Developing an Expressive Musical Interface for Music Interventions

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Abstract

This thesis has explored the design of a musical interface aimed at allowing patients without formal musical training to express themselves during music interventions. The prototype focused on the ideas of musical improvisation and mirroring a person's movements through sonic features. The instrument-inspired controller was not meant to replace specialists but to offer them a flexible tool that allows the ones in need to collaborate non-verbally. Such a device offers promising opportunities for both individuals and groups in interventions where they actively engage with music. Whether the musical interface is genuinely capable of that remains at the stage of a demo.

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Chapter 1

Introduction

1.1 Motivation

Music interventions and musical interfaces are two domains located at the border between music and technology. Integrating musical interfaces in music interventions such as music therapy offers promising opportunities. Besides enhancing the therapeutic process and session analysis [1], one potential application in music interventions is fostering expressive and aesthetic freedom through technology, particularly for people without formal musical training.

1.2 Research Questions

The main goal of this study is to develop a musical interface to use in music interventions. After reviewing the literature and developing a number of prototypes, we will address the following research questions:

- **RQ 1**: What are the most important aspects to consider when developing a musical interface prototype?
- **RQ 2**: How usable is the musical interface prototype, according to user feedback from evaluation sessions?
- **RQ 3**: How effective is the musical interface prototype at enabling users to express themselves, and can it lead to better well-being outcomes, according to user feedback from evaluation sessions?

These research questions will have an impact on the design, implementation, and evaluation of the prototype.

Chapter 2

Literature Review

2.1 From Music to Music Therapy

2.1.1 Music

Whether we are driving in our cars, doing our groceries at the nearest supermarket, or engaging our cores at the gym, music accompanies us every step of the way. Music is omnipresent in our current society and maybe that is what makes it a challenge to clearly define this phenomenon.

Music held social and ethical influence in ancient Greece, imitating and provoking emotions [2]. *Mousiké*, as it was also known, consisted of dance and gestures and was performed in social settings. However, throughout the Enlightenment, music became non-discursive, and emotions were viewed as cognitive or aesthetic in nature, giving rise to the concept of *fine art*. Thus, a divide between the aesthetic and practical values of music was born.

Without a doubt, the specific motives behind listening to music are as varied as the songs in our playlists. Music serves several purposes, including aesthetic enjoyment, entertainment, symbolic representation, emotional expression, and communication [3]. Its influence spans across a wide range of behavioural contexts, including personal, social, consumer, educational, and motivational [4]. The essence of music is only revealed when considering the intentions, values, uses, functions, beliefs, and expertise of those involved in its creation and reception [2].

While music is often described by six concepts that serve as building blocks (see Table 2.1), such a limited description fails to capture its complexities and ignores the impact it has on our lives [2,5,6].

2.1.2 Health and Well-being

The WHO defines *health* as a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity [7]. Music, health, and well-being have a complex relationship, involving multiple facets and challenges. Throughout history, music has been recognized

Concept	Description
Rhythm	• Everything related to the time aspect. • Beats, accents, measures, etc. • Slow rhythms provide a sense of calmness. • Intense rhythms provide a sense of energy.
Melody	• Series of notes with varying pitches and organized in a recognizable shape. • Typically the element a listener follows. • Higher pitches provide a sense of stimulation. • Lower pitches provide a sense of relaxation.
Harmony	• Two or more notes played together. • Pleasing harmonies provide a sense of calmness. • Dissonant harmonies provide a sense of tension.
Timbre	• What distinguishes the sound of one instrument or singer from another. • Influenced by the construction, shape, materials, and technique, in the case of an instrument. • Influenced by the body and technique, in the case of a vocalist. • Associated with feelings, memories, and events.
Form	• Structure and design of a composition. • Provides comfort and predictability.
Dynamics	• Gradation of volume. • Soft music provides a sense of calmness, closeness, and intimacy. • Loud music provides a sense of energy and power.

Table 2.1: Descriptions of Music Concepts.

for its curative, therapeutic, and medical value. Even though cultural and arts practices are often absent from key discussions surrounding health and health promotion, music is an intrinsic and important part of human development and must be considered a universal resource for health and well-being [4].

Music has the capacity to evoke and shape our emotional states, allowing us to regulate cognition and overall psychological well-being [3]. Taking part in singing activities promotes happiness and joy while providing a profound sense of purpose. Singing boosts energy levels, cognitive focus, and self-confidence [2]. Moreover, both listening to and creating music improve communication and interaction among individuals [8].

Physiological responses are also impacted by music, namely, heart rate, blood pressure, immune response, and dopamine receptor activity [3]. Singing and dancing is proven to strengthen brain connections and stimulate neuroplastic changes, meaning active engagement with music can aid rehabilitation and alleviate developmental disorders [4, 8].

2.1.3 Music Interventions

Music interventions can take many forms. They can be passive (e.g., streaming music) or active (e.g., drumming), and can be employed individually or in groups. Depending on the purpose of the intervention, results may include physiological and/or psychological changes [5]. Music interventions can be offered not only qualified music therapists and trainees, but also other professionals like sport scientists, neuroscientists, teachers, or rehabilitation musicians [15]. Activities like listening to music, group singing, playing instruments, dancing, moving to music, rapping, reciting lyrics, songwriting, improvisation, and composing have several health benefits for people of all ages and backgrounds [16]. Table 2.2 summarizes the effects of music on different aspects, including academic performance, sleep, memory, and sports.

When conceptualizing the full range of interventions within the music, health, and well-being field, a number of distinct yet interconnected areas can be considered, as illustrated in Figure 2.1 [17]. For a descriptions of the areas presented in the conceptual framework, refer to Table 2.3.

2.1.4 Music Therapy

Music therapy harnesses the power of music to produce positive outcomes and can be regarded as complementary, integrative, and a primary means of treatment [4]. Considering that music is capable of promoting change, development, and growth, music therapy aims to improve health and induce change on individual and societal levels [18]. It is important to keep in mind that music itself has no therapeutic value but rather its methodological application to target specific conditions or behaviors [3].

The music therapist has an important role, providing a theoretical understanding of the function of music in therapy [19]. Unlike the traditional medical model, the power within music therapy is redistributed, shifting the balance of authority from the therapist to the client, who actively engages with music [18]. Figure 2.2 illustrates the elements and relationships in music therapy and music medicine; the traditional medical model resembles the music medicine one, where music and intramusical relationship are replaced with medical intervention and intramedical relationship [20].

Aspect	Findings
Academic Performance	• Listening to music improves spelling word retention, test scores, and report card grades. [9] • Listening to music reduces stress and increases focus. [9] • Music is a tool for improving mathematical understanding or other skills. [10] • Music increases student engagement and motivation. [10] • Music interventions show promise in addressing reading difficulties. [11] • Music interventions enhance reading skills. [12]
Sleep	• Music improves sleep quality. [13] • Music increases duration of certain sleep stages. [13] • Listening to music before nap reduces light sleep and enhances deep sleep. [13]
Memory	• Music enhances memory to a certain degree. [13] • Different styles of music impact memory differently. [13] • Music boosts short-term and verbal memory. [13]
Sports	• Listening to music regulates emotions in running. [14] • Runners benefit in performance from motivational music. [14]

Table 2.2: Effects of Music on Various Aspects.

Area	Description
Music Therapy	• Therapeutic relationship. • Delivered by qualified music therapist. • Positive psychological and/or physiological benefits. • Well-established journals dedicated to music therapy research.
Community Music	• Artistic access prioritized over therapeutic effects. • Defined by practical, activity-based features and fluid hierarchies. • Binds communities (e.g., LGBTQIA+ choirs).
Music Education	• Typically focused on developing conventional music skills. • Enhancing cognitive skills. • Expanded to include popular music and informal music activities.
Everyday Uses of Music	• Influences emotions. • Music selection as psychological self-help. • Positive impact documented outside clinical settings.
Music Medicine	• Therapeutic outcomes. • Using *prescribed music* in various medical areas. • Positive effects on psychological and physiological aspects. • Fewer practitioners

Table 2.3: Descriptions of the Areas of the Conceptual Framework for Music, Health and Well-being.

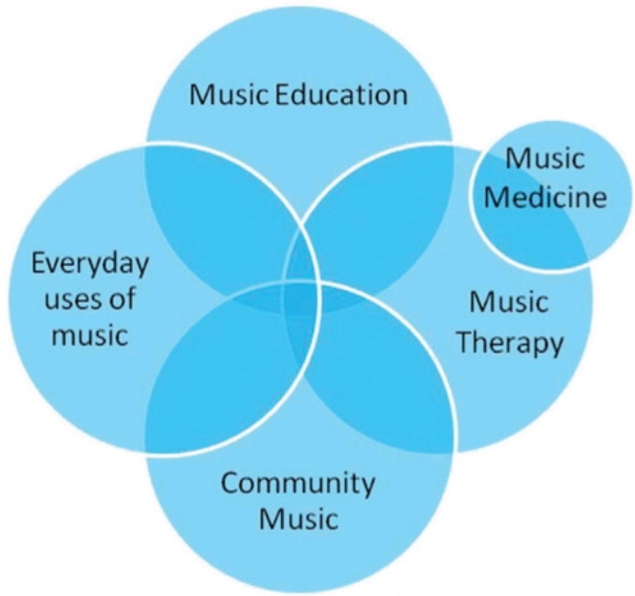


Figure 2.1: Conceptual Framework for Music, Health and Well-being.

People can take part in music therapy individually or in groups. There are two types of music therapy: active and receptive. In active interventions, patients actively engage with music during sessions (e.g., musical improvisation, composing, moving to music, and singing), while receptive interventions involve patients responding to music provided by the therapist (e.g., listening and discussing their emotions and experiences) [21].

At its core, music therapy mixes science and art, drawing inspiration from various theoretical and therapeutical orientations [20]. In its present form, music therapy has evolved into a neuroscience model, incorporating scientific work on music and the brain [19, 22].

2.1.5 Music Therapy Models

Music therapy comprises multiple theoretical perspectives and approaches, each music therapy domain highlighting music in a specific way to achieve therapeutic goals [3]. Some widely acknowledged models in music therapy include *Guided Imagery and Music*, *Analytical Music Therapy*, *Creative Music Therapy*, *Benenzon Music Therapy*, *Behavioural Music Therapy*, and *Community Music Therapy* [20]. The six models are presented in Table 2.4; the classification is made with the system of [23]. In addition to the models mentioned above, we would like to add *Neurological Music Therapy* (see Table 2.5) [24].

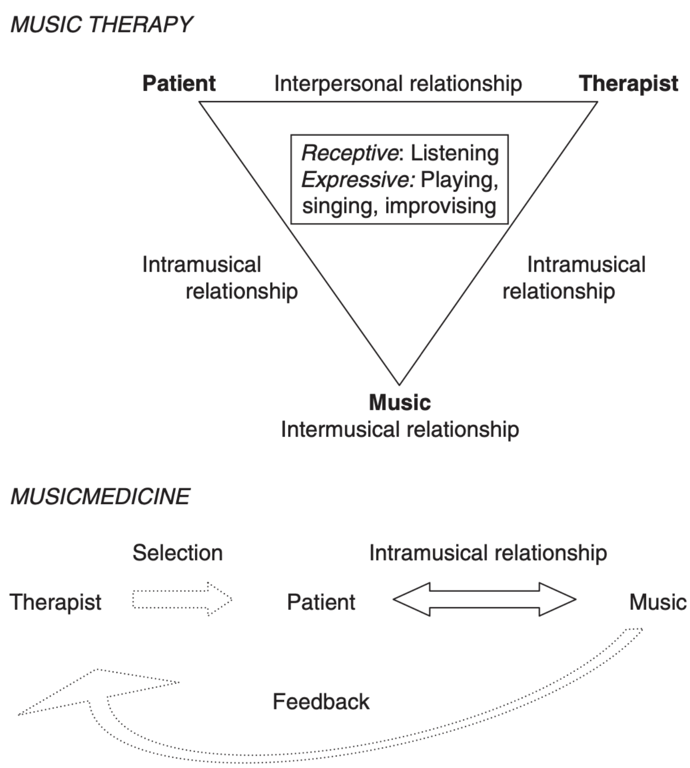


Figure 2.2: Elements and Relationships in Music Therapy and Music Medicine.

Table 2.4: Music Therapy Models.

Model	**Historical Outline & Definitions from Literature**	**Session Format**	**Clinical Applications**	**Documentation**	**Classification**
The Bonny Method of Guided Imagery and Music (GIM)	Developed in the early 1970s by Helen Lindquist Bonny. Imagery evoked during music listening. Specifically programmed classical music.	a) Prelude. b) Induction, relaxation, and focusing. c) Music travel. d) Return and drawing. e) Verbal conversation.	Self-development. Drug addiction. Abuse. Neurotic disturbances. Heart problems. Cancer. HIV. End-of-life care.	Clinical studies. Research in quantitative, qualitative, and mixed designs.	Intensive level. Transformative music psychotherapy.
Analytically Oriented Music Therapy (AOM)	Analytical Music Therapy developed in the early 1970s by Mary Priestley. Symbolic use of improvised music by the music therapist and client.	No specific format. Starts with verbal dialogue. *Playing rule* formulated.	Psychiatric patients. Rehabilitation. Training.	Several publications. Chapters in international publications.	Insight Music Therapy at intensive and primary levels.
Creative Music Therapy	Famous improvisational model by Nordoff–Robbins. Aimed at children with learning disabilities. Influenced by the anthroposophic movement in humanistic psychology. Innate responsiveness to music.	Improvisation. Therapist establishes a musical frame. Client's musical expressions integrated.	Extensive clinical use. Neurology. Psychiatry. Terminal illness.	Case studies. Diverse rating scales.	Developmental Music Therapy or Music Therapy in Healing or Transformative Music Psychotherapy at the intensive level.

Continue on the next page.

Music Therapy Models (Continued).

Model	Historical Outline & Definitions from Literature	Session Format	Clinical Applications	Documentation	Classification
Benenzon Music Therapy	First music therapy training program in South America founded by Rolando Benenzon in 1966. Blend of psychoanalytic and psychodramatic theories. Direct creative energies into opening channels of communication between people.	a) Warming up and catharsis. b) Perception and observation. c) Sonorous dialogue.	Autism. Vegetative states. Hypertension.	Benenzon's books on music therapy for children within the autistic spectrum translated to English, Portuguese, and Italian.	Not listed. Described as intensive or augmentative.
Cognitive-Behavioural Music Therapy (CBMT)	In 1966 Clifford Madsen and colleagues described Behavorial Music Therapy as a form of cognitive-behaviour modification using music. Music used to modify behaviour through conditioning. Results measured by applied behaviour analysis.	Firm structure. Predictable stimuli. Strict protocol. Depends on the cognitive or behaviour modification goals.	Developmental disabilities. Geriatrics. Psychiatric patients. Neurological rehabilitation.	Research-driven. Based on natural science standards. Applied behaviour analysis to measure effects over time. Reversal designs to assess intervention efficacy.	Didactic Practice at the augmentative level.

