An Evaluation of the role of Mapping in Skill Acquisition on Digital Musical Instruments

Mahtab Ghamsari-Esfahani

Schulich School of Music
McGill University
Montreal, Canada

December 2013

A thesis submitted to McGill University in partial fulfillment of the requirements for the degree of Master of Arts.

© 2013 Mahtab Ghamsari-Esfahani

2013/12/12

Dedication

This document is dedicated to the graduate students of the Music Technology area at McGill University, my friends and mentors, my supervisor and my family who have all been supportive and helpful throughout the completion of the research. This project involved tackling a new idea and the expertise of my colleagues at McGill were very helpful in seeing it come together.

Acknowledgements

I would like to thank my supervisor Professor Marcelo Wanderley for his guidance and support throughout my studies and for helping me realize my goals from this thesis. This project is the result of collaborative effort of many individuals who each have had extensive input to bringing it to its current state. I would specifically like to thank Avrum Hollinger for giving me the opportunity to collaborate with him on designing and building his novel DMI (the Ballagumi) and for his technical guidance on the instrument and its environment. In addition I would like to thank Amandine Pras for her help and expertise on conducting qualitative evaluations and for helping design the experiments conducted on the instrument. I would like to thank Beavan Flanagan as well for his artistic contribution to the project. He is the first composer to compose specifically for the Ballagumi and his insight helped to create a distinct notation system for the instrument and its sound synthesizer. Apart from the aforementioned, I would also like to thank the members of the Input Devices and Music Interaction Lab and the Music Technology area who not only contributed to the research process but also gave me important feedback on the writing on my thesis and it's development. These include: Vanessa Yaremchuk, Joseph Malloch, Stephen Sinclair, Alastair Porter, and Carolina Brum Medeiros.

Lastly I would like to thank the Centre for Interdisciplinary Research on Music, Media and Technology, the department of Music Research at the Schulich School of Music, McGill University and NSERC for helping fund parts of my collaborations for this research.

Abstract

Digital Music Instruments (DMIs) have become popular both in research laboratories and among performers of experimental music scenes. The concept of DMIs is very attractive, however few instruments make it beyond a laboratory environment. There is an apparent lack of historical and musical background enjoyed by acoustic instruments as well as a lack of pedagogy used to evaluate the effectiveness of DMIs and DMI players. While initial evaluation methods can be borrowed from the field of Human Computer Interaction (HCI), these methods need to be extended to evaluate the DMIs' integrated layers: the physical interface, the sound synthesizer and the abstract mapping block. This research was designed around the evaluation of a novel DMI called the "Ballagumi" with two main objectives: firstly determine the extent to which it is possible to obtain skills on the Ballagumi in a musical context (using musical compositions as tasks along with an improvisation setting) and secondly to determine how much the design of the mapping block affects the acquisition of skill on the instrument. For this purpose, two studies were conducted, a preliminary study that focused on discovering gestures on the Ballagumi and obtaining an initial perspective of the instrument features (e.g. latency), and a second study where professional musicians experienced in electronic music controllers were invited to play musical tasks and also improvise on the instrument with both mappings. The study results revealed interesting insights on the instrument itself, namely that the physical interface allowed for much of the learning in the interaction as it is built with material that have passive haptic feedback. The results also showed that of the two designed mappings, the simpler choice (a direct energy input mapping) was preferred for improvisation by participants. The choice of mapping resulted in very different impressions of the performance even though the instrument and the sound synthesis layer remained constant. Manipulating the instrument on an intuitive level was made easier by a direct energy input mapping since the physical interfaced required energy input and made use of both hands. The choice of mapping also affected the extent to which participants enjoyed playing the Ballagumi. The results from these two studies can be used to further improve the Ballagumi's sound and physical attributes to have it be used by more musicians. They also not only demonstrate the importance of the mapping block in acquiring skills to the point of improvising on the DMI (confirming in this regard past literature on the subject) but highlight the importance of accounting for the existing feedback before adding levels of complexity to the mapping.

Abrégé

Les instruments de musique numérique (DMIs) sont de plus en plus populaires dans les laboratoires de recherche ainsi qu'auprès des artistes de la scène musicale expérimentale. Le concept du DMI est très attrayant, cependant peu d'instruments vont au dela de la recherche en laboratoire. Au contraire des instruments acoustiques, les DMIs sont dépourvus de contexte historique ou musical et il n'existe pas de pédagogie permettant d'évaluer l'intéraction avec de tels instruments. Il est possible d'emprunter les méthodes d'évaluation au domaine de l'interaction homme-machine (IHM). Cependant, pour améliorer leur pertinence dans le contexte de 'interaction musicale, ces dernières doivent être enrichies pour intégrer les trois points suivants: l'interface physique, le synthétiseur et la partie intermédiaire de mapping. Cette recherche a été conçue autour de l'évaluation d'un DMI appelé "Ballagumi" avec deux objectifs principaux: tout d'abord déterminer dans quelle mesure il est possible d'acquérir des compétences musicales dans la pratique du Ballagumi, en concevant des études qui utilisent des compositions musicales et un cadre d'improvisation; puis déterminer comment le mapping affecte l'acquisition de ces compétences. Pour cela, deux études ont été menées: une étude portée sur la découverte des gestes ainsi que sur l'influence d'aspects technologique (par exemple, la latence) sur la perception de l'instrument et une seconde étude où des musiciens professionnels, familiers avec les instruments de musique électronique, étaient invités interpréter des morceaux de musique composés pour l'instrument et aussi d'improviser avec deux mappings. Les résultats de l'étude ont révélé un aspect intéressant de l'instrument, à savoir que l'interface elle-même donnait du retour sur l'interaction puisqu'elle possède des qualités haptiques propres. Par conséquent, des deux mappings conçus, le plus simple (un mapping à entrée d'énergie isotonique) s'est vu être privilégié par les participants, car perçu comme plus intuitif pour l'improvisation plutôt qu'un mapping à entrée d'énergie continue. On a pu aussi noté que, bien que l'instrument et l'algorithme de synthèse sonore soient restés inchangés, le choix du mapping a donné lieu à des impressions clairement différentes pour les interprètes. Les résultats de ces deux études peuvent être utilisés pour améliorer le Ballagumi sur le plan technologique, ainsi qu'au niveau de l'esthétique de l'interface. En plus de démontrer l'importance du mapping pour acquérir des compétences permettant d'improviser avec l'instrument, ces expériences ont permis de montrer qu'il est pertinent de prendre en compte les retours d'informations propres à l'interface physique avant d'avoir recours des configurations de mapping complexes.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

This thesis explores the idea of performance development on novel Digital Musical Instruments (DMIs), for which common learning methods do not yet exist. There is a current need in the scientific community on input devices and novel DMIs for further evaluations of users' interaction with these interfaces. Such evaluations would allow designers to better understand musicians' interactions with digital instrument and help build better instruments. An area that is of specific emphasis is the mapping of a DMI. The physical interface (input device) and the sound producing synthesis engine are vital pieces that affect the artistic interaction. Connecting these two components, the mapping defines how the input controls affect the sonic outputs. This abstract block plays an important role in shaping a musicians' understanding of an interaction. It's an important consideration when presenting a DMI to novice users as the mapping influences their appraisal of the instrument as a whole. Knowing this, mapping becomes as vital to the instrument as the interface and the sound. At the same time designing proper mappings that are understood by novice players, but offer a challenge for development of expertise is not trivial. Given that in DMIs the mapping is no longer coupled with the physical interface mechanically, the choices for mapping control to sound become unlimited. It becomes a challenge to design mappings for a new system and ensure that it continues to be interesting to musicians.

1.1 Project Description

The purpose of this project is to evaluate how users learn using an alternate controller [40] (not resembling known acoustic counterparts) that has never been played before. As well the study aims to determine the role that different mappings play in the given DMI interaction. Given the choice of instrument, study participants do not already possess playing techniques; as a result the interaction requires that users first become familiar with the instrument and then attempt to play and eventually improvise with it using different mapping configurations.

1.1.1 The Musical Instrument

The DMI of choice is the Ballagumi [38]. The Ballagumi was developed by Avrum Hollinger at the Input Devices and Music Interaction Lab (IDMIL). This instrument has many features that make it a unique case for studying variations of mapping and their influence on learning. The most important feature of the instrument is that its shape does not resemble any commercially available instruments or controllers. It has no buttons or sliders and the material with which it is built is silicone, making the Ballagumi bendable and deformable at almost any point on its structure. All the instrument signals can be captured simultaneously, however depending on the choice of mapping a subset of these signals are chosen to connect to the sound synthesis unit. The instrument signals are first obtained and parsed to correspond to musically meaningful mapping signals. These are then used to define a mapping for the interaction.

1.1.2 Mapping Methods

Two mappings have been designed to use with the Ballagumi and the modal sound synthesis unit, controlling the main excitation parameters of modal synthesis. Regardless of the specific choices of mapping, there are two ways in which the mappings can be arranged: explicit mapping and implicit mapping. In an implicit mapping, a generative algorithm is used to train gestures relating to sounds but the designer would not have complete control of the details of the connections where as in an explicit setting, the designer needs to create every single connection and controls its range and properties. For the purposes of this study, an explicit mapping method was applied and the incoming signals were treated in a middle layer before being sent to the synthesizer. This is to ensure that the input device and the sound synthesis unit remain consistent between different trials.

