, music learning requires three different "representations"—(1) a representation of the desired performance goal, (2) a representation that reflects the current performance, and (3) a representation of the music in terms of its production aspects [34]. The goal of practice is to strengthen all three types of representations, gradually reducing the difference between (1) and (2) using (3) as the means of doing so. The three representations of Lehmann rely respectively on mental imagery, auditory perception, and the embodied knowledge of movement.

The crucial role of imaginative processes for music-making has long been advocated by musicians [6, 11, 58]. Reknowed music educator Émile Jacques-Dalcroze writes that every method of teaching music should aim above all to awaken "inner hearing—that is the capacity for hearing music as distinctly mentally as physically" [30]. Within HCI Dalcroze's ideas have inspired design of interactive systems for music and dance [2, 60].

In recent years, musicians' capacity for inner hearing as well as the mental simulation of movement, visuals, and emotions have been studied in Neuroscience [11, 61]. The intangibility of the theremin draws attention to the existence and importance of these inner, embodied strategies of music playing and challenges music-related research in HCI to design interfaces that hone these skills.

5.2 Learning Strategies

Techniques of practicing the theremin echo common themes articulated in previous work on effective learning techniques across domains. Instead of simply repeating entire melodies, as subjects were asked to do in studies with theremin and haptic feedback, the first author's learning process followed principles of "deliberate practice," where she intentionally focused on particular difficulties over a prolonged period of time [16].

Specific practices described in our results correspond closely with the techniques of learning contemporary dance identified by Rivière et al. through interviews with professional dancers [47]. These include observation, repetition, imitation, marking, segmentation, and personal adaption. For learning theremin, observation is both visual, in the form of watching videos of other thereminists, and auditory, in listening to recordings of pieces. Like the interviewed dancers, the first author described the process of making movements "automatic" through repetition. Imitation, segmentation, and personal adaptation were described in the form of playing along with recordings, "module practice," and the process of "making

each song my own." Interestingly, even though "marking," sketching movements by performing a smaller version with less energy or one part of the body, may seem specific to dance, an analog can be found for theremin playing in the description of "sketch practice."

We can also connect the dots with learning strategies described for domains that do not involve movement. For example, the approach of modules practice, "debugging" difficulties, and breaking a melody down into recurring "basic vocabulary" based on music theory resembles principles of computational thinking articulated by Seymour Papert in the context of writing computer programs [45]. The first author's involvement creative projects like composing tracks for friends, engagement in jam sessions, or simply inventing "random stuff" highlights the themes of projects, peers, and play articulated by Resnick et al. as key components of creative learning [46].

These links with strategies from existing learning research show that despite the theremin's reputation for being extremely difficult, attaining proficiency does not require any special skills nor technological intervention but only motivation, time, and effective learning techniques. These findings suggest that the theremin's notorious reputation may be undeserved. As Lydia Kavina observes, "a musical instrument always requires hard study and much practice to master, and the theremin is no exception" [32].

5.3 Transformations

The personal transformations from our findings reinforce Kirsch's principle that interaction with tools change the way we think and perceive [33]. In particular, the types of "tuning in" practiced on the theremin leads to changes in listening, from hearing music as discrete notes that are either correct or not, to hearing tonal shapes that continuously vary in frequency and dynamics. Such a change in perception is reflected in the metaphor of "seeing a line in my mind's eye" and the increased sensitivity to melodic contours of speech and environmental sounds like door creaks.

Though anecdotal, these accounts suggest an alternative perspective to the common view of musical aptitude as largely innate with wide individual variability. While each person may have a different starting point based on a combination of nature and nurture, its seems that prolonged reinforcement of the link between movement, auditory feedback, and auditory imagination leads to profound improvements in auditory perceptive capabilities, even for adults.

A clear pathway for the improvement of auditory perception for adults opens doors for the design of new interfaces that promote lifelong learning of music, which is shown to be beneficial for cognition and health [1, 35]. Improved auditory perception also holds value for applications outside of music, such as learning the intonation of foreign languages [57, 59], especially tonal languages, typically considered challenging for adult learners.