Continue on the next page.

Music Therapy Models (Continued).

Model	Historical Outline & Definitions from Literature	Session Format	Clinical Applications	Documentation	Classification
Community Music Therapy	Term used in American literature since 1960. Recent emergence found in some early publications from Even Ruud. Situated health musicking in community. Focus upon promotion of sociocultural and communal change. Non-clinical and inclusive settings.	No common procedures. Adapted to the context. Needs and potentials of participants as point of departure.	Health. Human development. Social change. Marginalized individuals or groups.	Extensive literature. Several national contexts.	Ecological music therapy. Intensive level.

Principles
• Addresses issues caused by nervous system disorders or injuries. • Rooted in neuroscientific theories. • Standardized and can be adjusted to meet a patient's needs. • Aimed at therapeutic goals unrelated to music. • Requires practitioners with not only music and music therapy education but also in neuroanatomy, physiology, neuropathology, medical terminology, and rehabilitation. • Interdisciplinary.

Table 2.5: Overview of Neurologic Music Therapy Principles.

2.1.6 In Practice

Over the past six decades, music therapy has evolved into an evidence-based practice firmly established in the field [25]. Music therapy is considered a valuable tool for illness prevention, especially in the absence of surgical or pharmacological treatments. Music therapy is tailored to an individual's mood, coping abilities, medical status, and prior musical experiences [26]. However, because the patients' needs vary, predicting who will benefit from which interventions is rather difficult.

Music therapy has shown promise in treating substance use disorder, anxiety, depression, autism, schizophrenia, and dementia [27–32]. However, the effectiveness of music therapy has several drawbacks [3]. Research in these areas may be subject to high levels of bias, a lack of transferability of findings, and poor longer-term follow-up periods needed to corroborate findings and assess the long-term effects of music therapy.

2.2 Movement-based Design

2.2.1 Embodiment

Embodied design uses all senses, with the body as the ultimate instrument of external knowledge. Influenced by performative disciplines like theater, drama, dance, and yoga, embodied design relies on *estrangement* to improve the ideation process and introduce new design approaches [33].

When designing interactive systems, five key themes can be identified: *thinking through doing*, *performance*, *visibility*, *risk*, and *thickness of practice* [34]. *Embodied Cognition* (EC) is an effective method for investigating the design of interactive systems. Interactive systems influenced by EC transform perception, action, and social interaction by creating *expressive traces* in the environment and enacting the function of an artifact through concrete interactions that blur the boundaries between the digital and physical realms [35].

2.2.2 The Moving and Making Strange Methodology

Moving and Making Strange offers a comprehensive toolkit for designing and evaluating movement-based interactions with technology [36]. The methodology is based on key principles like *making* *strange* to disrupt habitual perceptions and ways of moving, sensing, and feeling. The emphasis lies here on direct bodily experiences, multiple perspectives, openness to phenomena, and creativity.

This methodology is organized around three perspectives (*mover*, *observer*, and *machine*), each providing orientation, guidance, methods, and tools at every stage of the design process. Refer to Figures 2.3 and 2.4.

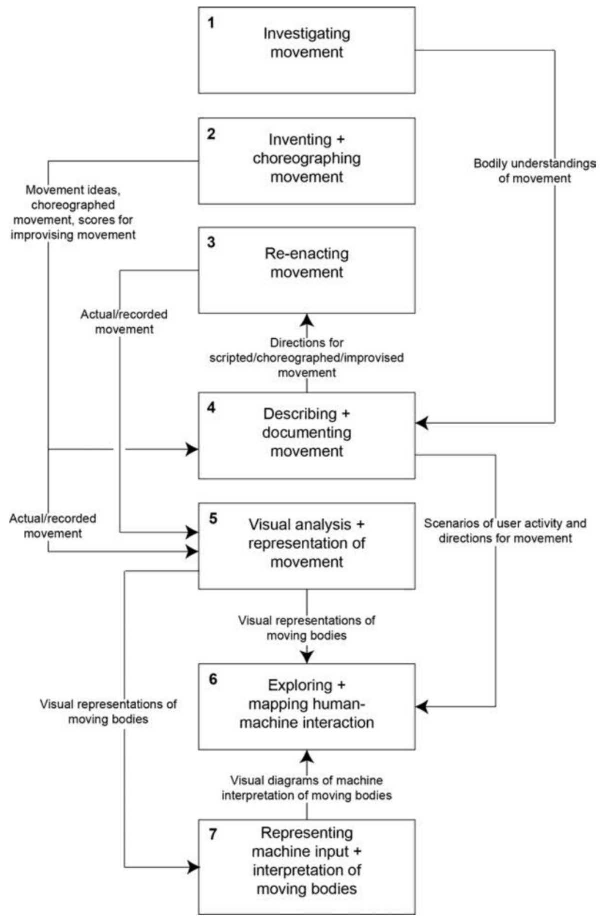


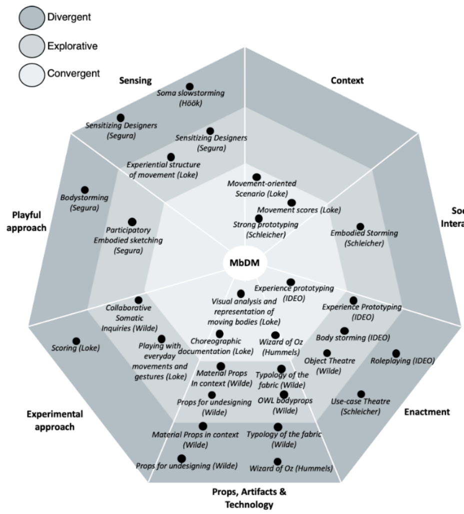
Figure 2.3: Key Activities Promoted by the *Moving and Making Strange* Design Methodology.

2.2.3 Movement-based Design Method Tools

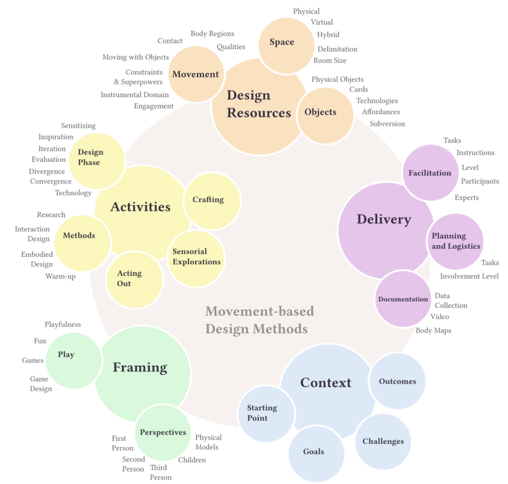
Deciding what movement-based design methods (MbDMs) to use can be a challenge. The typology of [37] serves as a practical guide for planning design processes, catering to the specific needs and purposes of designers. Figure 2.5a depicts a typology categorizing 23 MbDMs based on two factors: *sub-mediums* and *design stage*. The three design stages are the *opening/divergent* stage (creating new ideas and perspectives), the *exploring/emergent* stage (actively exploring, modifying,

Activity	Method/Tool	Perspective/Data
#1 Investigating movement	Experiential structure of movement Playing with everyday movements and gestures Scoring Generating movement from imagery	First-person perspective and experiential data on process and felt sensation of movement.
#2 Inventing and choreographing movement	Working with parameters and qualities of movement: 1. Scoring 2. Variations on a traditional movement form or gesture From words/concepts/images	First-person perspective and experiential data on movement possibilities, forms, patterns, motivations and corresponding felt sensations
#3 Re-enacting movement	Re-enacting movement-oriented scenarios and scripts, movement scores and directions for choreographed movement.	First-person perspective and experiential understandings of movement during user testing/evaluation.
#4 Describing and documenting movement	Describing user activity: 1. Movement-oriented scenarios and scripts 2. Directions for skilled or choreographed movement Documenting choreographed movement: combination of images, text and sketching.	Observational perspective documenting the movements of people and the motivations for movement.
#5 Visual analysis and representation of moving bodies	Movement sequences and silhouettes. Laban movement analysis: Effort/Shape descriptions Spatial movement schemas in Labanotation floorplans.	Observational perspective for visually analyzing and representing human movement. Observational data on the sequencing and bodily organization of the body-in-motion, the expressive qualities of movement and the spatial/social interactions between people.
#6 Exploring and mapping human-machine interaction	Interactivity table	Mapping between human movements and machine, combining the observational and machine perspectives.
#7 Representing machine input and interpretation of moving bodies	Machine input schemas	Machine perspective of the input and interpretation of moving bodies.

Figure 2.4: Activities, Methods/Tools, and Perspectives/Data Promoted by the *Moving and Making Strange* Design Methodology.



(a) Typology of Movement-based Design Methods Using Sub-Mediums and Design Stages.



(b) Overview of the Groups, Categories and Subcategories of Movement-Based Design Methods.

Figure 2.5: Movement-based Design Method Tools.

experimenting, and experiencing different movement perspectives), and the *closing/convergent* stage (performing, testing, and validating to expose weaknesses and places of improvement in the design). Sub-mediums are used in the design process to describe how movement is stimulated, formed, or catalyzed; the sub-mediums identified are: *Sensing*, *Playful approach*, *Experimental approach*, *Context*, *Social Interaction*, *Enactment*, and *Props, Artifacts, and Technology*.

Figure 2.5b presents an overview of the groups, categories, and subcategories of MbDMs. This can be both an inspiration and a document to support arguments for or against specific design choices [38].

2.2.4 The 4M Framework and the MeCaMInD Cards

The *4M* framework was created to design for, with, and through movement in sports, technology, games, and play [39]. The framework comprises four elements of movement-based design activities: *Movement Modifiers*, *Mood Setters*, *Movement Methods*, and *Movement Concepts*. By incorporating these different elements, the framework suggests that movement-based design practices have multiple layers and perspectives, which designers and facilitators must understand and consider when planning design processes. Table 2.6 provides a description of the four M's.

The *MeCaMInD* cards are a toolbox of embodied design methods, based on the *4M* framework. These cards provide a user-friendly approach to guide design activities. The five types of cards can be found in Table 2.7. Figure 2.7 shows examples of *MeCaMInD* cards.

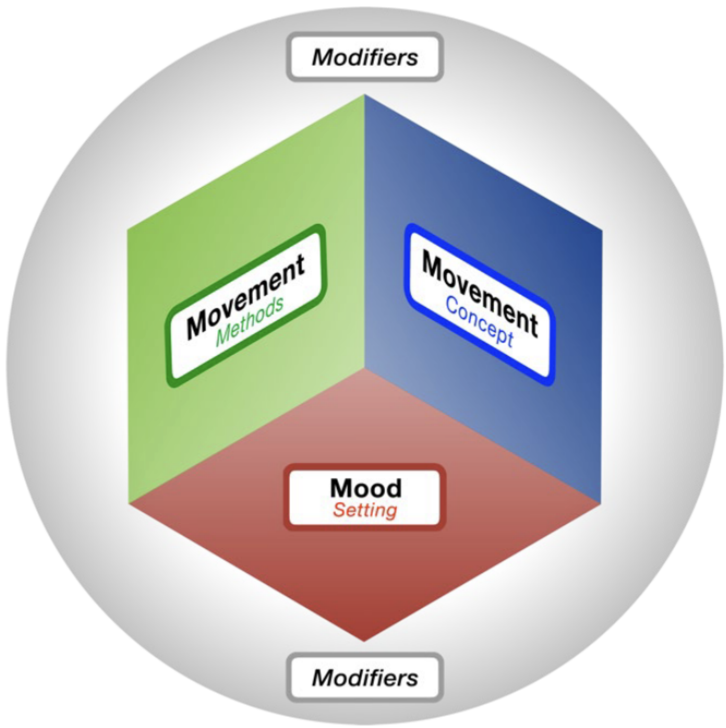


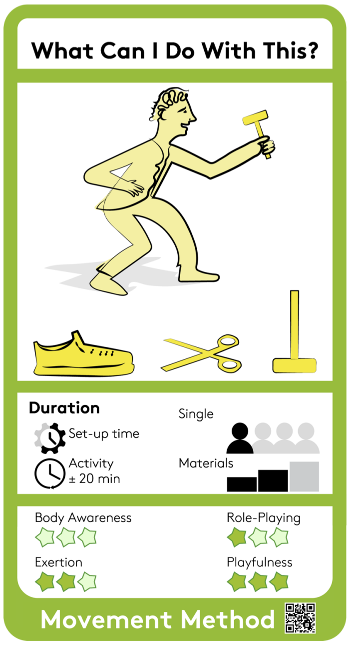
Figure 2.6: The *4M* Framework for Movement-based Design.

M	Description
Mood Setters	• Prepare participants physically, socially, and mentally. • Energize and enhance creativity before primary design tasks. • Icebreakers, warm-up exercises, team building, and tech-supported games.
Movement Methods	• Use movement to explore and stimulate creativity. • Stem from practices like dance, sport, rehabilitation, and theatre. • Have a specific context-bound design goal.
Movement Concepts	• Serve as a knowledge foundation for informed design. • Stem from areas like Philosophy of Sports and Movement, Psychology of Humans, Humans in Society, Motor Learning, and Biomechanics. • Theories, knowledge, evidence, generative and reflective questions.
Movement Modifiers	• Tools that support, modify, or disrupt. • Stimulate physical exploration and creativity.

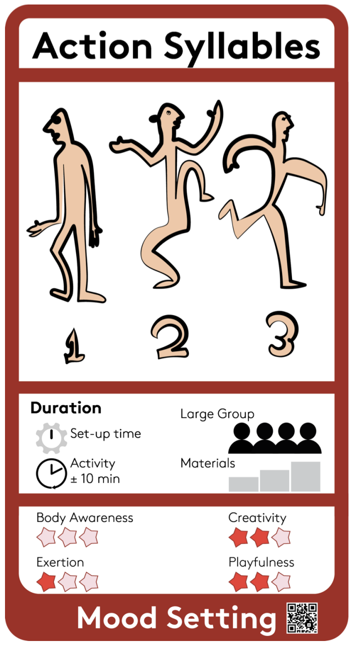
Table 2.6: Descriptions of the four M's of the *4M* Framework.