1.1.3 Hypothesis

Given a holistic interface with continuous sensing and without discrete states, it is possible to learn certain musical interactions within a short time period. We further hypothesize that though the interface is novel, changes in mapping would have an effect on the understanding of the interaction: a direct mapping method would enable users to learn to play the instrument faster and be able to instantly create a mental model of the interaction. A continuous mapping method requiring constant energy input could also be learned with more time; however it would have more expressive potential.

1.2 Overview of Thesis

The remaining chapters in this thesis, after reviewing known literature in this area, will describe the Ballagumi set-up in detail along with the development and analysis of two mappings and a fixed sound synthesis unit. The experiments isolated the mapping by maintaining other parameters in the interaction constant. For each mapping choice, the experience of participants was evaluated by their progress in learning as well as their impression of each interaction. This allowed for a more accurate analysis of the role of mappings in performance development. The evaluation of the Ballagumi was separated into two independent studies. In the first study, the main focus was on the acquired playing gestures that participants find the most intuitive and those which are shared among different users in order to start defining how the instrument should be played. In the second study, expert musicians were asked to play audio excerpts using a subset of the gestures that were discovered in the first study. Furthermore they were asked to improvise on the instrument as if in a performance setting. Their interaction was captured via interviews and analyzed to determine the most important features that affect the interaction as well as the role of the mapping in this process.

Chapter 2

Background

Digital Musical Instruments (DMIs) are a group of instruments containing "a control surface (also referred to as a gestural or performance controller, an input device or a hardware interface) and a sound generation unit. Both units are independent modules related to each other by mapping strategies" [40]. With advancements in technology, it has become more common for sound to be generated through "the use of a synthesizer and by means of a general-purpose computer" [40] thus making the case for DMIs.

In acoustic instruments, combinations of physical design and the coupling of components create natural mappings that connect the control surface to the sound generation; in many cases the control surface is the sound generation unit and the mapping is defined by the physical characteristics of the sounding object. Sounding features of acoustic instruments have evolved over many years and form an instrument's character. Defining a DMI using three blocks as described above is "analogous to breaking apart an acoustic instrument to separate the functionalities of the gestural interface and the sound generator" [40]. Using this model, DMIs would be composed of a physical interface, sound and an abstract mapping block that determines how each physical control affects the outgoing sound. The mappings in the middle block can be designed separately by the musician. It's fairly difficult to design different mappings for acoustic instruments without changing the nature of the instrument. Using a digital medium however enables such changes. In DMIs the mappings can be established independently from the interface; this allows for many possibilities of mapping. At the same time choices of mapping depend very much on the type of sound and gestures the composer has in mind for that instrument and designing them is not trivial [34].

The range of possibilities in the design and functionality of DMIs is endless however given the fact that these instruments are meant to be used in live artistic performances, and that there is a focus on musical creativity, methods of evaluating general-purpose computer interfaces do not address the musical interaction issues. Evaluation of DMIs to determine their usefulness in music beyond the laboratory is new and starting to grow [3, 12, 56, 58]; however more systematic methods of evaluation need to be devised. These methods would help create a better understanding of each instruments' interaction and better define its use by both novice and expert performers. When it comes to evaluating mappings, there are fewer evaluation methods yet [55].

The purpose of this study is to evaluate a series of mapping choices for a DMI known as the Ballagumi [38]. The Ballagumi is considered an alternate controller [40] and designing and evaluating mappings does not borrow metaphors from existing instruments.

2.1 Defining Digital Musical Instruments

The term Digital Musical Instrument (DMI) has been coined to refer to a class of musical instruments where user inputs are converted into electrical signals and then digitized to be modified; and the inputs to the sound synthesizer remain digital before being converted back to analogue or sonic form. This means that the processing of signals for creating music are digitally done. An abstract representation of a DMI essentially contains three black boxes each representing the control interface, mapping block and sound generation unit as shown in Figure 2.1. Energy would flow from the performer through these three blocks in sequence and out to create sounds. At every stage of the energy flow, the performer and/or the audience receive feedback on the state of the instrument. This can be visual, auditory and kinestetic feedback depending on the instrument's design.

Acoustic instruments follow a similar overall structure with the difference that the control interface is also the sound generation unit and the mappings are pre-determined by physical laws. Acoustic instruments depend on mechanical means for producing sound and the physical controls are tightly coupled to the generated sound. As an example a tense

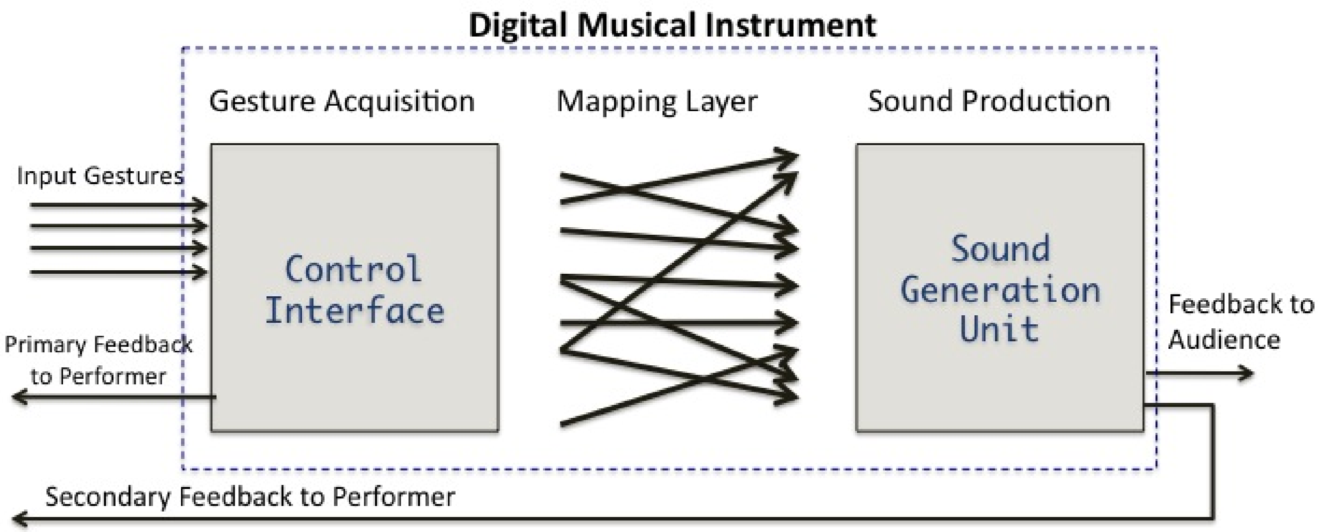

Fig. 2.1 An Abstract Representation of a DMI: Input Device, Mapping and Sound Synthesis Unit - Adapted from [40]

string can be activated by a performer's finger; the gesture occurs on the string and the resulting vibration generates sound. The control interface and sound generation are intricately linked thus imposing constraints on the instrument's usage and outgoing sound. As well, "the performance techniques that have evolved over this time all amount to the (real-time) control of systems that are bound together by physical laws" [26].

Breaking apart the control surface from sound generation lifts the physical constraints on sound production, enabling sounds to be generated independently and then linked back to the control interface (thus having three independent blocks as in the DMI model). In many cases the interface is a completely separate piece of equipment from the sound source to begin with [28]. Obviously in order to be able to generate sounds independently, we can no longer rely on mechanical means and need to move to an electrical or digital medium. Since "sound is generated by an electronic device (synthesizer or computer), the physics of vibrating structures that were determinant to the forms and features of acoustic instruments do not necessarily play any role in new instruments" [26]. The way in which the control interface is linked to the outgoing sound is now designed by the musician in an abstract digital layer. The choices made with regards to how each gesture controls the corresponding synthesis parameter(s) compose the mapping block of the DMI.

Essentially, any controller with one of more sensors can be used as an input device. The activation and control of the sensors shape the control interface. The mapping is designed separately having these control signals in mind and the outgoing sound is designed given the choice of synthesis algorithm, its capabilities along with the aesthetic measures needed to create the musical outcome in the composer's mind. Each of the three blocks in a DMI encompasses much research improving designs and utilizing new technology to achieve desired characteristics and new levels of interaction. Up until recently the design of DMIs and their interaction techniques had been driven more by what is technologically feasible than from an understanding of human performance. Their success relied in part, on the human ability to adapt to new situations [30]. Knowing that perception plays a key role in developing more mature interactions, more studies have focused on better defining the important parameters in such interactions [30]. This study is considered one such study where the focus is a particular DMI's decisions in the mapping block.