The accounts improvements in auditory imagination after prolonged theremin practice suggests promising directions for the design of tools to cultivate human creativity. Interestingly, the idea of mentally hearing melodies hidden in drones, speech, and everyday sounds resembles recent advances in artificial intelligence, where machines trained on certain visual forms can "perceive" these forms in arbitrary input [42]. The capability of "hearing Bach-like

improvised sequences" also resembles the capabilities of AI-based melody generators [10]. While much energy and resources are currently devoted to creating machines with extraordinary capabilities, which lead to empoverishing the capabilities of the humans that use them, we wonder if equal resources shouldn't be devoted to developing the right inputs and techniques that contribute to enrich humans and lead them to consistently achieve such capabilities. Our findings suggest that fostering a link between movement, auditory perception, and imagination is a promising direction of exploration.

5.4 In Praise of Intangibility

As observed in section 2.2, influential theories of embodiment within HCI often focus on the body's interaction with tools, objects, and artifacts, where there is an assumption of direct, tactile manipulation. Our findings with the theremin question this assumption in the foundation of embodied cognition. The theremin becomes "ready-to-hand" for the first author, where she is able to project a musical and expressive intention through the instrument, yet nothing is in the hand. As elaborated in section 4.2.1, profound changes can occur in the body schema through longterm practice of the theremin, without any direct, physical manipulation.

Tangible interactions do have their advantages. As Ishii points out, manipulating physical objects takes advantage of people's innate embodied skills for sensing and manipulating their physical environments [28]. The skill for manipulating physical objects is highly developed in able-bodied adults, which explains the success of tangibility as an interaction paradigm. However, these skills are far from innate, as seen in an infant's struggle to reach, grasp and pick up toys. Even the concepts of ready-to-hand and the affordances of objects are based on the many years of practice and struggle in acting on physical objects that every human engaged in at the beginning of life that altered our body schemas. Such practice, or rather play, involved focused attention, time, repetition, as well as the convergence of motor skills, perception, and mental imagery.

The lack of tangibility contributes to the challenge of the theremin in that we can no longer rely on existing skills for the sensing and manipulating of physical objects. Playing the theremin forces us to confront a totally different interaction model, in which we are like a child again, altering and extending our body schema to embody a new paradigm. Without familiar guide rails to grab on to, the intangibility of the theremin forces the player to concentrate on other embodied strategies, to develop listening, attention to the body, and the creative imagination. Longterm cultivation of these strategies not only allowed the first author to become a proficient theremin player but also endowed her with auditory and imaginative "superpowers" [2].

6 CONCLUSION

This paper presented a detailed autoethnographic account of one player's theremin learning experience over 3 years. We identified essential embodied strategies for attaining musical proficiency on the theremin despite the lack of tangible feedback, through "tuning in" to auditory feedback, proprioception, and various types of

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[2]The title of this section is a reference to the essay *In Praise of Shadows*, which invites the reader to look beyond the emphasis on light and brightness in Western aesthetics to appreciate the beauty in the subtle, nuance play of shadows as found in Japanese aesthetic. [55]

mental imagery. We also describe profound changes in the player that come about from practicing these strategies over time.

In terms of takeaways for the HCI community, some readers may have expected to see a list of design guidelines distilled from the player's experiences on the theremin. The absence of such guidelines was an explicit choice. In its essence, our paper challenges a commonly accepted principle in HCI, on the impoverished nature of mid-air interactions. If such a well-accepted notion can be shown to have its limitations, a meta-message is that others may be worth challenging as well, for the sake of discovering territories outside the confines of design guidelines, previously written off as uninteresting. Rather than replacing one fence with others, we contribute to the discourse of HCI at large by pointing out under-explored but richly interesting territories, connecting the dots with previous domain-specific efforts at exploration, and suggesting alternative means of exploration. Under-explored territories include the design of tools that develop listening and mental imagery skills, relevant not only for music-related HCI but also other domains such as language learning. Connections across domains include parallels with the learning of embodied and non-embodied subjects, from dance to debugging.

Alternative mean of exploration is exemplified by the focus of our study. Instead of judging the theremin for its inherent design, this papers shifts the focus to how a user appropriates the artifact, and how longterm usage transforms the user in the process. In shifting focus, we wonder if notions of design can be broadened beyond the device itself to include the relationship between the user and the artifact. In our findings, we observe design choices in the gestures chosen by the player, exercises aimed to practice specific movements, and even metaphorical ways of thinking about the interaction that arguably play a more important role in the successful "operation" of the device than its inherent design. Ultimately, our approach underscores the advantages of utilizing first-person methods and serves as a case study for fostering dialogue between the arts and HCI.

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