Category	Description
Mood Setting Cards	• 36 methods to set a creative mood. • Includes icebreakers, warm-ups, and team-building activities. • Characterized by setup time, activity duration, number of participants, and required materials. • Online version features 30 instructional videos.
Movement Method Cards	• 30 methods for sensitising designers, ideating, evaluating/polishing, and documenting solutions. • Emphasis on the moving body. • Characterized by setup time, activity duration, number of participants, and required materials.
Movement Concept Cards	• 38 knowledge chunks. • Related to various fields of study.
Modifier Cards	• 300+ cards with words or images. • Designed to tweak current design activities. • Helps find new perspectives and solutions. • Cards, physical artefacts, words, pictures.
Instruction Cards	• Detailed instructions for various card categories. • Facilitation guidelines. • Suggestions for music and physical props. • Examples of design flows to plan workshops and events.

Table 2.7: Descriptions of the *MeCaMInD* Card Categories.



(a) Example of *Movement Method* Card.



(b) Example of *Mood Setting* Card.

Figure 2.7: Examples of *MeCaMInD* Cards.

2.2.5 Facilitation

Figure 2.8 illustrates how participants' embodiment contributes to movement-based design through four key pillars of facilitation [40]. These pillars include creating a safe and welcoming design space, providing embodied training using selected techniques and methods, employing *show don't tell* practices, and verbalizing embodied experiences.

The person responsible for leading a process or workshop for a group of people with a shared objective is called a *facilitator*. A facilitator can take on different roles: *Instructor and Game Master*, *Coach and Mediator*, *Role Model*, and *Initiator and Animator*. Descriptions of the facilitator roles can be found in Table 2.8.

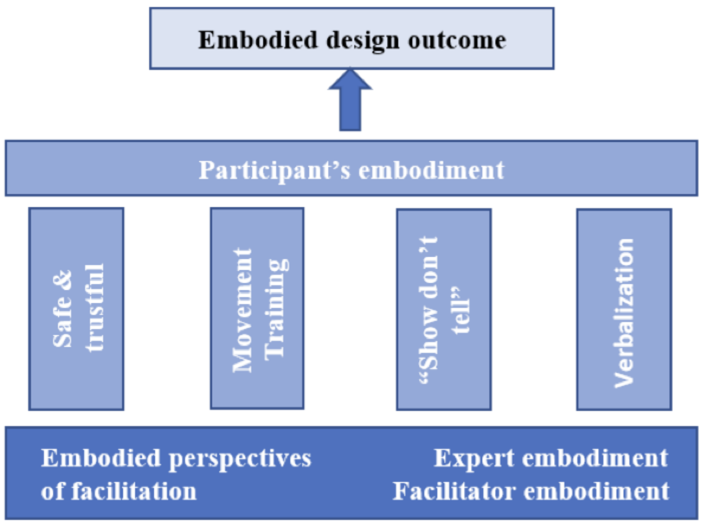


Figure 2.8: Facilitator Support in Movement-Based Design Activities.

2.3 Musical Interfaces

2.3.1 Designing Musical Interfaces

When designing musical interfaces, it is important to realize that they may lack the acoustic qualities of traditional instruments, hindering the embodied experience of their users. However, soma design principles can be employed to address this challenge [41]. By questioning, deconstructing, and offering alternative perspectives on everyday activities, new interactions can be imagined. Rather than simply focusing on sound generation, this approach highlights the bodily sensations and aesthetic aspects of playing an instrument, without explicit focus on the underlying technology.

Interactive music systems have both technological and experiential components. To develop a successful tool, the basic concepts of musical embodiment come in handy [42]. Our bodies connect with the physical environment and our personal experience, building a set of gestures and their consequences. This includes the connections between commands, external sensations, and movements.

Facilitator Role	Description
Instructor and Games Master	• Sets up activities and methods in advance. • Explains the activities and methods at the start. • Structures the execution of the activity. • Maintains a third person perspective. • Allows participants to take control of the activity.
Coach and Mediator	• Guides the direction of the activity. • Partial active involvement. • Steers the group towards the correct execution of the activity.
Role Model	• Acts as an undercover facilitator. • Helps other participants in the group activity.
Initiator and Animator	• Controls the purpose of the activity. • Full active involvement. • Manipulates the energy in the process to facilitate progress towards the goal. • Uses both first and second person perspectives.

Table 2.8: Descriptions of Facilitator Roles.

While gestures are typically considered a means to foster artistic expression, their effectiveness varies. When it comes to musical interfaces, technology may serve as a tool for experimentation, pushing beyond traditional norms [43]. Global methods from traditional music practices may not directly apply here. Instead, strong concepts should be prioritized over detailed implementations. The openness and modularity of the system are also crucial, allowing for flexibility and exploration. Furthermore, constraints and perturbations should be embraced, as they can yield beneficial outcomes in this artistic context.

The relationship between a musician and their instrument cannot be forgotten. To achieve true communication of musical meaning, the instrument must become an extension of the artist's body, allowing the artist to reach their full potential. Imposing restrictions on the user through forced and unnatural interventions could lead to frustration and cognitive overload [44].

New possibilities for interaction and control in music could be offered by deformable interfaces. This type of interfaces is commonly used for sound manipulation and filtering, rather than sound generation, and is perceived by musicians as expressive and embodying the sounds they control [45].

2.3.2 Examples of Musical Interfaces

When examining the state of the art, musical interfaces can be classified based on gestural controllers into: *alternate controllers*, *hyperinstruments*, *instrument-like controllers*, and *instrument-inspired controllers* [1,46].

2.3.2.1 Instrument-Like Controllers

Instrument-like controllers emulate the physical and sonic characteristics of acoustic instruments while offering a wider range of sonorities [1,46]. Examples of such controllers include electronic keyboards, guitars, violins, saxophones, etc.

2.3.2.2 Instrument-Inspired Controllers

Instrument-inspired controllers have a substantially different design from the acoustic instrument they are inspired by [1,46]. AirSticks 2.0 is a good example of that [47]. Taking inspiration from the design and functionality of drumsticks (see Figure 2.9a), the interface can trigger and manipulate discrete and continuous sound events in real-time, outputting them to a digital audio workstation (DAW). Based on the sensing capabilities, AirSticks 2.0 is a motion-based musical interface, making use of an inertial measurement unit (IMU).

2.3.2.3 Hyperinstruments

Hyperinstruments, also known as extended instruments, are augmented instruments with sensors or other devices [1,46]. A popular example of such instruments is the Yamaha Disklavier piano which allows for recording and playback of performances, internet connectivity, and various interactive and educational features [48].

2.3.2.4 Alternate Controllers

Alternate controllers differ from traditional instruments in terms of shape, ways to use, materials and built-in processes [1, 46]. These systems typically offer a unique and more accessible way for people to engage with music. Examples of such controllers include:

- **InterFACE** [49]: An interactive system featuring three virtual instruments - a drum machine, a granular synthesis sampler, and a laptop mouth organ. Figure 2.9b shows InterFACE in action.

- **Multi Rubbing Tactile Instrument (MRTI2015)** [50]: An egg-shaped instrument with LED lights that display the grasping nuances and produce real-time chaotic graphics visible to the user on a screen.

- **MiMU Glove** [51]: A smart glove renowned for its ability to translate hand and finger movements into expressive, real-time control of digital sound. Figure 2.9d depicts the MiMU glove on the hand.

- **Leap Motion** [52]: A USB device that tracks hand and finger locations, offering possibilities for motion-based control in musical expression.

- **VESBALL** [53]: A ball-shaped musical interface designed specifically for group music therapy sessions, targeting individuals with Autism Spectrum Disorder (ASD).

Each of these controllers possesses distinct sensing capabilities: audio-based (InterFACE), visual-based (InterFACE), touch-based (MRTI2015 and VESBALL), and motion-based (Leap Motion, Mi.MU, and VESBALL).

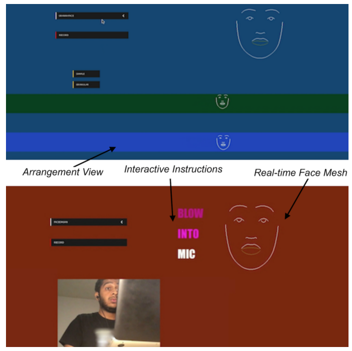
2.3.3 Prototype Requirements

Following this literature review on designing musical interfaces and discussing some popular examples, the following list of requirements for the prototype has been compiled (see Table 3.4). These requirements reflect the need for a musical interface that not only produces sound but also improves on the embodied experience of the people.

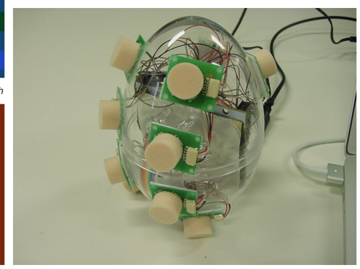
2.4 Conclusions

This study will focus on the development of an expressive musical interface for *people without formal musical knowledge*. This device will be designed to be used during *musical interventions*, in both *individual and group settings*, with a focus on *improvisation*. The instrument will not be meant to replace professionals but rather *serve as a tool* that they can employ to *improve the expressive flow* of individuals. The prototype will *reflect sonically* the movements of its users and will most likely be classified as an *instrument-like or alternate controller*. Given its appeal for a novice, the MeCaMInD cards will be employed during the design session. The outcomes of this session will work as a base for the development of two prototypes and their evaluations with a focus group.

(a) AirSticks 2.0 Device.



(b) InterFACE in Action.



(c) MRTI2015 Prototype.

(d) MiMU Glove.

(e) Leap Motion Device.

(f) VESBALL Prototype.

Figure 2.9: Musical Interfaces.

Requirement
The musical interface should apply soma design principles.
The musical interface should prioritize aesthetics and bodily sensations.
The musical interface should consider the connection between gestures, sensations, and movements.
The musical interface should serve as an extension of the artist's body.
The musical interface should ensure flexibility and experimentation.
The musical interface should prioritize strong conceptual foundations over detailed technical implementations.
The musical interface should embrace constraints and perturbations.
The musical interface should avoid any forced and unnatural interventions.
The musical interface should ensure expressive sound manipulation.

Table 2.9: Musical Interface Requirements Based on Literature Review.

Chapter 3

Design Session

The design session took place on the University of Twente campus and lasted approximately three hours. A spacious room accommodated five participants who were all students with a technical background. The session was divided into three phases, each lasting 50 minutes, with 10-minute breaks in between. The three phases focused on generating and presenting ideas, exploring expressive potential, and imagining sounds. Before the start of the session, participants were given information brochures and consent forms to sign (see Appendix A.1). During the session, participants were recorded by two cameras, one overview camera and one action camera. For the full schedule, refer to Appendix A.2.

3.1 Phase One

This phase started with a mood-setting exercise (*Action Syllables*) and was followed by a movement method (*What Can I Do With This?*).

Action Syllables is an exercise where all participants stand in a circle and take turns saying their name with a gesture for each syllable, which the group then repeats. A variation of this game was used by adding an adjective that alliterates with a participant's name like *Mighty Mihnea*. The purpose of this game was to learn the names of everyone in the participant group and practice the movement and language connectedness.

What Can I Do With This? involves participants experimenting with props and artifacts in various contexts, engaging with other participants, challenging their behaviors, and drawing inspiration from their surroundings. During this exercise, participants picked various objects from the cardboard box placed in the middle of the room, and performed diverse actions, ranging from swinging a basket and juggling a ball to balancing a bottle of sand, throwing dice into an empty pot of yogurt, or bouncing a spring around a metal bar.

At the end of this first phase, participants were asked to write all of their favorite things on the whiteboard. Once that was done, we held a group discussion to decide what the best ideas were and

Figure 3.1: Participants Surprised During the *What Can I Do With This?* Exercise.

removed the rest. Although our target was to generate 10 ideas for the next phase, we ended up with seven, only one of them clearly related to music (see Table 3.1). A short list of requirements was also compiled (see Table 3.2).

Idea
Throwing things around a target.
Balancing a plastic bottle half full of sand.
Pushing and pulling two springs.
Bouncing a spring around a metal bar.
Slapping and drumming an empty yogurt pot.
Moving a basket in all directions, throwing it, and catching it.
Pulling a rope, applying pressure to it, and receiving a shockwave.

Table 3.1: Ideas Generated during Phase One of the Design Session.

Requirement
The musical interface should have an asymmetric design ensuring its visual appeal and comfort.
The musical interface should have a weight ensuring its portability and comfort.
The musical interface should have a mind of its own.
The musical interface should be reactive and provide feedback.

Table 3.2: List of Requirements Generated during Phase One of the Design Session.

3.2 Phase Two

After a short break, the second phase started with a mood-setter exercise (*Clap Cross*) and continued with the movement method *Embodied Sketching*.

During the *Clap Cross* exercise, participants were divided into pairs and clapped hands as quickly as possible, either continuously switching or always clapping in the same spot. The aim of this playful and easy-to-go-to exercise was to set a positive tone for the participants.

Figure 3.2: Participants Surprised during the *Embodied Sketching* Exercise.

The *Embodied Sketching* method continued from the previous phase, allowing for a deeper exploration of the seven ideas. These ideas became more diverse as participants collaborated, observed, and demonstrated movements to each other, iterating based on a *yes, and?* mindset. To enhance this process, we also used some metaphor cards, asking participants to *Flow Like Water*, *Twist Like a Tornado*, *Move Like a Wave*, or *Fly Like a Bird*. Some new ideas we arrived at included spinning with the basket, drumming in space, and balancing the bottle while it is thrown at.

By the end, we had a longer list of requirements (see Table 3.3). Participants liked the multiplayer aspect, the easy and calm gameplay with minimal movement, and the organized chaos. Interestingly, the use of metaphor cards felt somewhat strange.

3.3 Phase Three

After a final break, the last phase started with a mood-setter exercise (*Circle Baton*) and continued with the *Embodied Sketching* method.

Circle Baton is an exercise where participants form a circle and count around with movements and noises, passing them around like a relay. The metaphor cards used were: *A Roaring Lion* for 1, *Swinging Like a Monkey* for 2, and *Prancing Like a Horse* for 3.

Requirement
The musical interface should support multiplayer interactions.
The musical interface should ensure intuitive operation with minimal cognitive load.
The musical interface should respond to both small and large movements.
The musical interface should maintain coherence in sound output regardless of user actions.

Table 3.3: List of Requirements Generated during Phase Two of the Design Session.

Then, we continued with the *Embodied Sketching* method to come up with sounds for the generated ideas. It soon became clear that it was hard to imagine sounds, as participants wanted to hear them. No specific movement could be linked exclusively to one sound, as these choices were personal. However, participants believed that sound transformations (e.g., volume, EQ, and tempo) could be linked to movements. Moreover, the main focus was on expression and ensuring all movements lead to something that sounds pleasant at all times.

3.4 Conclusions

Moving forward, the lists of requirements and possible movements compiled represented the starting point for our first prototype (see Tables 2.9, 3.4, and 3.5).