2.2 The Input Device

The Input Device or the gestural controller in a DMI is the performer's point of contact with the instrument. Its design determines both whether it will have any acoustic properties from its physicality and which parts of its surface can be used to couple with sensors. The main things to consider when building an input device is its physical look and handle as well as the choice of sensors or inputs that would define its character. The goal in music performance is to create an aesthetically pleasing effect given a set of tools, and to use one's creativity and expertise on the instrument in performance for an audience. According to Hunt and Kirk [27], several features prevalent in input devices would allow the creation of artistic effects:

- There is no ordering to the human-computer dialogue
- There is no single permitted set of options (e.g. choices from a menu) but rather a series of continuous controls
- There is an instant response to the user's movements
- The control mechanism is a physical and multi-parametric device which must be learned by the user until the actions become automatic
- Further practice develops increased control intimacy and thus competence of operation

Gestural controllers can be defined and classified by the level of their resemblance (or lack of) to existing acoustic instruments [40]. Using this classification, the main categories of controllers would be: augmented musical instruments, instrument-like gestural controllers, instrument-inspired gestural controllers, and alternate controllers [40]. Every category except alternate controllers has the benefit of retaining certain features from the acoustic counterpart thus informing performers of the possibilities of interaction with the DMI even before they start to play.

Alternate controllers refer to controllers where the interface does not resemble an existing acoustic or electric counterpart [40]. Numerous interfaces have been built with this metaphor and following the essential criteria for allowing creativity as mentioned above.

Some of these interfaces have moved beyond a laboratory environment and are being played by professional instrumentalists [34, 36]. In alternate controllers, the bias arising from the familiarity of interaction with conventional instruments no longer exists. This is advantageous in giving the performer a brand new platform to work with but also means that little or no known interactions exist for the alternate controller. While new gestures can be applied to all categories of input devices to control sound, in alternate controllers these gestures are no longer based on known playing techniques of acoustic instruments. The gestures start defining the interaction with the instrument and can be used as a metaphor for designing the mappings as well. An example gestural controller is the T-stick [34]. The T-stick's surface is uniform and along with its cylindrical shape promotes the application of gestures such as twisting and damping of sound [34].

2.2.1 Input Devices with Optical Sensing

"Optical sensing enables the remote transduction of forces or motion by modulating light intensity that is both transmitted and received via optical fibres" [21]. Optical sensing has been used more widely in other areas of research where specific sensing techniques are required. Properties of light in optical fibres have enabled the bending of membranes to activate signals[10]. Following this invention, pressure sensors [13] and bend sensors [33] have been created with optical fibres for various applications; specific properties of plastic fibres have been shown to have a linear response in certain ranges [32], making them ideal for controlling continuous signals with energy input and connecting to sound properties. Examples of Digital controllers that have been built using optical sensors include the fibre-optic guitar [9] and the fMRI (functional Magnetic Resonance Imaging) compatible keyboard [21]. These instruments are interesting in particular since the physical controller does not need to contain any metallic parts and thus can be used in fMRI/MRI studies on movement, motor control and learning.

2.3 The Sound Synthesis Block

The sound synthesis block can be designed as an embedded entity as part of the instrument hardware or can be designed separately and only connected when an input device needs that type of synthesis in performance. Audio synthesis has a long history going back to the work of Max Matthews at Bell Labs in the 1950s [47] and revolutionary discoveries such as the use of FM synthesis by John Chowning in modifying the spectra of sound waves [14]. Numerous methods of sound synthesis have been introduced and improved to make synthesized sounds more similar to natural sounds. A synthesis method of interest is modal synthesis [2], as this method is used to build the synthesizer used in this research. The modal theory of sound synthesis describes the vibration of physical objects under excitation at given frequencies known as modes [2]. The use of modal synthesis has been demonstrated in projects such as the MOSAIC framework [42] and is used in conjunction with input devices such as the T-stick.

2.4 The Mapping

The abstract middle section in the DMI composition determines how the input device affects the outgoing sound. As mentioned earlier, sound generation is no longer physically constrained by the input device, therefore their relationship is defined independently in this mapping block. In other words, when aspects of a system that were formerly intrinsically coupled are separated, a new degree of freedom is introduced [51] that is essentially under the control of the designer.

Generally the term mapping is used to define the mathematical process of relating the elements of one data set onto another [26]. This could also refer to a function where a given input or set of inputs is transformed into a set of outputs via a formula that defines their associative relationship. The function 'maps' the inputs to outputs [44].

In the DMI definition, this relationship is specifically between the set of interface control parameters (also called the performance parameters [8]) and the set of sound synthesis parameters. As mentioned in section 2.1 In acoustic instruments the mapping of control to sound is pre-defined by the physical properties of the instrument. The only way to modify an instrument's mapping then is by physically changing the mechanical properties of the strings or tubes in the instrument, for example putting frets on a guitar or using a mute on an wind instrument. John Cage demonstrated that the sonic properties of the piano can be modified, or the keys re-mapped to different sounds by changing properties of the strings inside the piano (creating the Prepared Piano). In instruments such as the piano or pipe organ where the resonating body is mechanically linked to the input source but not directly coupled, re-mapping becomes easier to do. Moving to electrical instruments, a more abstract mapping exists between the point of contact with the transducer and the sound leaving the speakers. Configurations of the wiring and manipulations of the electrical signals determine the mapping between control and sound (for example, pitch-shifting a microphone signal). In a DMI, electrical signals are digitized and can be manipulated in software, allowing for unlimited possibilities of mapping. The role of mapping in digital musical interaction has been mentioned as early as in 1982 by Abbot when discussing the 'parameter-definition problem' in a general purpose digital interface that could be divided into a "gesture objectification problem and a parameter-mapping problem"[48].

Hunt, Wanderley and Paradis have shown that mapping is a determinant factor in the musical interaction and affects how an instrument is in essence brought to life [28]. As well, new movement tracking technology, sensing devices and software have allowed for more ways to "map human gestures to acoustic results [29]. Choices for mapping controls to sound synthesizer parameters are endless making it an art in itself to design meaningful mappings.

From the point of view of the musician, the DMI model's three blocks have been shown to affect the interaction in the following ways: The "Input devices establish the physicality of [a] system[,] the synthesis methods govern the sound quality, [and] the mapping somehow affects how the player reacts psychologically and musically to the instrument." [28]. It can thus be claimed that the mapping block determines the player's psychological appraisal of the instrument. This makes the design of proper mapping essential to the instrument.

Putting aside the specific mapping choices for a given system, the theoretical approach to designing mapping strategies can take one of two directions [27]:

- By explicitly defining how every control parameter affects the synthesizer parameters. This method is referred to as explicit mapping.
- By using a generative training algorithm that takes the controls and the outgoing sounds in various situations and adapts the system to replicate the trained movements. This method is referred to as implicit mapping.

Where using an implicit mapping method is strong in adapting the system to the given gestures without the designer's direct intervention, explicit mappings allow the designer to be in complete control of every parameter that's modified from input to output. For systems with numerous inputs and outputs this may become a tedious task. In cases where the detailed variations of single mappings need to be controlled however, an explicit mapping strategy is preferred.

Knowing that mappings determine the performer's perception of the instrument's controllability [20], the goal of this research is to evaluate mapping choices on an interface in order to design mappings that allow the performer to develop expertise on the instrument. Previous research in this area has analyzed performers' experiences on new interfaces of varying complexity in terms of the mapping and the physical interfaces [27]; mapping techniques have been proposed which consist of "dynamic, independent [and] visual layers" [41]. Important guidelines have also been proposed for defining expressive DMIs such as offering a "low entry fee with no ceiling on virtuosity"[59].

2.4.1 Mapping Tools

Advancements in technology and the creation of standard messaging protocols such as MIDI [39] and more recently Open Sound Control [61] have greatly contributed to creating unlimited possibilities for mapping control to sound and controlling sound digitally. These protocols along with the availability of software environments such as Max/MSP allow for mappings to be designed in a separate block and isolated from the control source or the sound synthesizer in an instrument. While the technology to make numerous mappings exists, guidelines and tools for creating meaningful mappings are relatively new and limited. Many mappings have been integrated as part of the design of each DMI and added in an environment such as Max/MSP. It has been shown that the mapping design has a deep effect on the musician; it would give them an understanding of the way they would be interacting with the instrument [28] and would also benefit from known metaphors for expressive musical interactions [16, 60]. Mappings which give more complex and fine control to users have been shown to be more interesting and musically satisfying to both novices and expert performers even for common interfaces such as a computer mouse [26, 50].

Given the above guidelines, several tools currently exist that not only allow the creation of simple, one-to-one mappings but more complex and engaging ones without forcing the designer to perform detailed signal processing operations within a DMI. These tools also provide designers with more possibilities of mapping that they may not have thought of before. These include:

- The MNM tools for implicit mapping [6]
- The Digital Orchestra Toolbox and the Libmapper [35, 37]
- JunXion Data Routing Application [5]
- The [hid] Toolkit and the mapping library for Pure Data (PD) [54]

These tools are developed to facilitate the process of mapping control to sound parameters. This enables more artists to create new musical effects without needing to be expert programmers or proficient in signal processing theory.

2.5 Evaluating Digital Musical Instruments

Evaluating DMIs encompasses both an evaluation of the control interface, the outgoing sound and the mapping block all at the same time. Research in the past has focused on comparing interfaces to each other and evaluating their usage for pre-defined tasks. As an example, Hunt compared users' impression of three different input devices, one which was a conventional monitor and mouse setting, another a set of physical sliders and a third a multi-parametric interface still using the computer mouse but with changed mappings and minimal visual feedback [24]. Another experiment by Stowell et al. looked at the use of discourse analysis of speech for qualitatively evaluating an interface controlling vocal timbre [55].