Requirement
The musical interface should have an asymmetric design.
The musical interface should have optimal weight.
The musical interface should have a mind of its own.
The musical interface should be reactive and provide feedback.
The musical interface should support multiplayer interactions.
The musical interface should ensure intuitive operation with minimal cognitive load.
The musical interface should respond to both small and large movements.
The musical interface should maintain coherence in sound output regardless of user actions.
The musical interface should play sounds and loops according to the movements.
The musical interface should toggle sound layers on and off according to the movements.
The musical interface should add sound effects to the sound layers according to the movements.

Table 3.4: List of Requirements Generated during the Entire Design Session.

Movement
Move (in any direction)
Throw
Catch
Swing
Circle
Twist
Juggle
Shake
Caress
Balance
Pull
Push
Hit
Punch
Slide
Scratch
Squish
Tap
Slap
Bounce
Roll
Drum
Spin
Flip

Table 3.5: List of Movements Encountered during the Entire Design Session.

Chapter 4

First Prototype

4.1 In Search of a Musical Interface Idea

After conducting a brainstorming session, we ended up with a list of over 50 musical interface ideas. To determine the best option, we evaluated each idea based on the level of *Interactivity* (I), *Expressivity* (E), *Feasibility* (F), *Originality* (O), *Portability* (P), and *Comfort* (C). All of these were organized into an elaborate table, allowing us to compare the total scores across all categories. The scores are from 1 to 5 where 1 is *Low* and 5 is *High*, meaning that the idea with the highest score is the best one. Table 4.1 shows the ratings for all the musical ideas.

Table 4.1: Comparison of Expressive Musical Interface Ideas.

Idea	**I**	**E**	**F**	**O**	**P**	**C**	**Total**
Bounce Ball	5	4	2	3	1	5	20
Spiky Ball	4	4	2	3	5	4	22
Bowling Ball	3	3	1	3	2	1	13
Stress Ball	3	3	2	2	5	5	20
Marbles	3	3	1	3	5	3	18
Curling Stone	2	2	2	3	2	1	12
Yoyo	4	4	2	5	5	4	24
Fidget Spinner	5	3	1	5	5	4	23
Pop It	3	2	2	3	5	4	19
Darts	2	2	3	3	4	3	17
Boomerang	4	3	1	4	5	4	21
Expandable Ball	5	4	1	4	4	3	21
Frisbee	4	3	1	4	5	4	21
Slinky	5	2	1	5	4	3	20
Spinning Top	5	2	3	4	5	3	22

Continue on the next page.

Table 4.1: Comparison of Expressive Musical Interfaces Ideas (Continued).

Idea	**I**	**E**	**F**	**O**	**P**	**C**	**Total**
Hula Hoop	5	3	2	4	2	3	19
Rope	2	2	1	3	2	2	12
Jump Rope	3	3	3	3	4	4	20
Battle Rope	3	3	2	3	1	3	15
Jungle Rope	4	3	2	4	1	3	17
Bungee Cord	3	3	1	5	1	2	15
Hammock	2	1	1	5	1	5	15
Bean Bag	2	1	1	5	1	5	15
Trampoline	5	3	1	4	1	4	18
Carpet	2	1	1	5	1	4	14
Baton	3	3	4	3	4	4	21
Wand	3	3	4	3	4	4	21
Bat	3	3	3	3	3	3	18
Staff	3	3	3	3	3	3	18
Club	3	3	3	3	3	3	18
Drumstick(s)	4	4	4	2	4	4	22
Juggling Stick(s)	4	3	4	3	3	3	20
Cane	3	3	3	3	3	3	18
Hammer	3	2	4	3	3	3	18
Rattle	3	3	4	4	5	4	23
Cabasa	3	4	4	4	5	4	24
Maraca(s)	3	3	4	3	5	4	22
Tambourine	3	3	4	4	4	4	22
Caxixi	3	3	4	4	4	3	21
Egg Shaker	3	3	4	3	5	4	22
Rainstick	3	3	4	4	4	3	21
Room Pendulum	3	3	3	3	1	3	16
Laser Strings	4	5	1	5	1	3	19
Glass Harp	3	3	2	4	1	3	16
Pole	3	2	3	3	1	2	14
Sandbox	5	5	1	3	1	5	20
Drum Ball	4	4	3	3	3	3	20
Glove	4	4	4	2	5	4	23
Ring	3	3	1	3	5	4	19
Zipper	3	3	1	4	5	5	21
Bracelet	3	3	3	3	5	4	21
Earrings	2	2	1	3	5	4	17
Headband	3	3	2	3	5	4	20
Foot Jingle	3	3	3	3	4	3	19
Tiles	4	3	3	3	3	3	19

Among the top contenders, we found the yoyo and the cabasa, with 24 points, and the fidget spinner and the rattle, with 23 points. In the end, the cabasa was picked as the most promising idea as it had a higher feasibility rating and was already linked to the musical domain.

4.2 What is a Cabasa?

A cabasa is a percussion instrument with African origins. It typically consists of a handle, a cylinder surrounded by a looped chain of beads, and caps to keep it in place. This percussion instrument is used in a multitude of music genres, creating rattling sounds when shaken or twisted. It is often used in music therapy, especially with patients suffering from physical or neurological disabilities since it requires minimal hand effort to produce sounds, making it a good fit for our scope [54].

4.3 Our Prototype in a Nutshell

The general idea of this first prototype was that it would work similarly to a loop machine. More specifically, the user would make a specific movement that activates the loop; the more movements made, the more loops activated to create a more complex musical composition. When classified, it would be an instrument-inspired controller, functioning similarly to AirSticks 2.0 (see Section 2.3.2.4).

4.4 Hardware

4.4.1 Microcontroller

To track the movements, we needed a small piece of electronics that could sense them and send data to an external source for further processing.

One of the most important elements for such a project is the microcontroller. Here, we made use of an Arduino Nano RP2040 Connect [55]. This Arduino board has a small footprint and great on-board connectivity options like WiFi 802.11b/g/n, Bluetooth, and Bluetooth Low Energy v4.2. It features a dual-core Arm Cortex M0+ silicon running at 133MHz, 264KB of SRAM, and 16MB of flash memory. But, the most impressive part is the on-board built-in sensors, specifically the six-axis smart IMU.

An ESP32 microcontroller could have also been a valid choice. They are very popular and come at a fraction of the price of the Arudino Nano RP2040. However, they do not have the same built-in sensors or support like the Arduino product.

4.4.2 Casing

To store the microcontroller safely, we designed a casing for it. The design of the casing was simple and inspired by the instrument itself, though it was flatter. As seen in Figures 4.2 and 4.3, the beads were missing and the handle was a cylinder.

The casing consisted of three parts (top part, handle, and cap), all 3D printed using PolyTerra PLA filament. The handle featured a slot at the bottom where the microcontroller could be slid

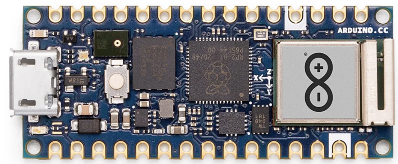
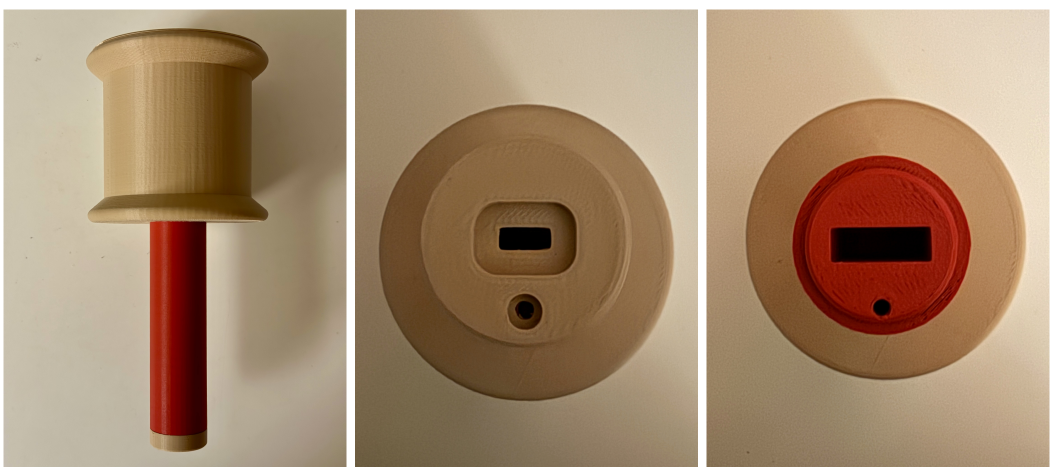


Figure 4.1: Arduino Nano RP2040 Connect.

(a) Cross-section View. (b) Isometric View.

Figure 4.2: Initial Casing of the First Prototype (Digital).

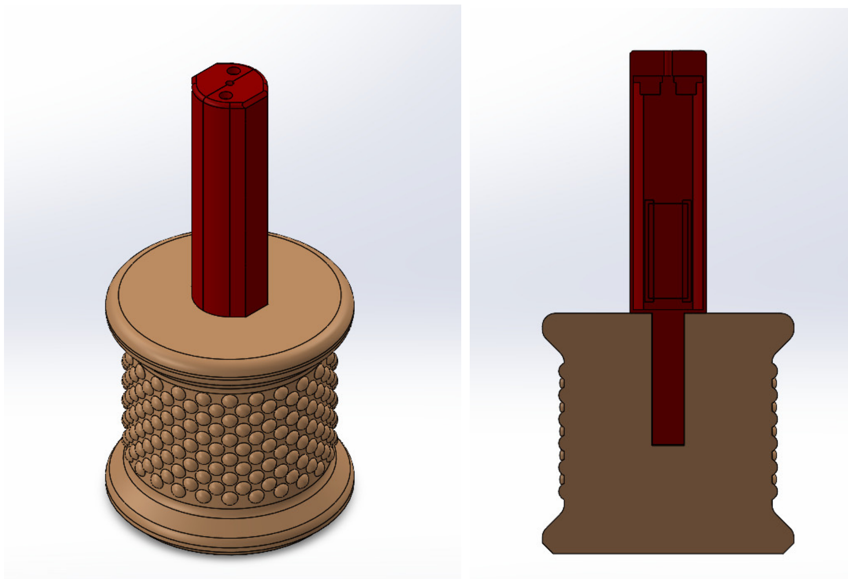


(a) Top View. (b) Bottom View (Cap On). (c) Bottom View (No Cap).

Figure 4.3: Initial Casing of the First Prototype (Physical).

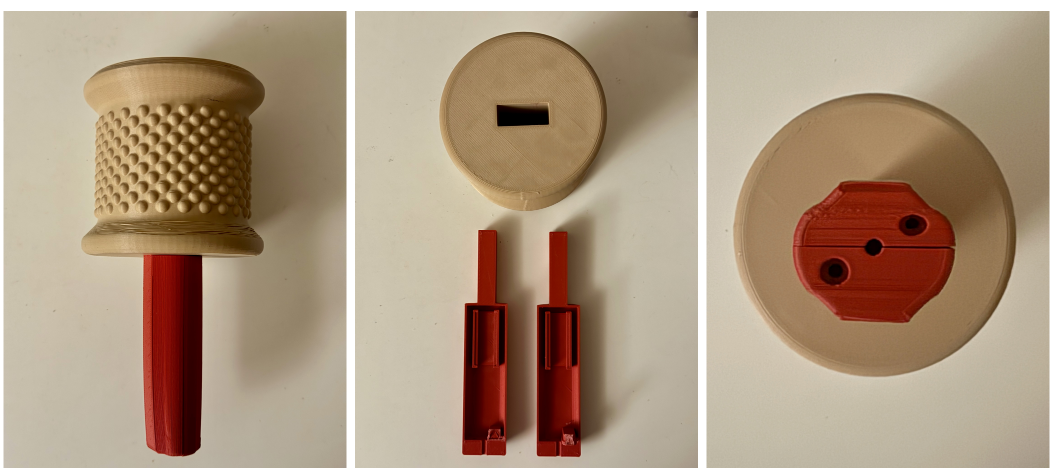
in. The cap could be easily removed and secured the connection with the microcontroller, while also keeping it in place. The top part was glued to the handle using superglue, while the cap was secured by the tight fit with the handle.

After some testing, we came to the realization that the cap could not withstand drastic movements, breaking the connection with the laptop. This was a concerning issue, as it could certainly ruin the user experience during a future evaluation. Moreover, the slot dedicated to the microcontroller was slightly too large, leaving room for unwanted movement. Thus, we acknowledged the need for a new design that better secured the connection and the microcontroller.



(a) Cross-section View. (b) Isometric View.

Figure 4.4: Final Casing of the First Prototype (Digital).



(a) Top View. (b) Disassembled View. (c) Bottom View.

Figure 4.5: Final Casing of the First Prototype (Physical).

The revised design consisted of only the top part and the handle. Instead of placing the microcontroller in a slot at the bottom of the handle, we moved it further inside and created a tray-like compartment where it could be placed securely, leaving plenty of room for the cable. The cap was removed, and instead, the two handle parts were secured by screws. Figures 4.4 and 4.5 show the two mirrored halves that comprise the handle when put together. Further, the handle was no longer glued to the top, but rather, kept in place by the tight fit after being inserted into the top part. This was a necessary change to maintain access to the microcontroller. Moreover, this iteration featured a bead-like texture on the top part, reminiscent of the real instrument.

4.4.3 Connection

The connection mentioned in the previous section refers to the one established with a laptop. The laptop was a MacBook Air 2020 (M1) running MacOS Sonoma 14.0 and equipped with 8GB of RAM. The connection cable was a 3-meter-long black cable (USB-A to USB Micro-B) with a speed of 480 Mbit/s.

4.5 Software

4.5.1 Collecting Data

Two pieces of code were used for the collection of data: one Arduino Sketch in C++ and one Python script. The Arduino Sketch was uploaded to the microcontroller, while the Python script ran on the laptop. To put it simply, whenever the Arduino received a Serial message, it would send back data from the IMU sensor (accelerometer and gyroscope data) for 10 seconds. When the Python script received the data on the other end, it would store it locally into a CSV file. Each sample recorded was 10 seconds long and was stored in one CSV file.

The 10 movements we decided to collect data for can be found in Table 4.3. These movements were selected from Table 3.5 based on their suitability for the cabasa prototype.

When building our dataset, we followed the recommendations of [56]. The Arduino collected samples of 10 seconds at a frequency of 62.5Hz. We also made sure to perform varied movements while collecting the data. For example, the movements were performed both fast and slow, or the prototype was held in both the right and left hand.

4.5.2 Building a Motion Recognition Model

Once all the data was collected, we uploaded it to Edge Impulse, a development platform for machine learning on edge devices. In order to create our motion classification model, we followed their tutorial on *Continuous Motion Recognition* [56]. A total of 50 minutes of data was uploaded, 5 minutes for each class. With the training set in place (80% of the data), we could design an impulse. An impulse takes the raw data, chops it into smaller windows, uses signal processing blocks to extract features, and then uses a learning block to classify new data. In our case, the data was chopped into windows of size 2000 ms, with a window increase of 80 ms, at a frequency of 62.5 Hz, and no zero-padding data. The spectral analysis block was configured automatically using the autotune parameters function. Our neural network had 30 training cycles, a learning rate

Movement	Definition
Idle	Holding the device while not engaged in any active movement.
Shake	Moving the device rapidly back-and-forth or side-to-side.
Twist	Turning or rotating the device clockwise or counterclockwise.
Hit	Striking downward forcefully while holding the device in the hand.
Slap	Slapping the textured side of the top part of the device with the palm.
Tap	Tapping the flat side of the top part of the device with the palm.
Swipe	Swiping across the flat side of the top part of the device with the palm.
Punch	Punching in any direction while holding the device in the hand.
Swing	Moving the device like a pendulum while holding it in the hand.
Circle	Tracing a circle while holding the device in the hand.

Table 4.2: Recognized Movements and Their Definitions.

of 0.0005, and the default architecture (Input layer, Dense Layer with 20 neurons, Dense Layer with 10 neurons, and Output layer with 10 classes). After training, our model had an accuracy of 98.3% and a loss of 0.09. The model testing results led to an accuracy of 96.78% (see Figure 4.6). Finally, we deployed our model as an Arduino library with examples. We also optimized it to increase on-device performance for a slight bump in accuracy. With the EON compiler enabled, our final model had an accuracy of 95.89%, with a latency of 312 ms and RAM usage of 25.1K.

	CIRCL	HIT	IDLE	PUNC	SHAK	SLAP	SWIN	SWIPI	TAP	TWIS	UNCE
CIRCLE	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HIT	0%	96.0%	0%	0%	2.8%	0%	0%	0%	0%	0%	1.2%
IDLE	0%	0%	90.6%	0%	0%	0%	0%	0.2%	6.1%	0%	3.1%
PUNCH	0%	0%	0.5%	99.3%	0%	0%	0%	0%	0%	0%	0.2%
SHAKE	0%	0%	0%	0%	98.2%	0%	0%	0.8%	0%	0.2%	0.8%
SLAP	0%	0%	0%	0%	0.2%	97.7%	0%	0%	0%	0%	2.1%
SWING	0.5%	0%	1.7%	0%	0%	0%	97.0%	0%	0%	0%	0.8%
SWIPE	0%	0%	0.2%	0%	0%	0%	0%	99.5%	0.3%	0%	0%
TAP	0%	0%	1.7%	0%	0%	0%	0%	0%	97.2%	0%	1.2%
TWIST	0%	0%	4.8%	0%	0%	2.0%	0%	0%	0%	92.2%	1.0%
F1 SCOR	1.00	0.98	0.91	1.00	0.98	0.98	0.98	0.99	0.95	0.96	

Figure 4.6: Confusion Matrix for the First Model.

4.5.3 Designing Sound Loops

In order to hear something after performing a movement, we also need some loops to play. To create the sound loops, we used Ableton Live 11 Lite. Live is a *digital audio workstation* (DAW) widely used for music production, live performance, and DJing. We used the digital instruments and sounds included with it to create eight loops: a *kick* loop, a *hi-hat* loop, a *cowbell* loop, a *shaker* loop, a *clap* loop, a *scratch* loop, a *bass* loop, and a *lead* loop. The loops were created at a tempo of 100 BPM, ensuring they are rhythmically synchronized.

4.5.4 Controlling Music

Once the Arduino sends the movement prediction along with the IMU data, the Python script receives it, processes it, and sends commands to REAPER. REAPER is similar to Ableton Live but is more customizable, more resource-efficient, and, most importantly, free. With the reapy library installed, it is easy to control and automate REAPER using Python scripts.

Table 4.3 displays all the movement predictions the Python script could receive and what it does afterward. The IMU data received is used for calculating the positioning of the device, while the tempo decreases automatically after a set amount of time. The mappings were done by the researchers; some were common sense (e.g., linking a hit to a kick or a slap to a clap), while others were created as a basis for the future evaluation.

Movement	**Consequence**
Hit	Unmute the kick track.
Tap	Unmute the hi-hat track.
Shake	Unmute the cowbell track.
Twist	Unmute the shake track.
Slap	Unmute the clap track.
Punch	Unmute the scratch track.
Swipe	Unmute the bass track.
Swing	Unmute the lead track.
Circle	Increase the tempo by 10 until 200 BPM.
Idle	Mute all tracks when idle for 10 seconds, stop the project, and reset tempo to 100 BPM.
Device held up	Apply high-pass filter to the track mapped to the current movement.
Device held down	Apply low-pass filter to the track mapped to the current movement.
Device held in the middle	Apply no effect to the track mapped to the current movement.

Table 4.3: Recognized Movements and Their Consequences.

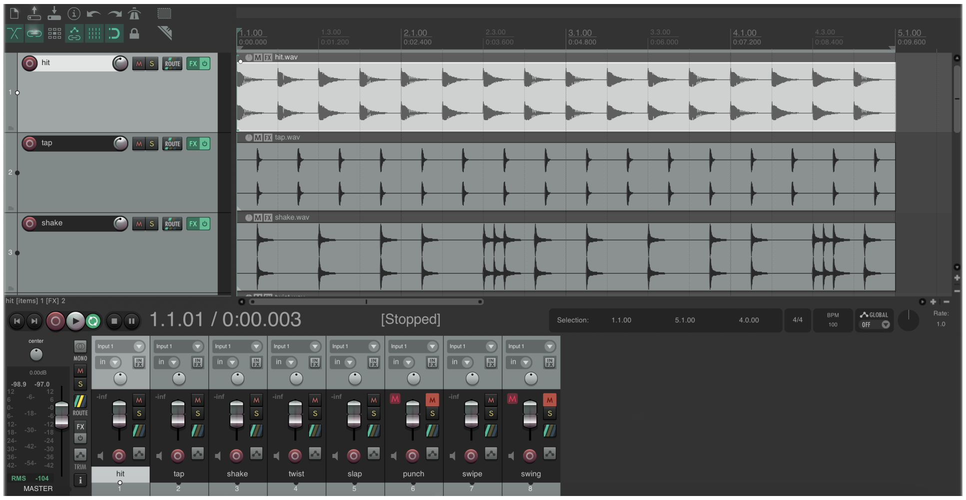
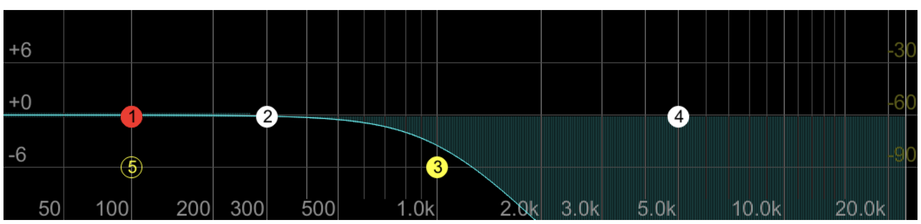
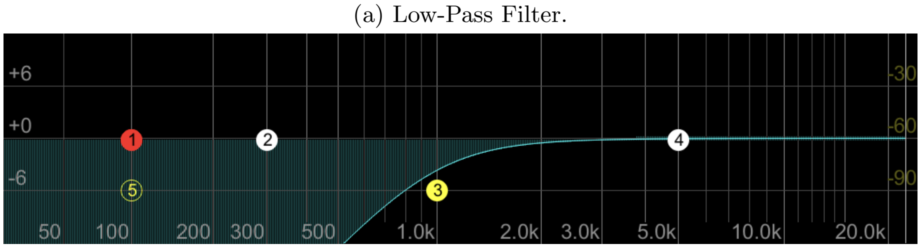


Figure 4.7: Screenshot of the First REAPER Project.



(a) Low-Pass Filter.



(b) High-Pass Filter.

Figure 4.8: Screenshots of Low-Pass and High-Pass Filters Applied in REAPER

Chapter 5

First Evaluation Session

Our first evaluation session also took place on the University of Twente campus and lasted approximately three hours. A spacious room accommodated three participants, all of whom were students with a technical background; two of which had also been present at the previous design session. This evaluation session was dived into five parts of different durations: *First Impressions*, *Movement Detection*, *Volume and Tempo Adjustment*, *Sounds and Sound Effects*, and *Free Play*. Before the start of the session, participants were given information brochures and consent forms to sign (see Appendix B.1). During the session, participants were recorded by one overview camera. For the full structure of the evaluation session and questions asked, refer to Appendix B.2.

5.1 First Impressions

During the *First Impressions* round, participants were introduced to the prototype for the first time and asked to express their opinions on its appearance and feel.

Regarding the appearance, one of the participants was reminded of a maraca, but also of a whack-a-mole game. The shake and hit motions came naturally to them. The participants appreciated the color choice, as it made a clear distinction between the handle and the top part. In their opinion, the colors were calming, yet the red color grabbed their attention, making it clear where to hold it. The bead-like texture was also well-received, but its color could match the handle. When asked about the colors they preferred, they said the current look was traditional and that dark brown would better suit the handle for a wood aesthetic; they also mentioned that they could see the prototype being personalized and wouldn't be surprised to see it copying the aesthetics of a PC or laptop, given the cable attached to it.

Regarding the feel, the participants would have liked the handle to be sturdier with a curved and thicker bottom for a better grip. Participants did not like the idea of cushions or dents in the handle to accommodate fingers since it would force them to control the device in a specific way. The weight balance was good, but the top part could be slightly smaller. However, because the top part was too big to grab with only one hand and was also heavier, it forced them to use the handle. The cable also felt in the way, suggesting that a wireless version of the prototype would be desirable.

5.2 Movement Detection

Let us proceed to the *Movement Detection* section. Participants were instructed to recreate all movements that the prototype was able to detect in order to assess its performance in a real-life scenario. For each movement, participants replicated it for several minutes before passing the prototype on to the next participant

Most movements were correctly recognized as long as they did not deviate from the training set samples. However, the *shake* and *circle* movements were occasionally confused due to their similarity. Likewise, the *hit* and *punch* movements, as well as *tap*, *swipe*, and *idle*, were occasionally mistaken for one another. In contrast, *swing* and *twist* were consistently recognized, probably due to their uniqueness. The *slap* movement was rarely recognized correctly.

Following this, participants were requested to rate the movements performed. The *shake* and *hit* movements received the most positive feedback. On the contrary, the *punch* movement was poorly received, mainly because it felt unnatural. Participants were neutral regarding the other six movements. When asked to suggest any additional movements they could perform with the prototype, participants only mentioned the *roll* motion while interacting with a flat surface.

5.3 Volume and Tempo Adjustment

To test the volume and tempo adjustments, participants were allowed to play freely with their two favorite movements (*hit* and *shake*) and the *circle* movement.

The increase and decrease in tempo were noticeable. However, the participants did not like the fact that the change in tempo was not smooth and that the tempo would decrease automatically over time. The volume adjustment was also clearly noticeable, but the participants found that the prototype would wait too long before becoming quiet when put down.

Participants offered valuable feedback to enhance the overall experience. They argued that they want to be more in control, but the music should always sound good regardless of their actions. They also emphasized the importance of a guide which would make things clear from the start and how the prototype should be more reactive to their movements without a noticeable delay. The addition of some new control movements would improve the experience, such as an *undo* movement (for removing the last sound layer added), a new movement for decreasing the tempo (preferable the *circle* movement but in reverse), and possibly a movement for locking in a new sound that was played.

5.4 Sounds and Sound Effects

Concerning the sound effects, such as the low-pass filter and the high-pass filter, participants noticed a difference in sound but were unsure of the reason behind it. While some enjoyed having the sound effects as they invited them to move, others felt they could be rather complex at the start and expressed using them at a later stage when familiar with the system. Speaking of additional sound effects, participants suggested an *echo* effect could be mapped to the *swing* movement. They also emphasized their preference for more responsive sound effects that allow them to instantly perceive the changes.

Regarding the sounds that were played, participants generally appreciated them, the mappings, and the fact that one movement triggers only one sound. However, they suggested that the *lead* could be a bit slower, the *bass* could be removed, the sound from the *punch* movement could be mapped to perhaps the *swipe* motion, and the sounds from the *twist* and *shake* movements could resemble those of a cabasa. Additionally, the frequency of the movements performed should also have an impact on the audible outcome.

Figure 5.1: Participants Surprised During Free Play During the First Evaluation Session.

5.5 Free Play

During the last part of the session, participants were given the opportunity to explore the prototype freely.

Participants seemed to enjoy the movements and changing the tempo of the song. However, the general perception of this experience was more about accumulating all sounds rather than creating music; once all sounds were playing, the only options left were changing the tempo or starting again.

In terms of the prototype's sound capabilities, playing all the sounds simultaneously could become overwhelming. When asked whether they would like the prototype to produce the music, participants agreed that an external source such as a laptop or a connected set of speakers, would make more sense. A new sound suggestion they had was something similar to a *splash cymbal*.

Regarding the appearance and feel of the prototype, participants expressed appreciation for the colors and textures. They also reversed their earlier stance on the cable, mentioning that it did not significantly disrupt their flow. However, the prototype felt somewhat heavy when in motion, probably due to its top part.

Functionality-wise, participants highlighted the need for an *undo* feature to remove the last sound layer added, as well as the ability to increase and decrease the tempo. They desired feedback for all their movements and clarity regarding the sounds they produced. Participants also suggested that repeating the same movement could trigger a different sound rhythm and that certain movements should trigger transient sounds, such as a clap, while others should create enduring sounds that fade out over time. Moreover, participants envisioned, when picking up the prototype, the possibility of having one sound, like the lead, serve as a foundational base upon which additional sounds could be layered. The idea of incorporating a single movement or button to add a sound to the song was reiterated.

5.6 Lessons Learned from the First Evaluation Session

Based on the insights gathered, we formulate the following list of requirements for the second iteration of the prototype (see Table **??**). This list of requirements represent the base for the second iteration of the prototype, aiming to enhance its appearance, functionality, and user experience.

Table 5.1: Design and Functionality Specifications for the Second Prototype.

Category	**Details**
Overarching Design Goals	• The prototype should strike a balance between control and musical creativity. • The prototype should be responsive to users' actions. • The prototype should be intuitive and user-friendly. • The prototype should offer a high level of customizability. • The prototype should provide an immersive and enjoyable musical experience.
User Documentation	• The prototype should come with a short manual.
Appearance and Feel	• The color of the bead texture should be prominent to ensure it stands out. • The handle should be strengthened with a curved and thicker bottom for a better grip. • The size of the top part should be slightly reduced.