Both quantitative and qualitative evaluation methods can greatly improve the design of DMIs and help them move beyond the laboratory environment, however given the lack of musical pedagogy and practice on digital instruments, the main methods of evaluation are being borrowed from other research fields.

2.5.1 Methods from Human Computer Interaction

A major research area that lends theories to DMI design and evaluation is Human Computer Interaction (HCI). Standardized methods have been borrowed from the field of HCI in order to carry out evaluations on DMIs. The control interface of an instrument is by itself an interface that could be evaluated using more standard methodologies in HCI. This is beneficial since the "Evaluation of Input Devices [in general] has been extensively researched in HCI literature and as a result, several widely used measures and models for input device performance have been developed." [29]

While methods practiced in HCI have proven beneficial in assessing an interface's usability and efficiency, they are not fully suited to musical instruments. These methods focus on the completion of tasks for any given interface meaning that the process itself is of less importance. In music performance however, an interface is being used constantly to express musical ideas in real time. There is not one task that needs completion in musical performance; but multiple processes running in parallel to create an aesthetic effect. Essentially the process of controlling multiple musical parameters simultaneously is the musical task, making fine control of every parameter in the instrument essential to its capability for live performance. In HCI, most systems are designed to reduce a potential user's cognitive load [16] reducing the possibilities of errors. In terms of mapping this typically means simple, choice-based and one-to-one mappings. In the design of instruments however, the goal is artistic expression demanding a challenging yet learnable design that can allow for virtuosity. As a result, criteria used to evaluate musical controllers need to extend beyond simple task completion and feedback. Additional evaluation criteria that can be used on musical controllers specifically include: performability, explorability and timing controllability[29].

Knowing the above differences, some HCI methods can be used and modified to obtain preliminary information about the performance of a musical instrument. An example is the measurement of time it takes to perform tasks using metrics borrowed from HCI [45]. Another example more suited to this study is the evaluation of the input device given musical tasks and using guided interviews to understand user impressions of musical interactions [45]

2.5.2 Quantitative Evaluation Methods

Quantitative evaluation methods range anywhere from analyzing musical gesture accuracy using techniques such as Motion Capture [15], to analyzing specific measures of sensor data and even measuring user feedback using Likert-scale data [56]. Timing evaluations of tasks using methods such as generalized forms of Fitt's Law [1, 17] are also quantitative evaluation methods that have been extensively used in HCI and are applicable to musical interfaces as well. In instruments where the gestures are known, comparing timing analysis of performance among variations of instruments gives valuable insights for that context [12]. It remains however a challenge to use quantitative measures when it comes to expressive musical gestures on interfaces where the gestures have not been refined through practice. It's also a challenge when changes in context and subjective experiences influence the interaction.

2.5.3 Qualitative Evaluation Methods

Qualitative methods are consistently used in HCI in order to evaluate interfaces and input devices with user groups given the users' subjective experience. Many of these methods have been successful in other fields such as social psychology [4] and have started to be used in musical interface evaluation more recently [56]. The main qualitative data that would be collected in such studies are user questionnaires and as such, the qualitative evaluation method needs to analyze the questionnaire data. Where quantitative methods fall short of giving valuable feedback on a musical experience, qualitative methods are useful. They can be "centred on a user (performer) perspective, or alternatively could be composer-centred or audience-centred (e.g. using expert judges)" [56].

Qualitative methods that have been shown to extract meaningful results from user impressions of musical interfaces include but are not limited to:

- Discourse analysis [4]
- Content analysis by Grounded Theory [19]

The above methods are specifically useful when used with interview data from practice sessions using an instrument. They allow to extract interaction trends which could be generalized to other DMI models. These methods can give useful insight into musical interactions, however the methods are sometimes time-consuming, subjective and "a clear distinction between data gathering and data analysis is [...] problematic for many qualitative researchers" [43].

2.5.4 Evaluating Mappings

The evaluation of mapping, for the purposes of this research, utilizes methods that assess the controllability and learnability of an input device given different mappings. A mapping though created explicitly by the designer, is an abstract block in the DMI and can only be evaluated through its influence on the performer and his/her understanding of the instrument. Evaluating the mapping therefore will only be possible by evaluating the DMI as a whole and maintaining the other two blocks of the instrument consistent throughout different cases. Previous research has evaluated the mapping in a DMI keeping in mind other factors that affect the interaction such as the physicality of the interface itself, the system's resemblance to conventional input devices and the changes in sound. Hunt experimented with three distinct input devices, playing a set of sound samples that were prepared using four sound parameters. The interfaces were distinctly different both in terms of their feel and use and in terms of their mapping. While the choice of interface is deliberate to encourage an analytical or holistic mode of thought [25] in users, it is shown that the users' familiarity with a known input device affects their impression of the interaction as well as their learning curve for simple and complex tasks.

A second experiment by Hunt demonstrated the importance of mapping in a setup where a slider box was mapped to FM synthesis in three distinct ways: one-to-one, one-to-one with energy input as a requirement, and many-to-many with cross coupling of parameters [28]. This experiment draws closer to the proposed topic of this research; however because of the choice of synthesis, the sound varied with each mapping choice so the mapping was not fully isolated from other factors. In all the above examples, mappings have played a significant role in the interaction and many conclusions have been drawn that highlight the importance of good mapping design, however their role have not been completely isolated from other factors such as interface physicality, sound, sensor capacity or controller familiarity.

Using the above two examples as a starting point, this study is framed to only modify the mapping block of the DMI. It uses two similar mappings where one requires continuous kinetic energy input to play the desired sounds and the other can maintain sound with static positions of the instrument. From obtaining users' impressions of their interaction with the instrument, we can observe whether they are capable of learning the alternate interface as an instrument and whether continuous energy requirement in the mapping helps or hinders their learning.

2.6 Summary

Digital Musical Instruments (DMIs) are defined using their physical interface (input device), sound synthesis unit and mapping configuration. Each aspect of this overall set up has an important role in the musical interaction it creates. As shown by previous literature, evaluating DMIs primarily uses methods borrowed from Human Computer Interaction (HCI) however incorporating a musical context in the evaluation can be beneficial in reproducing a more realistic environment. Furthermore evaluating the abstract mapping block is more difficult as both the sound and the input device affect the interaction and thus need to be controlled for.

Chapter 3

Ballagumi - Description and Mapping Methods

3.1 Overview

The Ballagumi is an alternative interface designed and built by Avrum Hollinger at the Input Devices and Music Interaction Laboratory. This instrument was chosen for the study on mapping in particular since its shape and form do not resemble known interfaces, thus reducing elements of bias during a study. The instrument is very flexible and sensors embedded inside correspond to the amount of bending or pressure applied to the surface.These signals can then be modified by different mapping schemas and connected to sound parameters in order to create different musical experiences.

3.2 About the Ballagumi

3.2.1 Physical Design

"The Ballagumi consists of a flexible physical interface cast in silicone"[38].The instrument has an overall cream color and is composed of three distinct physical sections that are fully attached together. There exists a central piece to the instrument with two wings on its sides. The entire instrument is malleable due to the material it is built with, however the wings have a higher range of bending than the core since they are thinner.