Continue on the next page.

Table 5.1: Design and Functionality Specifications for the Second Prototype (Continued).

Category	Details
Motion Detection	• A decreasing tempo movement should be implemented. • An undo movement should be implemented to remove the last sound layer added. • The punch movement should be removed. • The prototype should have a movement or button for locking in a newly played sound. • The motion detection should be more accurate and faster.
Sound and Sound Effects	• The tempo changes should be smooth. • The volume should adjust faster when the prototype is set down. • Sound effect changes should be perceived instantly. • The lead sound loop should be slower. • The bass sound loop should be removed. • The sounds from the twist and shake movements should resemble a cabasa. • The prototype should incorporate more similar sounds.
User Experience	• The prototype should have the lead sound, or a similar one, serve as a base for layering additional sounds when picking up the device. • The prototype should differentiate between transient sounds, such as a clap, and enduring sounds that fade out over time. • The prototype should provide clear feedback indicating that a movement has been received. • The prototype should trigger different sounds when the same movement is repeated. • The prototype should play the triggered sounds instantly.

Chapter 6

Second Prototype

The second prototype was developed with the goal of fulfilling as many of the previously outlined requirements as possible.

6.1 Hardware

The new casing design improves on the previous one, the main changes concerning the handle of the device and the color palette.

The handle was updated with a curved and thicker bottom for a better grip, while the size of the top part was slightly reduced. The two halves that make up the handle now leave the cable only the necessary space and nothing more. Next to that, two small cubes secure the lower part of the handle, while the upper part is now glued to the top part of the device. We moved away from the previous system, as applying too much force led to the movement of the top part. Even though it is glued, the new locking system at the bottom of the prototype allows easy access to the microcontroller.

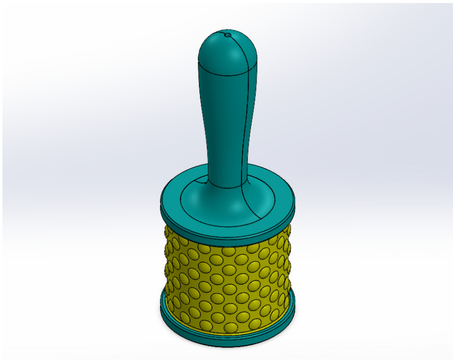
We also updated the colors of the device and made the bead-like texture more prominent. The colors, yellow and green, are analogous colors and work well together. They also have specific meanings: yellow signifies optimism and creativity, while green - harmony and peace [57].

6.2 Software

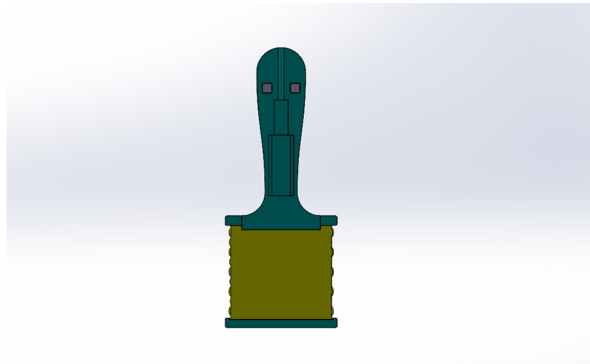
The list of requirements necessitates changes across all aspects of the software.

6.2.1 Collecting New Data

This time, we collected more motion data and strived for more variation by including movements similar to those performed by the users during the evaluation session. Our list of movements was



(a) Isometric View.



(b) Cross-section View.

Figure 6.1: Casing of the Second Prototype (Digital).

Figure 6.2: Casing of the Second Prototype (Physical).

also updated: we removed the *punch* movement since it was unnatural, and the *swipe* movement since it was very similar to the *tap* movement. Finally, we ended up with a total of 1 hour, 6 minutes, and 40 seconds of motion data, consisting of 50 samples of 10 seconds for each class.

6.2.2 Building a New Motion Recognition Model

When chopping the data, the window size was 800 ms instead of 2000 ms. After training, our model had an accuracy of 95.4% and a loss of 0.21. Testing the new model led to an accuracy of 91.75% (see Figure 6.3). In the deployment phase, after optimization, our final model had an accuracy of 91.79% with a latency of 143 ms and RAM usage of 12.3K. While the accuracy decreased by 4%, the latency and RAM usage improved by approximately 50% each.

	CIRCLE	HIT	IDLE	SHAKE	SLAP	SWING	TAP	TWIST	UNCER
CIRCLE	94.7%	0.1%	0%	0%	0%	1.1%	0%	0%	4.1%
HIT	4.8%	90.9%	0.1%	0.6%	0.1%	0.8%	0.2%	0%	2.5%
IDLE	0%	0%	92.9%	0%	0.3%	0.2%	2.9%	0%	3.6%
SHAKE	0%	0.2%	0%	98.3%	0%	0%	0.3%	0.1%	1.1%
SLAP	1.3%	0.5%	1.4%	0.3%	80.2%	0.4%	4.2%	0.2%	11.6%
SWING	0.7%	7.1%	0%	0.2%	1.0%	79.7%	0%	0.1%	11.2%
TAP	0%	0%	0%	0%	0%	0%	100%	0%	0%
TWIST	0.2%	0%	0%	0.4%	1.1%	0%	0%	97.2%	1.1%
F1 SCO	0.94	0.92	0.96	0.98	0.88	0.88	0.96	0.98	

Figure 6.3: Confusion matrix for the second model.

6.2.3 Designing New Sound Loops

Now, we have five layers of sound: *kick*, *hi-hat*, *shake*, *clap*, and *lead*. For each of these layers, we designed five loops, as our users preferred to have more similar sounds to choose from. We also made sure that the *lead* loops are slower, that the *shake* sound resembles that of a cabasa, and that there is no *bass* sound any longer. The loops were designed in a similar fashion as before at BPM 100, making sure that they would fit together nicely in any combination. If categorized, most loops are reminiscent of current pop or trap music.

6.2.4 (Re)Controlling Music

REAPER features 27 new tracks controlled by the Python Script: 25 sound loops and 2 feedback sounds (see Figure 6.4). The mappings were also updated according to the list of requirements; the full list of movements and their consequences can be found in Table 6.1.

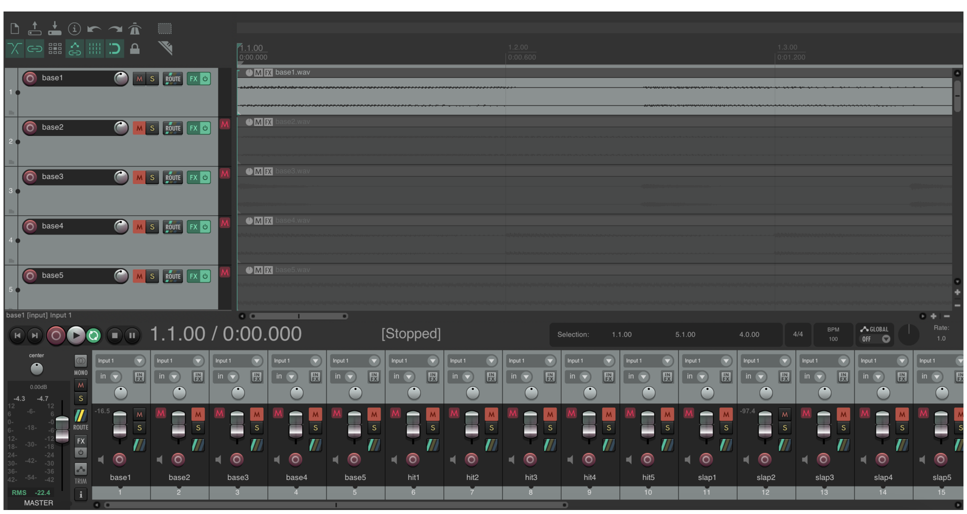


Figure 6.4: Screenshot of the second REAPER project.

Movement	Consequence
Hit/Tap/Shake/Slap	Unmute the kick/tap/shake/slap track for the current kick/tap/shake/slap index for 2.4 times the ratio of the current BPM to the initial BPM seconds (transient). If done continuously for 3 seconds, unmute the track for 9.6 times the ratio of the current BPM to the initial BPM seconds seconds (enduring). If done continuously for 3 seconds when enduring, mute this track, increase the index, and unmute the kick/tap/shake/slap track 'for the current kick/tap/shake/slap index for 9.6 times the ratio of the current BPM to the initial BPM seconds seconds (enduring).
Swing	Mute the last track that was unmuted.
Circle	Increase the tempo by 25 until 200 BPM.
Twist	Decrease the tempo by 25 until 50 BPM.
Idle	Mute all tracks when idle approximately 5 seconds, stop the project, and reset tempo to 100 BPM.
Pick Up	Unmute track lead no. current lead index.
Device held up	Apply high-pass filter to the track mapped to the current movement.
Device held down	Apply low-pass filter to the track mapped to the current movement.
Device held in the middle	Apply no effect to the track mapped to the current movement.

Table 6.1: Table listing the movements data was collected for along with their definitions.

The movement to decrease the tempo was implemented and linked to the *twist* movement, as the *circle right and left* movements could not be differentiated by the classification model. The *twist* movement is used for lowering the tempo since it is a quiet movement; the *circle* is more energetic, thus used for increasing it. An *undo* movement was also implemented and linked to the *swing* movement. Instead of incorporating a separate movement or button for locking in a newly played sound, we believed that repeating the movement for 3 seconds could achieve that.

When picking up the prototype, a lead sound loop starts playing, serving as a base for layering additional sounds. When put down, the volume diminishes within 5 seconds. Each time you pick it up, a different loop plays, inviting to create something new. One sound motion (*hit*, *tap*, *shake*, or *slap*) activates a transient sound, while repeating the motion triggers an enduring sound that gradually fades away. If you repeat the same motions for about 3 seconds while the enduring sound is playing, you replace it with a different loop from the same category.

To provide clear feedback, we added *confirmed* and *impossible* sounds that indicate whether a change has been made successfully (e.g., adjusting the tempo, undoing, or activating/replacing a sound loop) or a change cannot be executed (e.g., the tempo cannot go lower/higher or there are no sound layers to remove). This also has a positive impact on the tempo changes, which are not as abrupt as before.

Having only four movements for sounds (excluding the *lead*) should not be a problem, since playing eight sound loops simultaneously was previously regarded as exhausting. Thus, having a maximum of five sound layers at the same time should be sufficient. For similar reasons, we decided not to implement the *echo* effect given that users found sound effects to be complex and preferred to focus more on the sounds themselves.

6.2.5 User Documentation

A short one-page manual introduced the user to the world of the prototype. The instruction manual presented the user with all the possible movements they could perform, alongside a description and the consequence.

6.3 Conclusion

On an end note, with this second prototype, we aimed to achieve a balance between control and musical creativity, introducing new functionalities like *undo* and tempo adjustment. We tried to make the prototype more responsive to users' actions by reducing the latency. We offered a *lead* loop that starts playing when the prototype is picked up. Moreover, we differentiated between transient sounds and enduring sounds and offered a high level of customizability with more loops to choose from. Finally, we made this iteration more intuitive and user-friendly by adding feedback sounds and offering an user manual.

Chapter 7

Second Evaluation Session

Our second evaluation session was organized similarly to the first one and was conducted with four participants who had also been present at the previous sessions. This evaluation session was dived into six parts of different durations: *First Impressions*, *Movement Detection*, *Volume and Tempo Adjustment*, *Loop Activation, Replacement, and Removal*, *Sounds and Sound Effects*, and *Free Play*. Before the start of the session, participants were given information brochures and consent forms to sign (see Appendix C.1). During the session, participants were recorded by one overview camera. For the full structure of the evaluation session and questions asked, refer to Appendix C.2.

7.1 First Impressions

During the *First Impressions* round, participants were introduced to the new iteration of the prototype and asked to express their opinions on its appearance and feel.

Regarding its appearance, some said it reminded them of a children's toy (because of the material used and the bright colors), an ice cream (because of the color palette), and, surprisingly, the cabasa itself. Some participants wowed when seeing the colors, while others weren't big fans of the combo, suggesting the prototype should come in white, neutral tones, bright colors, dark colors, or patterns; the color choice was clearly a matter of personal preference. The bead-like texture on the top part was considered a good addition but could be improved by changing its material (e.g., something similar to a pop-it toy) or functionality (e.g., make it rotate). All participants automatically grabbed the prototype by the handle, and it was clear how it was meant to be held.

Regarding the feel, the participants touched it, rubbed it, shook it, twisted it, and knocked on it immediately. Some participants mentioned it reminded them of a wooden instrument, even though they knew it was 3D printed, which they would prefer over plastic. While the fact that it did not rattle or that more weight could have been added to it (maybe have grains in the top part) was noted, all participants agreed that the new prototype felt good in their hands, was easy to grab, and had a good size.

7.2 Movement Detection

As long as the movements were done as instructed, the detection worked well. While some participants performed the movements with no issues and found them pleasant and intuitive, others did not appreciate movements like *slap* and *twist*. These participants preferred performing certain movements in their own way (e.g., the *slap* movement) or tried to test the limits of the model (e.g., shaking while drawing a circle). Because of this, it is rather complicated to calculate any valid accuracies. One participant suggested a calibration phase when starting to use the prototype to teach the device how each individual performs their movements and have their own movement profile created.

On a side note, there was a bit of a struggle with the cable, especially when making bigger movements. Additionally, one participant complained that the edges might be too sharp or the material too hard, making the slapping motion slightly painful when performed for a longer period of time.

7.3 Volume and Tempo Adjustment

Regarding the volume, the base loops that start playing when picking up the device and the fact that there is a new one when you put it down and pick it up again were well received. The interval of time you have to wait after putting down the device for it to go quiet was also satisfactory.

Regarding the tempo, one participant mentioned a preference for a progressive increase rather than an incremental one, as they wouldn't like to wait for a confirmation. The two movements linked to it could also be switched up: a big movement for slowing down, and a small movement for speeding up.

Additionally, the feedback sounds could disrupt the musical flow, which is not ideal. One participant expressed that the sounds should only be for the musical composition, and maybe the feedback could be given through vibrations or lights. The *failed* feedback sound also felt somewhat aggressive to some, and at the beginning, it did not make it clear what went wrong. The fact that the loop always started from the beginning after the feedback sound instead of just continuing was also noticed and disliked by some. We also noticed that one wrong classification could ruin the flow, as participants needed to keep repeating the movements for more than three seconds.

7.4 Loop Activation, Replacement, and Removal

Overall, the activation, replacement, and removal features worked correctly. However, the loops were on for too short a duration, making the swing movement useless; by the time you would use it, the activated loop would expire. Two participants who tested the first prototype recognized that they had more control over the second one and found the system much more responsive. On the contrary, one participant said that while the prototype reacted to them, they did not control it like they would an actual instrument. Finally, the idea of replacing the feedback with vibrations was reiterated, as it would better fit with movement.

7.5 Sounds and Sound Effects

The sound effects (low-pass filter and high-pass filter) were not noticeable at all until participants were asked about them. This might have been due to the delay and the number of sounds already playing. However, the idea was embraced by the participants, who thought it was a nice addition once they learned how to use the device. A more complex effect, like an echo effect, would have been very confusing. Despite not making a huge difference, participants liked the subtle change in sound and regarded the feature as a long-term improvement. Additionally, a muffled sound effect could be added when pointing forwards or backwards.

Figure 7.1: Participants Surprised during Free Play during the Second Evaluation Session.

7.6 Free Play

For the last part of the session, participants were allowed to play freely.

Regarding the physical design, although the prototype had a good design and was comfortable in the hand, a silicone sleeve could be added for a better grip. This sleeve could come in different colors, making the device feel more personal. The bead-like texture was regarded as pleasant, but it did not add much to the interaction for some, while for others it made it clear that it was the instrument cabasa. The device could also go wireless or use a 360-degree rotating wire so the cable does not get tangled anymore and interrupt the experience.

Talking about the sounds, participants liked the loops but wanted many more in a real-life scenario. The mapping between sounds and movements performed (*slap*, *clap*, *hit*, and *tap*) made sense and was satisfactory. Experimenting with the different loops was entertaining, but participants wished that the activated loops would stay on longer before expiring.

Discussing additional changes, someone suggested that the middle part could rotate and act as the loop changer or that sleeves of different colors and textures could be added for new interactions.

The feedback sounds could be removed and replaced with vibrations in the handle. A multiplayer function could also be implemented, allowing people to work on the same song together.

Overall, the device was pretty intuitive after a few minutes of use and was much more interactive and purposeful compared to the previous iteration. Participants had an enjoyable experience with the prototype, even when just watching others use it.

7.7 Lessons Learned from the Second Evaluation Session

Based on the insights gathered, we formulated the following list of requirements for a third iteration of the prototype (see Table 7.1). The overachiving design goals stay the same as before.

Table 7.1: List of Requirements for the Third Prototype.

Category	**Details**
Overarching Design Goals	• The prototype should strike a balance between control and musical creativity. • The prototype should be responsive to users' actions. • The prototype should be intuitive and user-friendly. • The prototype should offer a high level of customizability. • The prototype should provide an immersive and enjoyable musical experience.
User Documentation	• The manual should make use of illustrations. • The manual should come with a video tutorial.
Appearance and Feel	• The prototype should come with a silicone sleeve for better grip and personalization. • The prototype should have more rounded edges to prevent discomfort during prolonged use. • The prototype should be wireless or use a 360-degree rotating wire to prevent tangling. • The prototype could come in different colors and patterns. • The prototype could come in cases of different materials (e.g., wood). • The prototype could have different texture sleeves for the bead texture (such as a pop-it texture).

Continue on the next page.

Table 7.1: List of Requirements for the Third Prototype (Continued).

Category	Details
Motion Detection	• The prototype should include a calibration phase to teach the device the unique movement profile of a user. • The mappings should be personalized.
Sound and Sound Effects	• The disruptive feedback sounds should be removed. • The sound effects should be more noticeable. • A progressive tempo adjustment could be implemented to avoid delays. • A new sound effect (e.g., echo or reverb) could be added for the front and back.
User Experience	• The prototype should provide feedback through vibrations. • The prototype should ensure loops are activated, replaced, and removed smoothly without expiring too quickly. • The prototype could have a multiplayer functionality for collaborative music creation. • The prototype could have new features depending on the sleeve attached to the top part. • The top part could feature a rotating mechanism for replacing the active loops.

Chapter 8

Final Discussion

After one design session, two prototypes, and two evaluation sessions, there are several aspects to discuss.

8.1 Reflections

8.1.1 Hardware and Software

When deciding what pieces of hardware or software to integrate into your project, there are several aspects to consider. Quality, features, documentation, and costs are some of them. The challenge lies in prioritizing these aspects and striking a balance. Not all decisions are right or wrong, but they need to be motivated.

Working with the Arduino Nano RP2040 Connect was straightforward. We did not have the chance to explore its Bluetooth or Wi-Fi features, as we focused on the wired version of the prototype, but this piece of technology was well-documented and supported. Even though it was on the expensive side, the benefits of having various sensors *embedded* (IMU, microphone, temperature sensor, etc.) made it a *no-brainer*.

Good software should come with a community of like-minded people and a considerable amount of online resources. It should allow for quick and easy integration with other tools, benefiting the users rather than exploiting them. For example, take REAPER, a DAW that offers projects with an unlimited number of tracks and beautiful Python integration. Or Edge Impulse that has a well-documented website tool that simplifies the process of building and evaluating a motion detection model.

8.1.2 Sounds

Sounds are the most distinctive elements of an instrument. When you play one, you know exactly what to expect. That should also be the case for musical interfaces. Easier in theory than in practice. Our last prototype did not work real-time and always suffered a delay of at least one second. Not only did this affect the sounds played but also the sound effects, ultimately hindering the user experience.

In the context of music interventions like music therapy, the input from a music therapist is vital to ensure the therapeutic outcomes. However, the sound loops used were not created by a professional but a music enthusiast. This was not a problem per se given that the main goal of the current study was *developing* a prototype for musical expression rather than treating people.

8.1.3 Motion Detection

When dealing with motion-based projects, the gathered data needs to be varied, unlike the present case. Even though the prototype was held in both hands at different orientations, with movements replicating those seen during the sessions, the fact that data only came from only one person impacted the generalizability of the model.

An ideal version of a musical interface would respond to user input in real-time, and do so accurately. Here, the model was unable to always detect movements fast enough and react accordingly. One movement classified wrongly had a high risk of obstructing the expressive flow of the users, especially when repeating the movements multiple times was needed.

8.1.4 MeCaMInD Cards

Having a tool for when planning and executing a design session is more than welcome.

While planning, we used the *MeCaMInD* cards to check all possibilities and find the best fit for us. We made use of *Mood-Setter* cards, *Movement Method* cards, and *Modifier* cards. One can make an educated decision based on the information provided on them and learn how to employ them by watching the associated tutorial videos.

During the session, we appreciated having the cards at our fingertips. They served not only as a reminder but also as a checklist. We recommend having some backup cards in case the main ones do not work as expected (e.g., another warm-up exercise or movement method). Moreover, while *Modifier* cards have their benefits, they do not always work in practice. *Modifiers* were a great addition during warm-up exercises but did not add any value and were at times confusing during the main movement methods.

8.1.5 Movement-based Design Methods

Choosing the right movement-based design methods provides a structured way to engage with such a project. In our case, both the mood-setting exercises and main movement methods were easy to understand and employ, making them accessible even for novices. The mood-setting exercises helped prepare participants for each phase during the session, energizing them and setting a positive tone, while the movement methods allowed for a more in-depth exploration of our ideas.

There were naturally some challenges to overcome. Methods like *Embodied Sketching* required more time than planned and even though they fostered creativity, they lacked clear outcomes.

We recommend a good time management for maintaining a natural flow and the focus of the participants. Further, better results could be achieved by explicitly linking movements to the overarching goals of the project.

8.1.6 Facilitator Roles

Looking back on the design session, the researcher took on three facilitator roles. In the first phase, the roles of *Instructor and Games Master* and *Coach and Mediator* were performed, while in the second phase, the *Initiator and Animator* role was clear. Our recommendation is to have more people taking on the different facilitator roles given that performing more than one role can become overwhelming and impact the overall session negatively.

8.1.7 Virtuosity

Our main target groups include individuals without formal music training and healthcare professionals like music therapists. The music interface prototype we developed would serve as an excellent tool for music therapy sessions where patients can improvise music individually or in groups. The prototype could also be used for rehabilitation, as a way of encouraging movement. Furthermore, the target groups could be extended to include children and educators, and why not, the general public. Teachers could make use of the prototype to introduce children to music in a fun way and opening the door for music education, while the general public could regard using it as a hobby or group activity.

The prototype may be less suited for musicians and music production due to its simplicity. This is not to be considered a drawback as the device was designed for ease of use rather than skill. When compared to other musical interfaces like the *Mi.Mu Gloves* (see Section 2.3.2.4), ours offers a considerably lower level of complexity and control, which resonates better with our target groups.

8.2 Addressing RQ 1 and RQ 2

RQ 1: What are the most important aspects to consider when developing a musical interface prototype?

Our first research question can be answered with the help of the overarching design goals.

First, when developing a musical interface, a balance needs to be struck between control and musical creativity. Users should feel in control, yet be assured that their actions will not negatively impact the musical composition.

Second, the prototype must be responsive to users' actions. This highlights the importance of providing appropriate feedback. When it comes to music, timing is crucial, so user input must be matched with almost no latency to avoid hindering the flow of expression.

Third, the design needs to be intuitive and user-friendly. Learning how to use the prototype should be relatively straightforward no matter one's skills. Providing a set of clear instructions or examples can offer additional support.

Fourth, a high level of customizability is required. A good design allows users to edit settings, controls, or sounds according to their preferences. This can extend to visual aesthetics like colors, textures, materials, etc.

Finally, the musical interface should provide an immersive and enjoyable musical experience. The prototype should be inviting and the process of creating a musical composition should feel rewarding. To keep the level of engagement high, incorporating elements like sound effects is recommended.

Addressing these aspects when developing an expressive musical interface prototype can provide valuable insights and guide the development process.

RQ 2: How usable is the musical interface prototype, according to user feedback from evaluation sessions?

To answer our second research question, we will use the insights gathered during the second evaluation session. Although there were many aspects to improve upon and several suggestions for new additions, the prototype was overall well-received, showing potential for usability. The physical design was praised, especially the size of the device and the feel of the handle. Users quickly learned the movements, as most of them were intuitive. The mappings to the sounds made sense and experimenting with different loops was entertaining, participants enjoying both playing freely and simply watching others.

8.3 Future work

8.3.1 Third Version of the Prototype

The plan for a future version of the prototype can be outlined using our last requirement list (see Table 7.1).

Regarding the appearance and feel, a silicone sleeve could be designed for the handle, while the edges of the end caps could be rounded more. Since a wireless version would probably lead to higher latencies, a 360-degree rotating wire could be considered in order to prevent tangling. Instead of a rotating mechanism, a sleeve for the bead-like texture could do.

To increase the level of personalization, the color of the prototypes (and sleeves) could be agreed upon with the participants before the evaluation session. Using a material like wood would not be feasible for such a prototype.

To improve motion detection, a calibration phase could be implemented before using the prototype. Although time-consuming, once done, the profile (model) could be stored for future use. This could be done alongside the mapping of the movements to the sound loops/controls.

To make the sound effects more noticeable, they could be applied to the entire musical composition. Implementing an *echo* or *reverb* effect when pointing forwards or backwards could be considered. However, a progressive tempo adjustment would likely not be integrated in a future version due to the current setup.

Once the disruptive feedback sounds are removed, they could be replaced with vibrations. Designing the vibration motor system could be challenging, as we do not know anything about the amount of vibration motors needed, the feel when inside the casing, or the preferred vibration pattern for receiving feedback.

A new design session could explore how the sleeves for the bead-like texture could look like and what new features they should include (e.g., representing a sound pack or a sound manipulation/filtering, similar to deformable interfaces [45]). The future design session could also consider the implications of a multiplayer function in the case of group improvisations.

8.3.2 Addressing RQ 3

RQ 3: How effective is the musical interface prototype at enabling users to express themselves, and can it lead to better well-being outcomes, according to user feedback from evaluation sessions?

The design and evaluation sessions carried out in this research served as an initial exploratory phase. Thus, given the latest state of the prototype, we could not answer the third research question. Moving forward, there should be at least one more iteration of the prototype and one more evaluation session before testing the prototype for its well-being potential.

To check whether the prototype enables users to express themselves and contributes to better well-being outcomes, these concepts need to be defined. The participant group also needs to be defined, while the potential ethical concerns need to be examined. An experimental study will need to be designed to measure these concepts using both qualitative and quantitative methods. The data gathered from the experimental group and the control group will be compared to determine whether there was a statistically significant difference when using the prototype as part of a music intervention. The results will then be interpreted, and the implications for the field of music interventions discussed.

Appendix A

Design Session Documents

A.1 Consent Form and Information Brochure

Designing a Musical Interface to Improve Well-being

Purpose of the Research
The thesis will comprise the design and evaluation of a musical interface prototype with the potential to improve well-being. Currently, we do not aim to engage in any medical-related activities. Instead, we are fully focused on the development of musical expression technology.

What Will Happen During the Session
The session is expected to take three hours. The workshop will be conducted in a controlled environment with two rooms: a workshop room and a break room. Cameras, speakers, post-its, pens, and various props will be present in the workshop room. Participants will be offered drinks and snacks during the break in the other room. The workshop for the designing of the prototype will be divided into three phases. The first phase will focus on the participants generating ideas and presenting them to each other. In the second phase, after a number of ideas are selected, the participants will delve into their expressive potential. In the last and third phase, participants will explore the possibility of imagining the expressive sounds that the musical interface would produce.

Benefits and Risks of Participating
Participating in this research offers the opportunity to contribute to the development of new technology. The main risk associated with the movement-based design session is the potential for participants to feel uncomfortable, awkward, or vulnerable. To mitigate these risks, we will choose appropriate warmup exercises, monitor the participants, and establish a "stop protocol." Please note that this research project has been reviewed and approved by the Ethics Committee for Information and Computer Science.

Withdrawal from the Study
Withdrawing from the study at any time is possible without providing a reason and will not affect the relationship with the researcher or the university.

Collection and Use of Personal Information
Observational notes and recordings will be taken with the researcher present. Cameras and note-taking tools such as iPads will be used. Two cameras, one overview camera and one action camera, will record the session. The faces, bodies, and voices of the participants will be visible and audible in the recordings. The topics of discussion will focus on the participants' experience, creative output, and workshop effectiveness. Video recordings are essential for later analysis. The researcher can revisit the footage to gain deeper insights into user interactions, preferences, etc. for the design of the musical interface.

Data Usage and Confidentiality
Data collected will be used for research purposes only. Personal information will be safeguarded, and access to data will be limited to the researchers.

Retention Period for Research Data
All gathered data will be retained until the end of the research (July 2024).

UNIVERSITY OF TWENTE.