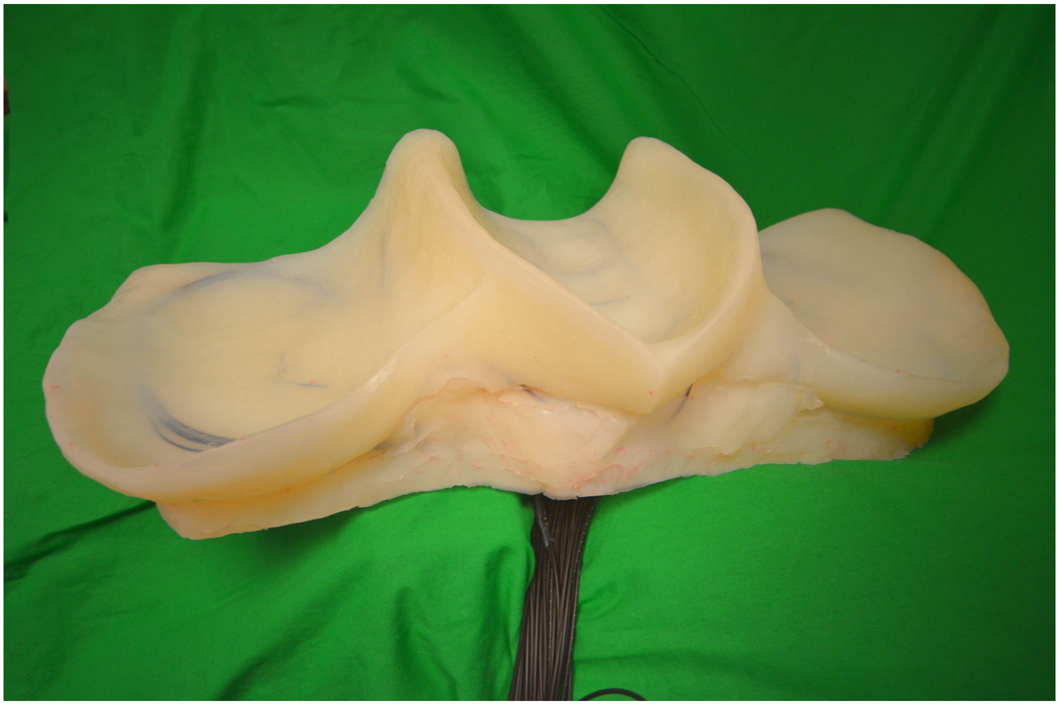

Fig. 3.1 The Ballagumi

The Ballagumi has embedded optical fibres that behave as “flexion and pressure sensors” [38] by taking in light at the ends of the fibre for the pressure sensors or by losing light from a looped fibre as a result of bending. For the bend sensor, bending of the optical fibre changes the amount of light lost from the middle of the fibre; additionally in certain areas through the loop, the fibre cladding has been removed to allow for bigger loss of light from bending. For pressure sensors, there are three fibre ends, one which emits the light and the other two that receive it; more alignment between these fibre ends means bigger transfer of light and a stronger signal. The changes in signal strength are not consistent in the instrument as fibres are located at various depths in the silicone and some areas are more bendable than others. The goal was for the Ballagumi to have “nuanced control of timbre, pitch and amplitude” [38] and as a result the sensors “collect information about the deformation of the instrument as a whole”[38]. The optical fibre ends show the emitted light and are visible at certain points on the instrument as illustrated in Figure 3.2. These light points are specifically visible in low ambient lighting

Using silicone to construct the instrument is advantageous since the “qualities of the

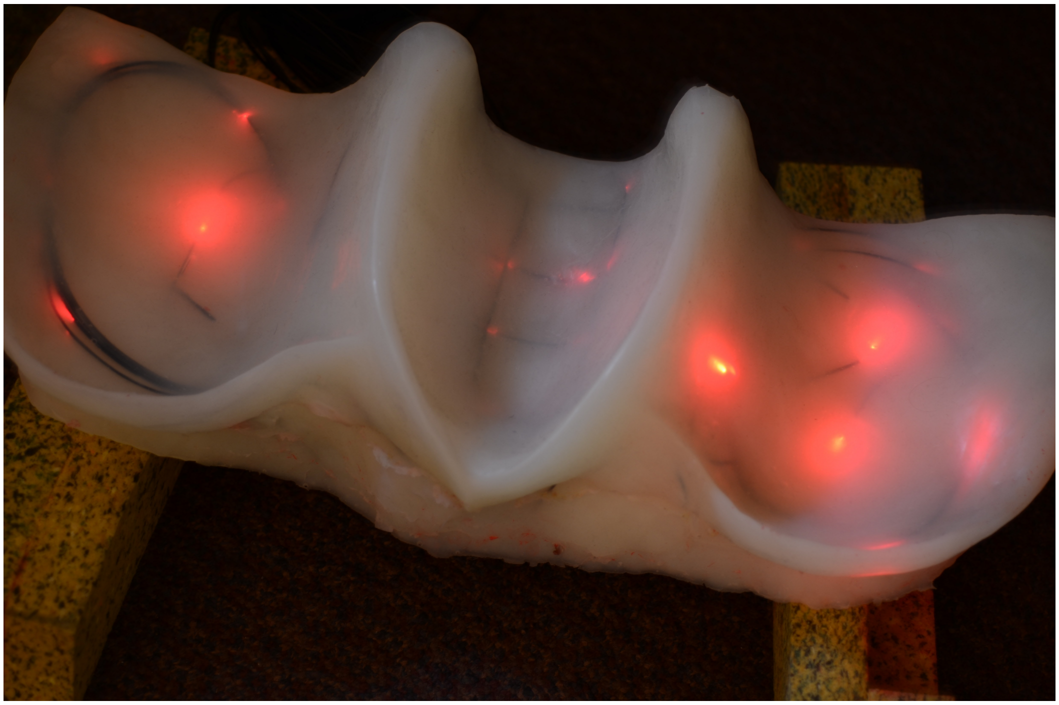

Fig. 3.2 The Ballagumi - View from top with low ambient light

construction materials [is used] to generate resistance, leading to a more satisfying user experience" [18]. The instrument's construction material creates haptic feedback and tries to reduce the disconnect between the user and the instrument; the elastic material "affords a continuous range of sensitivity" [18] and promotes new gestures to be performed such as twisting, stretching and squeezing. These gestures are being used in other controllers and hyperinstruments, for example the Music Shapers [46], the SillyTone Squish Factory [18] or the Sonic Banana [53]. The gestures are used for composing music and notating the controls of the Ballagumi. Since the instrument on its own does not have an inherent sound or a predefined playing technique, the gestures become a defining factor in creating its compositions, mappings and musical interactions. The cycle between gesture extraction, composition and mapping is on-going on the Ballagumi throughout the evaluation.

3.2.2 Signal Acquisition and Processing

Three custom-made acquisition boards were used as part of the hardware platform for the optoelectronic signal acquisition for the Ballagumi [22]. The sensor signals were named by their position in the Ballagumi, whether they are single-ended or differential sensors and the board that was connected to obtain their signal. The hardware platform was built such that deformation information from all the optical fibres can be collected simultaneously though in this application, the signals with lower sensitivity were not collected. Signals can also be acquired in three different ways: LED ON, LED OFF and compensated (LED ON - LED OFF). The analog acquisition boards were designed by Avrum Hollinger as part of a modular system that can be extended to use for acquisition, processing and communication of more optical fibres depending on the needs in other applications [22]. The hardware platform"uses analog-to-digital conversion (ADC) and can be auto-calibrated" [22].

Within the communication stage of the acquisition system, commands have been written to configure the board settings to control the acquisition and processing of signals, making the system more customized for a given application. In the case of the evaluations on the Ballagumi, we decided to only collect the compensated signals (LED ON - LED OFF). Compensating the values by taking the difference between LED ON and LED OFF signals minimizes the influence of changes in outside ambient light. Using the compensated signals means any changes observed in the outgoing values are solely from deformations in the instrument. Within the software environment, the compensated signals are labeled with "/COMP"

Signal values were received through the computer USB port and were transformed into distinct mapping messages as per the requirements in [37]. Using a custom-made parsing script that communicates with the boards, the acquisition rate and the printing rate of data can be set for each board. Signal values range between 0 and 128 for single-ended signals and between 0 and 255 for differential signals.For every gesture or deformation on any part of the instrument, all the sensors are activated and each respond depending on their proximity to the deformed area, the optical fibre's active range and the gains set on the instrumentation amplifiers within the hardware for the corresponding signals [22]. The signal value for each sensor is an indication of the loss or gain of light in the location of the optical fibre head for pressure sensors, and bending point for the bend sensors.

The parsing script that communicates with the hardware also includes methods for performing simple signal processing on the data. After some simple filtering, Libmapper signals were built and updated with the incoming data. Each signal was named using the physical position of the sensor in the instrument, the board that was acquiring the signal, the signal name, and whether the data was acquired with the LEDs on, LEDs off or compensated (LED on - LED off). The signals are formatted as Open Sound Control messages [61] to enable them to work with the Libmapper framework. As an example for a single-ended bend sensor signal located in the instrument's right wing and acquired through board 3 of the hardware with the LED Off, the representation will be as outlined in 3.1:

Name	**Min**	**Max**
Fungible1.1/3/RightWingBend/1/OFF	0	128

Table 3.1 Sample Ballagumi Signal on Libmapper

In order to optimize the performance of the Ballagumi and the signal transfer to the mapping layer, control parameters of the hardware were continuously tweaked until a combination was found that has the least drops in the signal value and has minimum latency with the current set-up. The combination was for the two parameters that set the acquisition rate of the ADCs and the printing rate of each board to its USB port. The commands "!a" and "Sc" are programmed to correspond to these parameters. The values can be changed and sent to each board separately since each has an independent USB connection. The printing rate to the USB port is the primary parameter that controls the data transfer; for the ADC acquisition rate, as long as the data can be passed to the USB port its levels will be adequate.

For the ADC acquisition rate, the sent control value is a unit-less scalar that determines the frequency of signal acquisition in Hertz from the ADC internal clock. The conversion is made as per equation 3.1.

$$\textbf{ADC Sample Rate} = \frac{DataClockFrequency}{1024 + AcquisitionRate} = \frac{4000Hz}{1024 + !a} \tag{3.1}$$

For the printing rate to the USB port, the commanded value is an input level frequency in Hertz that is converted to clock period (from the board clock) as per equation 3.2 and then transferred to the frequency value at the output (in Hertz) as per equation 3.3. Although these 2 equations seem to be the inverse of one-another, the resulting values are not always identical due to the integer division that occurs during the conversion.

$$\textbf{Printing Rate Period - T (s)} = \frac{TotalClockTicks}{SampleRate} - 1 = \frac{307692}{Sc} - 1 \tag{3.2}$$

$$\textbf{Actual Printing Frequency (Hz)} = \frac{307692}{T+1} \tag{3.3}$$

The control values that were tried are outlined in Table 3.2.

Printing Rate (Sc)	Acquisition Rate (!a)	Resulting Signal
150	25000	Few drops in signal
100	25000	Few drops in signal
50	25000	Numerous drops in signal
25	25000 20000 10000	Less drops in signal Several drops in signal Minimal drops in signal

Table 3.2 Ballagumi Perfromance Optimization - Values calculated in samples per second

It is important to note that the receiving end of the signals at the computer USB port has limitations; as such the optimal board parameters are not necessarily the fastest but more-so those that can be read as frequently as possibly by the computer USB port. Board parameters used that give the best performance for the Ballagumi with the current hardware implementation are as follows:

- Printing rate to the USB port : 25 Hz
- ADC Acquisition Rate : 10000 (unit-less)

The signals received at the USB port were converted to ASCII to be human readable. While this greatly helped understand the process, it introduced some latency in the signal processing that were later noticed when playing the instrument. Parsing the ASCII signals also had performance issues as the boards were generally sending data faster than the parser could handle.

3.2.3 Gestures

The initial set of gestures on the Ballagumi were obtained by observing random participants freely deform parts of the instrument as explained further in Chapter 4. The most salient gestures could be extracted from these interactions and used for establishing the several sound controllers in the synthesizer. To classify these gestures, areas of the instrument that could potentially be used to create sound were identified and labeled accordingly.

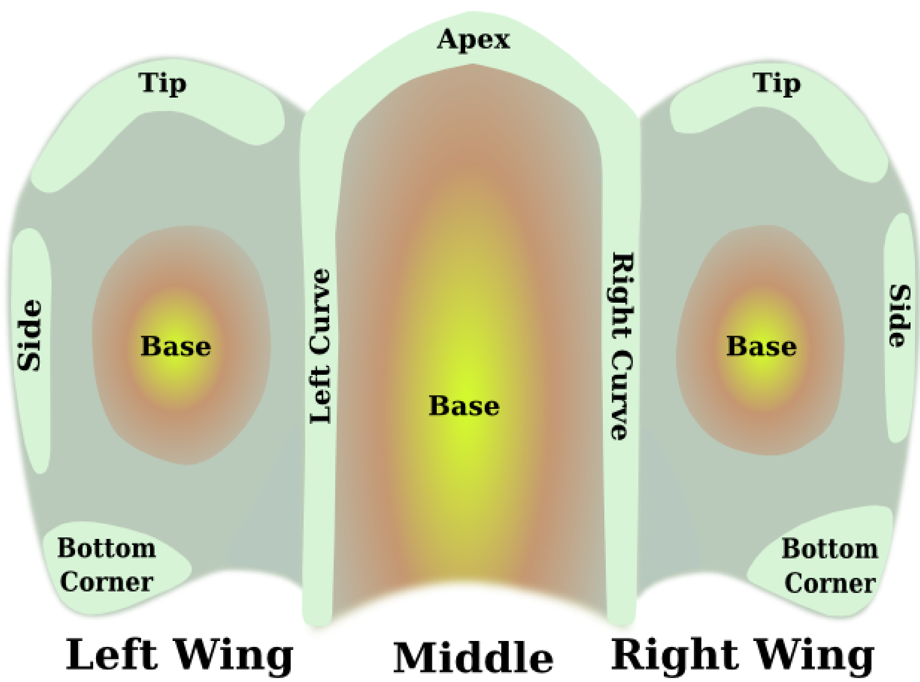

Fig. 3.3 Ballagumi Positions used for Gesture Categorization

The model presented in Figure 3.3 defines the different areas of the Ballagumi and is used to categorize the gesture locations on the instrument. The gestures used to play the Ballagumi, are categorized based on several parameters including the location, the type of movement (push, bend, squeeze) and the nature of movement (continuous or percussive). The categorization of the gestures is presented in Table 3.3.

Obtaining all the signals for each gesture, we can observe the signals that are most affected by that movement.An example is illustrated in Figure 3.4. The gesture performed

Category	Choices
Position	Instrument Middle Right Wing Left Wing
Hand	Left Right Both Hands
Movementwere	Bend Down Bend Up Push Down Squeeze Percussive hit or tap

Table 3.3 Ballagumi - Gesture Categorization

on the instrument was moving the apex towards the middle and releasing it 5 times. The apex was bent quickly and held in place for about one second then released for the same amount of time.

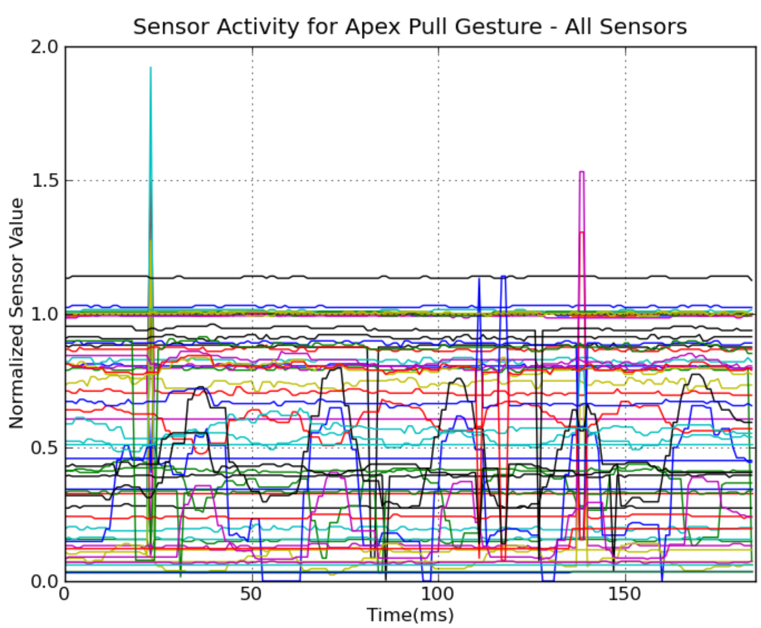

Fig. 3.4 Ballagumi All Signal Responses - Moving the Apex

By taking out the signals that were insensitive or minimally sensitive to the gesture, a subset remain which follow the movement as illustrated in Figure 3.5 though with different ranges. In this example again, the gesture involves moving the apex in and out five times and holding it in place for one second each time.

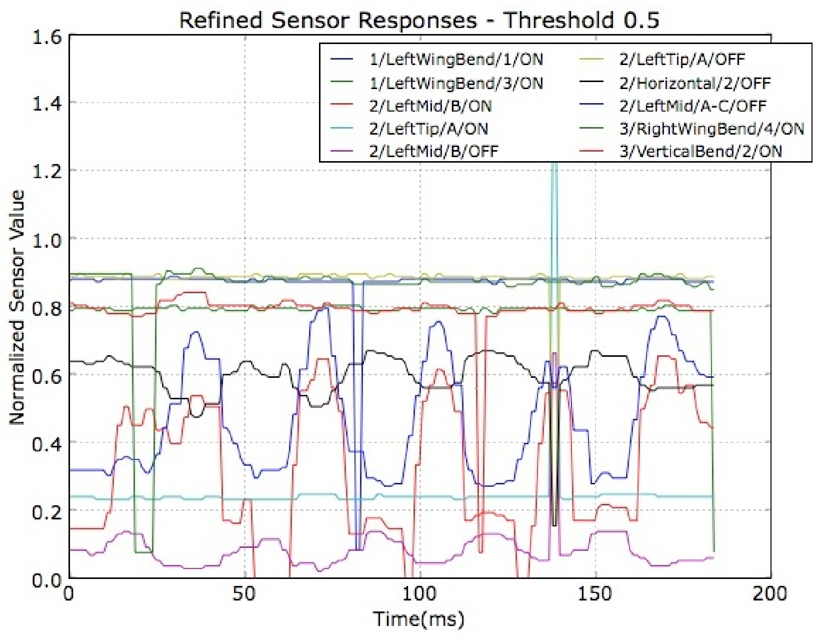

Fig. 3.5 Ballagumi Significant Signal Responses - Moving the Apex

Knowing which signals are most affected by the corresponding gestures, we can either map those signals to sound synthesis parameters explicitly, or use an implicit mapping method involving all or a subset of the signals assuming that less active signals will have reduced weights in the learning algorithms compared to more sensitive ones. After multiple trials of the signals, an explicit method was preferred (described in more detail in section 3.4.2).

3.3 Modal Synthesizer

This synthesis module was designed by Joseph Malloch using Max/MSP as part of the digital orchestra tools [35]. This synthesizer was built on modal synthesis theory where

"The behaviour of a linear, distributed, time-dependent problem [is] decomposed into contributions from various modes, each of which possesses a particular vibrating frequency. Sound output [is] obtained through a precise recombination of such frequencies, depending on excitation and output parameters."[7]. Data needed in order to use modal synthesis in any situation was divided into two categories: The first is a partial differential equation system that includes information about material properties and geometry of a given vibrating string or object. The second includes excitation information such as initial conditions and/or an excitation function and location[7].