Contact Information

Mihnea-Adrian Udrea
m.udrea@student.utwente.nl

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science:

ethicscommittee-CIS@utwente.nl

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 30/11/2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a video-recorded design session with a group of participants and that written notes will be taken. I understand that the audio or video recordings will be transcribed as text. I understand that the video recordings will be analysed to gain deeper insights into user interactions, preferences, etc.	☐	☐
Risks associated with participating in the study		
I understand that taking part in the study involves the risk of physical or mental discomfort.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for a Master's thesis.	☐	☐
I understand that personal information collected that can identify me, such as my name or where I live, will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs.	☐	☐
I agree to be audio/video recorded. I understand that two cameras, one overview camera and one action camera, will record me. I understand that my face, body, and voice will be visible and audible in the recordings.	☐	☐
I understand that all data collected will be stored on an encrypted hard drive and will only be accessed by the researcher.	☐	☐
I understand that all data collected will be deleted at the end of the research (July 2024).	☐	☐

Signatures

______________________	______________________	30.11.2023
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Mihnea-Adrian Udrea	______________________	30.11.2023
Researcher name	Signature	Date

A.2 Playbook

When	What	Where	How
9:00	Preparations	Workshop Room & Break Room	☐ Open the rooms ☐ Move the furniture to create space in the workshop room ☐ Set up video cameras and speakers in the workshop room ☐ Prepare the table with snacks in the break room ☐ Prepare the box with props, MeCaMInD cards, pens, and post-its in the workshop room
10:00	Phase 0	Workshop Room	☐ Short introduction ☐ Sign consent forms
10:10	Phase 1	Workshop Room	• **Purpose:** Generate and present ideas • **Goal:** 10 ideas ☐ **Mood Setter:** Action Syllables 1. Everyone is in a circle. 2. The first person says their name, making a gesture (an action) for every syllable. 3. Everyone repeats the first person's name with the same gestures. 4. Then, the second person in the circle calls their own name with a gesture per syllable. 5. The group repeats the second person's gestures and then repeats all previous names and syllables. 6. Continue until all participants have gestured their name. ☐ **Mood Setter Variation:** Add an adjective that alliterates with your name, e.g. "I'm Wonderful Wendy" ☐ **TURN ON CAMERAS** ☐ **Movement Method:** What Can I Do With This? 1. Choose a prop or artefact. 2. Explore ways of acting with the artefact and the context you are moving in. 3. Play with different artefacts and participants. 4. Disrupt and play with other people's behaviour of playfulness. 5. Get inspired by everything around you. ☐ **Movement Method Variation:** Constrain (No Hands, No Arms, No Legs, No Vision) • **Back-up Movement Method:** Bodystorming with Props ☐ Short debriefing [list the ideas, quickly comment, how it felt...] ☐ **TURN OFF CAMERAS**
11:00	Break	Break Room	☐ Munch ☐ Hydrate ☐ Chat
11:10	Phase 2	Workshop Room	• **Purpose:** Explore expressive potential ☐ **Mood Setter:** Stop Dance 1. Move freely to the music (with focus on being able to suddenly stop). 2. When the music is stopped, all participants freeze. Inspire participants to challenge themselves with movements that are hard to stop. 3. Participants combine movements in which they depend on each other. ☐ **Mood Setter Variation:** Use different modifiers to inform and enhance the creativity of the different stop-exercises (Dance, Fitness, Ball sports, Ice sports, Water sports) ☐ **TURN ON CAMERAS** ☐ **Movement Method:** Embodied Sketching, group approaqch 1. Based on a core movement with a prop, as identified in previous phase, the participants must create ideas for many different expressive musical movements. 2. Participants are encouraged to also do this by playfully osberving, demonstrating to each other, responding to each other, and trying many different styles. 3. Based on a "yes and" mindset, an idea is worked on by everyone (all can move) until the participants have suggestions for changing the idea. 4. Subsequently, a whole new idea comes up and is worked on. ☐ **Movement Method Variation:** Metaphor (Flow Like Water, Twist Like a Tornado, Move Like a Wave, Fly like a Bird) ☐ Short debriefing
12:00	Break	Break Room	☐ Munch ☐ Hydrate ☐ Chat
12:10	Phase 3	Workshop Room	• Purpose: Imagine musical interface sounds ☐ **Mood Setter:** Circle Baton 1. Place the participants in a circle. 2. The community counts to three. At each count, you make a movement and a noise. 3. The movement and noise is started successively around the circle. 4. After a few rounds, a new movement and noise is started around the circle. 5. The different noises and movements should as in a relay catch up with each other. ☐ **Mood Setter Variation:** Use Metaphor modifiers (A Roaring Lion, Swinging Like a Monkey, Prance Like a Horse) ☐ **TURN ON CAMERAS** ☐ **Movement Method:** Embodied Sketching 1. Based on a core movement and noise, the participants must create ideas for many different expressive musical movements and sounds. 2. Participants are encouraged to also do this by playfully osberving, demonstrating to each other, responding to each other, and trying many different styles. 3. Based on a "yes and" mindset, an idea is worked on by everyone (all can move and make sounds) until the participants have suggestions for changing the idea. 4. Subsequently, a whole new idea comes up and is worked on. ☐ **Movement Method Variation:** Constrain (Slow-motion), Sensor (HR-monitor, Pressure sensor, Gyroscope, Touch sensor, Accelerometer) ☐ Short debriefing
13:00	Post-session	Workshop Room & Break Room	☐ Cleanup ☐ Close the rooms

Appendix B

First Evaluation Session Documents

B.1 Consent Form and Information Brochure

Designing a Musical Interface to Improve Well-being

Purpose of the Research
The thesis will comprise the design and evaluation of a musical interface prototype with the potential to improve well-being. Currently, we do not aim to engage in any medical-related activities. Instead, we are fully focused on the development of musical expression technology.

What Will Happen During the Session
The session is expected to last one to two hours. The session will be conducted in a controlled environment. Cameras, speakers, post-its, pens, and markers will be provided. Participants will be offered drinks and snacks during the break. The session will be divided into three phases. During the first phase, participants will offer their initial impressions. The second phase will involve testing the movement detection, volume adjustment, and sound effects of the prototype. In the last and third phase, participants will have the opportunity to interact freely with the prototype.

Benefits and Risks of Participating
Participating in this research offers the opportunity to contribute to the development of new technology. The main risk associated with the movement-based design session is the potential for participants to feel uncomfortable, awkward, or vulnerable. To mitigate these risks, we will choose appropriate warmup exercises, monitor the participants, and establish a "stop protocol." Please note that this research project has been reviewed and approved by the Ethics Committee for Information and Computer Science.

Withdrawal from the Study
Withdrawing from the study at any time is possible without providing a reason and will not affect the relationship with the researcher or the university.

Collection and Use of Personal Information
Observational notes and recordings will be taken with the researcher present. Cameras and note-taking tools such as iPads will be used. Two cameras, one overview camera and one action camera, will record the session. The faces, bodies, and voices of the participants will be visible and audible in the recordings. The topics of discussion will focus on the participants' experience, creative output, and session effectiveness. Video recordings are essential for later analysis. The researcher can revisit the footage to gain deeper insights into user interactions, preferences, etc. for the design of the musical interface.

Data Usage and Confidentiality
Data collected will be used for research purposes only. Personal information will be safeguarded, and access to data will be limited to the researchers.

Retention Period for Research Data
All gathered data will be retained until the end of the research (July 2024).

Contact Information

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If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science:

ethicscommittee-CIS@utwente.nl

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 26/03/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a video-recorded design session with a group of participants and that written notes will be taken. I understand that the audio or video recordings will be transcribed as text. I understand that the video recordings will be analysed to gain deeper insights into user interactions, preferences, etc.	☐	☐
Risks associated with participating in the study		
I understand that taking part in the study involves the risk of physical or mental discomfort.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for a Master's thesis.	☐	☐
I understand that personal information collected that can identify me, such as my name or where I live, will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs.	☐	☐
I agree to be audio/video recorded. I understand that two cameras, one overview camera and one action camera, will record me. I understand that my face, body, and voice will be visible and audible in the recordings.	☐	☐
I understand that all data collected will be stored on an encrypted hard drive and will only be accessed by the researcher.	☐	☐
I understand that all data collected will be deleted at the end of the research (July 2024).	☐	☐

Signatures

______________________	______________________	26.03.2024
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Mihnea-Adrian Udrea	______________________	26.03.2024
Researcher name	Signature	Date

B.2 Playbook

1. First Impressions (10 min)

- **Goal:** Gather first impressions on the prototype.
- **Questions:**
  - What are your thoughts on the design of the prototype?
  - How does the prototype feel in your hand? Is it comfortable to hold?

2. Movement Detection (20 min)

- **Goal:** Ensure accurate detection, while trying out all movements.
- **Movements:**
  - Shake
  - Twist
  - Hit
  - Slap
  - Tap
  - Swipe
  - Punch
  - Swing
  - Circle
  - Idle
- **Questions:**
  - Do you feel that the movements are natural and intuitive?
  - Are there other movements that you can think of?

3. Volume Adjustment (10 min)

- **Goal:** Ensure accurate volume adjustment based on repeated movements and inactivity.

- **Questions:**
  - Did the volume increase progressively with repeated movements?
  - Did the volume decrease occur as expected during inactivity?
  - Do you feel that the volume adjustments based on repeated movements or inactivity enhance the overall experience?

4. Sound Effects (10 min)

- **Goal:** Ensure different sounds based on the position of the prototype.
- **Questions:**
  - Did you notice differences in sound based on the position of the prototype?

5. Free Play (20 min)

- **Goal:** Gather feedback on user experience, design, and functionality of the prototype.
- **Questions:**
  - How intuitive was it to use the prototype?
  - How comfortable was the prototype to hold during use?
  - Is there anything specific you would like to change about the design of the prototype?
  - Do the sounds produced by the prototype correspond well with the movements performed?
  - What are your thoughts on the sounds produced by the prototype? Do you like them?
  - Are there other sounds that you can think of?
  - How do you perceive the differences in sound based on the position of the prototype? Do they add value to the experience?
  - Are there other sound effects that you can think of?
  - Is there anything specific you would like to change about the functionality of the prototype?

Appendix C

Second Evaluation Session Documents

C.1 Consent Form and Information Brochure

Designing a Musical Interface to Improve Well-being

Purpose of the Research
The thesis will comprise the design and evaluation of a musical interface prototype with the potential to improve well-being. Currently, we do not aim to engage in any medical-related activities. Instead, we are fully focused on the development of musical expression technology.

What Will Happen During the Session
The session is expected to last one to two hours. The session will be conducted in a controlled environment. Cameras, speakers, post-its, pens, and markers will be provided in the workshop room. Participants will be offered drinks and snacks during the break. The session will be divided into three phases. During the first phase, participants will offer their initial impressions. The second phase will involve testing the individual features of the prototype such as movement detection, tempo adjustment, volume adjustment, etc. In the last and third phase, participants will have the opportunity to interact freely with the prototype.

Benefits and Risks of Participating
Participating in this research offers the opportunity to contribute to the development of new technology. The main risk associated with the movement-based design session is the potential for participants to feel uncomfortable, awkward, or vulnerable. To mitigate these risks, we will choose appropriate warmup exercises, monitor the participants, and establish a "stop protocol." Please note that this research project has been reviewed and approved by the Ethics Committee for Information and Computer Science.

Withdrawal from the Study
Withdrawing from the study at any time is possible without providing a reason and will not affect the relationship with the researcher or the university.

Collection and Use of Personal Information
Observational notes and recordings will be taken with the researcher present. Cameras and note-taking tools such as iPads will be used. Two cameras, one overview camera and one action camera, will record the session. The faces, bodies, and voices of the participants will be visible and audible in the recordings. The topics of discussion will focus on the participants' experience, creative output, and session effectiveness. Video recordings are essential for later analysis. The researcher can revisit the footage to gain deeper insights into user interactions, preferences, etc. for the design of the musical interface.

Data Usage and Confidentiality
Data collected will be used for research purposes only. Personal information will be safeguarded, and access to data will be limited to the researchers.

Retention Period for Research Data
All gathered data will be retained until the end of the research (July 2024).

Contact Information

Mihnea-Adrian Udrea
m.udrea@student.utwente.nl

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science:

ethicscommittee-CIS@utwente.nl

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 12/05/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a video-recorded design session with a group of participants and that written notes will be taken. I understand that the audio or video recordings will be transcribed as text. I understand that the video recordings will be analysed to gain deeper insights into user interactions, preferences, etc.	☐	☐
Risks associated with participating in the study		
I understand that taking part in the study involves the risk of physical or mental discomfort.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for a Master's thesis.	☐	☐
I understand that personal information collected that can identify me, such as my name or where I live, will not be shared beyond the study team.	☐	☐
I agree that my information can be quoted in research outputs.	☐	☐
I agree to be audio/video recorded. I understand that two cameras, one overview camera and one action camera, will record me. I understand that my face, body, and voice will be visible and audible in the recordings.	☐	☐
I understand that all data collected will be stored on an encrypted hard drive and will only be accessed by the researcher.	☐	☐
I understand that all data collected will be deleted at the end of the research (July 2024).	☐	☐

Signatures

_______________________	_______________________	12.05.2024
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Mihnea-Adrian Udrea	_______________________	12.05.2024
Researcher name	Signature	Date

C.2 Playbook

1. First Impressions (10 min)

- **Goal:** Gather first impressions on the prototype.
- **Questions:**
  - What are your thoughts on the design of the prototype?
  - How does the prototype feel in your hand? Is it comfortable to hold?

2. Movement Detection (20 min)

- **Goal:** Ensure accurate detection, while trying out all movements.
- **Movements:**
  - Shake
  - Twist
  - Hit
  - Slap
  - Tap
  - Swing
  - Circle
- **Questions:**
  - Do you feel that the movements are natural and intuitive?
  - Are there other movements that you can think of?

3. Volume Adjustment (10 min)

- **Goal:** Ensure accurate volume adjustment based on repeated movements and inactivity.
- **Questions:**
  - Did the volume increase progressively with repeated movements?
  - Did the volume decrease occur as expected during inactivity?

- Do you feel that the volume adjustments based on repeated movements or inactivity enhance the overall experience?

4. Sound Effects (10 min)

- **Goal:** Ensure different sounds based on the position of the prototype.
- **Questions:**
  - Did you notice differences in sound based on the position of the prototype?

5. Free Play (20 min)

- **Goal:** Gather feedback on user experience, design, and functionality of the prototype.
- **Questions:**
  - How intuitive was it to use the prototype?
  - How comfortable was the prototype to hold during use?
  - Is there anything specific you would like to change about the design of the prototype?
  - Do the sounds produced by the prototype correspond well with the movements performed?
  - What are your thoughts on the sounds produced by the prototype? Do you like them?
  - Are there other sounds that you can think of?
  - How do you perceive the differences in sound based on the position of the prototype? Do they add value to the experience?
  - Are there other sound effects that you can think of?
  - Is there anything specific you would like to change about the functionality of the prototype?

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