In this modal synthesis Max/MSP patch, the first set of information (modal shapes and frequencies) are stored within the synthesizer as presets that can be made either manually in the patch or loaded in a separate file. Single frequencies of vibration in the modal synthesizer are available as mappable signals on the network, however they cannot be manually changed on the synthesizer interface. The presets describing the frequencies are written in plain text as a list separated by commas. Two preset files can be loaded into the patch simultaneously and an interpolator is available for moving between their frequencies. The interpolator position is also a mappable signal ranging between -1 and 1. The outgoing sound was filtered and output using the IIR filter bank Max/MSP objects built by Adrian Freed et al. [31]

3.4 Mapping

3.4.1 About Libmapper

The libmapper is a system for "collaborative development of a digital musical instrument mapping layer" [37]. It is composed of a C library describing the network architecture, a user interface for graphically mapping signals between controllers and sound synthesis units, and a series of Max/MSP objects along with additional patches that each modify signals to obtain a desired mapping. These tools were initially created to allow the dynamic "mapping [of] new instruments in collaboration with experienced performers, as well as with composers tasked with writing pieces for these [digital] instruments" [37] during the development of the McGill Digital Orcehstra [49]. The system has since evolved and its flexibility allows controllers to be virtually connected over a network for use in interactive

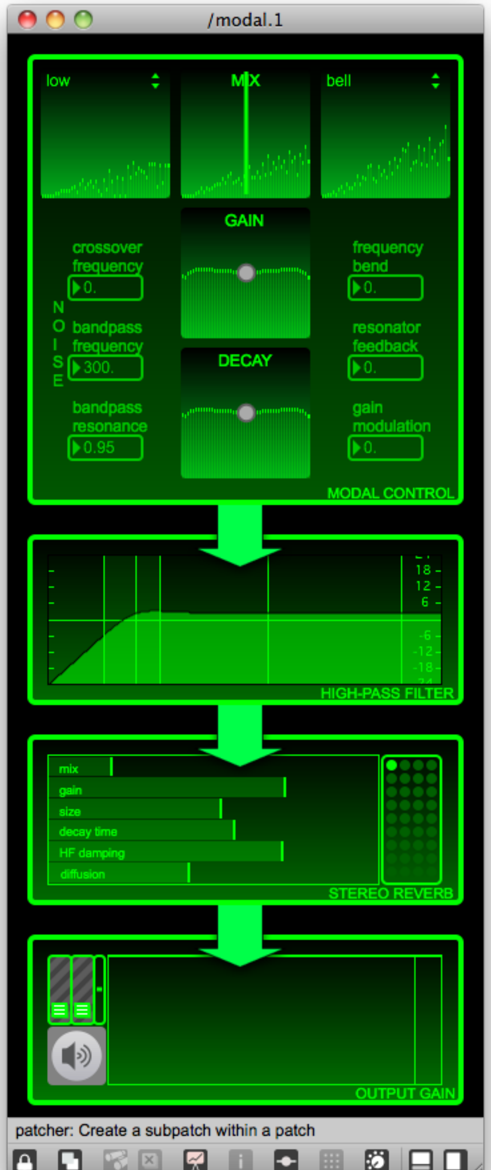

Fig. 3.6 Modal Synthesizer - Digital Orchestra Toolbox

installations, experiments and live performances. The Libmapper interface exists both as a Max/MSP patch as well as a web-based interface.

Given that the Ballagumi is a novel interface, Libmapper was chosen to allow experimenting of different mappings between the instrument and with the modal sound synthesis unit. Its use has greatly facilitated the mapping process for the experiments on the instrument as new mappings could be tried on the instrument signals with various gestures instantly, reducing waste time in the development process. Libmapper also has the capability of normalizing all incoming signals and performing basic signal processing functions on them to optimize the values for each scenario. In the case of the Ballagumi, given that the sensors receive different amounts of light, they sometimes only make use of a subset of their full range. As a result these changes have to be accounted for within Libmapper in order to ensure full coverage of range in the output.

3.4.2 Mapping Configuration

As mentioned in section 2.4 the method in which the Ballagumi's control signals were mapped to the modal synthesis parameters can be either defined such that each relationship between control and sound is explicitly laid out (explicit mapping), or defined using a generative mechanism such as a neural network where the mapping strategy is provided by "means of internal adaptations of the system through training" [27]. Mappings have also been categorized based on the individual assignments between the gestural output and the musical parameter. With this definition, mapping strategies can be either one-to-one, one-to-many, many-to-one and many-to-many. [27] Performing all four types of mapping is possible through explicit mapping.

Using implicit mapping, all or a subset of the signals could be acquired and trained with an artificial neural network. Choosing specific signals to map in this case would no longer be necessary since the effect of signals that are heavily influenced in each gesture dominates the neural network's coefficients and less influential signals will cancel out as noise. The exact mapping configuration would be taken care of by the learning algorithm. With implicit mapping, it can be stated that the mapping is likely a many-to-many mapping with all control parameters influencing the musical parameters. In an Artificial Neural

Network for example, this would be determined by the coefficients of the network. The exact configuration of each signal however will no longer be controlled by the designer. After several trials, the Ballagumi signals with the given parsing script were found to be too unstable to efficiently train in a Neural Network. With future improvements to the signal parsing and hardware implementation, this method would be more advantageous as it takes all the signals into account leading to more engaging gestures. For the purposes of this research, an explicit mapping strategy was chosen.

The initial set of experiments on the Ballagumi were performed with two mappings each designed using a subset of the control signals from the instrument. Using the most salient gestures on the instrument, more active signals were chosen as the control signals for explicit mapping. The signals mapped from the Ballagumi to the middle mapping layer for treatment and then to the modal synthesis patch are as follows:

- /3/RightWingBend/1/COMP
- /1/LeftWingBend/1/COMP
- /2/Horizontal/2/COMP

The signal values coming in from the instrument are simply a measure of the deformation of the silicone. Information known about the signals include the value, range and signal names but their behaviour was unknown and highly dependent on their placement within the silicone. It was observed that for certain ranges in the optical fibre response, there was a linear response behaviour. To limit the range of values to those of interest in the linear regions and to additionally treat the signals, an additional intermediate layer was created where the incoming signals were smoothed, filtered and scaled before being sent to the synthesizer. Given the objective of the experiment and the flexibility of Libmapper, by only modifying the signals within this intermediate layer, two distinct mappings were designed without making any changes to the controller nor the modal synthesizer.

In order to truly isolate the controller, gesture layers and the sound layer in the DMI, each mapping has to be designed such that no new gestures are introduced in the overall instrument configuration; or if new gestures are discovered, the sound parameter they control could be equally controlled by an existing alternate gesture. From the mappable parameters, signals corresponding to the sound onset, the overall gain shape, the interpolator between the two presets of modes and the filter's central frequency were mapped from the intermediate layer to the modal synthesizer. This allowed the players to control changes in timbre using the right wing of the Ballagumi, frequency using the left wing and the amplitude using the centre of the instrument.

3.5 Designed Mappings

To evaluate the exact role of the mapping layer, the system needs to be tested with at least two different mappings. Since other aspects of the interaction remain unchanged, it can be concluded that resulting differences in the two interactions are in part due to the mapping. The two explicit mapping choices for the experiment are described below.

3.5.1 Explicit Mapping Set 1 - A Direct Energy Input Mapping

In this mapping set, a sensor from each area within the Ballagumi was chosen to be directly mapped to a sound synthesis parameter. From the instrument's left wing one bend sensor was chosen. From the middle section of the Ballagumi one of the horizontal bend sensors was chosen, and from the right wing a bend sensor placed in the wing was chosen. The choice of sensors was based on testing the responsiveness of all the sensors in each region and choosing the most responsive. The bend sensor in the right wing was mapped to the central frequency of the filter in the modal synthesizer. The signal was filtered, smoothed and scaled before going to the sound synthesis unit as to ensure proper and continuous control of frequency. The bend sensor in the left wing was mapped to the parameter interpolating between the two modal presets, allowing a change in timbre. The central sensor was mapped to the overall gain, also controlling sound onset.

3.5.2 Explicit Mapping Set 2 - A Continuous Energy Input Mapping

The continuous energy input mapping was designed such that the user had to continuously move the middle section of the instrument to make sound as opposed to holding one deformed position. In this mapping, the choice of sensors remained as they were in the direct energy input mapping. The left wing and right wing bend sensors were still linearly mapped to frequency and timbre. The signal from the middle bend sensor (Horizontal/2) however was differentiated and then passed through a leaky integrator with a linear leak. By holding the instrument core in one place, the signal value would slowly decay and lose energy. The middle sensor was essentially obtaining the slope of the deformations in the middle of the instrument. This signal was mapped to the overall gain of the modal synthesizer causing the sound to fade off if the player simply holds the instrument in one place without continuously supplying energy to it. The required energy input changes how the instrument maintains and/or changes sound while other parameters are adjusted.

3.6 Composition and Notation

Composing for the Ballagumi was commenced by first focusing on the physical properties of the instrument and the possible ways of creating sound that could be applied. The initial set of gestures were defined based on the positioning of sensors within the Ballagumi and the strength of each of their signals. Since composition and mapping evolved simultaneously, the composition process began after fundamental choices had been made for the first mapping set. The same mapping set has since evolved to ensure all elements within the notated composition can be played. The continuous energy input mapping has been designed to both present a different interaction with the instrument while ensuring that the same sound can be obtained from the instrument, making it possible to play the same compositions. The compositions and notation system have also evolved to not make use of sounds that are solely present for one mapping.

For the initial evaluation of the Ballagumi five compositions were created; each one focused on a different aspect of control or sound: From continuous steady control to rhythmic abrupt sounds. Each composition was also roughly one minute long with a steady tempo. Elements of traditional western music notation were introduced into the notation such as tempo, beats and the positioning of hands using two staves. The classical notation combined with the symbolic representation of overall gestures created a notation system that's mostly gesture-based. For the first study this type of notation was ideal since the instrument's sounds had not yet been established. From the results of the first study (presented in detail in Chapter 4, it was shown that participants use much variation in the details of their gestures even when overall notations of gestures are presented on the score. To advance further on the instrument, participants also needed to become familiar with the musical possibilities and to try to recreate certain musical outcomes. In this case, a gesture-based notation system would be not be sufficient as it would not be able to indicate the exact nuanced sound that needs to be recreated.

Knowing from study 1 that the participants were capable of producing a wide range of sounds by applying gestures that they themselves have brought to life, the second study (presented in Chapter 5) used a score that focused on the outgoing musical patterns from the synthesizer. The score (included in Appendix A) consisted of new symbols that corresponded to the sounds coming from the synthesizer as well as its controls such as volume or pitch modulation. This score was used to record 30 second audio representations that were presented to participants in study 2 during the task-reproduction session (Chapter 5).

3.7 Summary

This chapter described the Ballagumi, its physical features and the process with which its signals were connected to a synthesizer. The Ballagumi is built with optical sensors that react to changing levels of light caused by the deformation in the silicone. Avrum Hollinger, the creator of the Ballagumi has also written a command line program to control the optical hardware that treat the sensor signals. Using these commands, optimum levels of signal acquisition and printing were determined and filtered further before being converted into mapping signals that can be read via Open Sound Control. These signals were then treated and sent to the synthesizer. Multiple trials of the instrument with various mapping methods and synthesizers were performed before deciding on a Modal Synthesizer and 2 sets of explicit mappings: a direct energy input mapping and a continuous energy input mapping. The refining of the signals also gave the creators an idea of the possible gestures that can be performed on the instrument, hence allowing to categorize gestures by their locus on the instrument, the hand in use and the type of movement.

Chapter 4

Study 1: Exploring Gestures

The evaluation of performer-instrument interaction on the Ballagumi is divided into 2 studies. The first study is a free exploration on the instrument's look, feel and capabilities as well as on the available sonic possibilities of the modal synthesizer. This study is conducted with randomly chosen participants of diverse musical backgrounds, but who are trying the instrument for the first time. With a preliminary design for the direct energy input mapping and the continuous energy input mapping, giving the instrument to participants without explicit guidance on the mapping allowed for the discovery of different possibilities of sound-producing gestures. This study was also important in providing the designers with adequate feedback to improve the instrument independent from the mapping.

4.1 Study Design

4.1.1 Objective

To evaluate the development of performance skills on the Ballagumi using distinct mappings, a study was put together that firstly extracts salient information from participants' first interaction with the instrument and then assesses their ability to play given gesture information by asking them to play from a written score. The score consists of compositions specifically created for the Ballagumi, with notation that specified general gestures that need to be used and also had a distinct musical character.

4.1.2 Participants

Participants were selected without any specific requirements on musical background. For the exploratory study there were a total of 14 participants. 10 people participated in the first trial of the direct energy input mapping and 4 people participated in the trial for the continuous energy input mapping. Ethnographic information on the participants was collected to obtain an overall understanding of their familiarity with music as well as with digital controllers. All participants were recorded during their interaction. For four of the total participants, data from the Ballagumi's sensors were also collected to help improve the instrument response for the future (using the mapperRec tool [52]).

From the total participants, 4 are female and the rest are male. 3 of the female participants played with the direct energy input mapping and 1 experimented with the continuous energy input mapping. From the ethnographic information sheets, we know that all participants had some musical background and 10 participants have seen or used DMIs to DJ or add effects to existing instruments, however none were professional performers of DMIs.

4.1.3 Experimental Procedure

In this study, participants were presented with the instrument for the very first time. This was an opportunity to explore the gestural and sonorous capabilities of the Ballagumi. The experiment was designed in two consecutive parts and lasted 20 minutes overall for each participant:

In the first part, the participant was given the instrument with either the direct energy input mapping or the continuous energy input mapping in place, and was asked to discover the different sounds on the instrument. The participant was given no guidance as to how to create sound from the instrument and was asked to describe as many gestures as he/she finds during the experiment. The purpose of this session was to determine the range of gestures and possibilities on the instrument. The participant had never heard the Ballagumi played and had no prior knowledge of how it functions. Presenting a new interface to users without any background information allowed them to look for the most intuitive modes of interaction with the instrument and to try out gestures which would potentially not have been conceived of by the composer. The participant's interaction with the instrument was recorded on video and individual gestures were extracted and categorized based on how many times they were commonly observed among all participants.

In the second part, the same participant was given the score for one of the gesture-based one-minute compositions and was asked to practice it first and then play it from start to end using the score. The music score included general drawings of the required gestures to guide the participant, however detailed variations of these gestures were not suggested. This part of the study gave participants a chance to try playing the instrument at a given tempo and with a few general instructions on where the hands should be placed. Since the composition prepared for this evaluation was gesture-based, it did not demand participants to play a particular sound, making it possible to explore variations in gestures for a given instrument area. The instrument sensor responses in this part were recorded using the mapperRec program [52] to observe for future improvements. This program has been designed to record active signal values and is part of a series of tools that use libmapper for analysis and visualization of signals. While having the sensor data did not explicitly provide information on the musical interaction during the experiment, it can be used to analyze dynamic ranges of the signals in the future.

4.2 Results

4.2.1 Gestures

As mentioned above, all participant sessions were video-recorded. Common gestures were extracted by observing the videos in segments. It was observed that the choice of mapping did not make a difference in the extraction of gestures in this phase as the major difference between the two mappings occurs when trying to maintain a constant and continuous sound. In other words, the locations of the instrument where sound was produced remained constant between the direct energy input mapping and the continuous energy input mapping. When playing the instrument in search of possible sounds, most participants applied the same gestures regardless of the possibility from one mapping to create more sustained sounds. A movement was considered a sound-producing gesture if it's position or velocity had an active role in creating or changing the sound.

In total, 52 gestures were extracted from participants out of which 19 were repeated more than 4 times regardless of the mapping in place. These "popular" gestures are presented in Table 4.1. A summary of all found gestures with the corresponding hands or legs used to perform them can be found in Appendix C.

Locus	Gesture	Repeats
Right Wing	Bend tip down	5
Right Wing	Bend bottom corner up	12
Right Wing	Bend wing base up	9
Right Wing	Bend side up	8
Right Wing	Bend side down	9
Right Wing	Push middle of base down	6
Left Wing	Bend tip up	7
Left Wing	Bend tip down	9
Left Wing	Bend bottom corner up	9
Left Wing	Bend bottom corner down	6
Left Wing	Bend base up	12
Left Wing	Bend base down	6
Left Wing	Bend side up	6
Left Wing	Bend side down	6
Left Wing	Push middle of base down	6
Middle	Push middle down	7
Middle	Bend left ridge inwards	7
Middle	Bend entire ridge inwards	9
Middle	Bend apex inwards	6

Table 4.1 Ballagumi gestures repeated more than 4 times among 14 participants in study 1

A number of the gestures from Table 4.1 are demonstrated in Figures 4.1 through 4.3. For gestures on the wings, (Figure 4.1) while both hands were used to perform the gesture, one hand often took on the principal role of bending. For gestures performed on the centre piece, one or both hands were used depending on the effort required to make sound.

(a) Start gesture (b) Half bend (c) Full bend

Fig. 4.1 Gesture Example: Left wing bend base up

(a) Start gesture (b) Half bend (c) Full bend

Fig. 4.2 Gesture Example: Bending the entire middle curve inwards

(a) Start gesture (b) Half bend (c) Full bend

Fig. 4.3 Gesture Example: Bending the apex inwards

4.2.2 Study Questionnaire

The questionnaire was given out to every participant in the group after finishing their practice on the Ballagumi. It included both open-ended questions and closed questions that are geared more towards obtaining a better understanding of the user's feel of the instrument, the sound and the overall system. Participants found similar gestures between the direct energy input mapping and the continuous energy input mapping; the choice of mapping did not prevent them from finding certain gestures; they did however comment on the effort and control required to play the instrument with each mapping. As such the questionnaire results are presented separately for each mapping. The responses for the closed questions were prepared on a 7 point Likert scale and for each question, the mode of the results is presented. The open-ended questions focus both on the gestures as well as on aspects of the musical interaction that could facilitate creativity and development of skill. Full responses to these questions are found in Appendix D.

Generic questions

From the questionnaire, questions 1,2, 5 and 6 were open-ended questions that were common between both mappings and were designed to obtain and initial perspective of the Ballagumi (Details of the questionnaire responses are available in Appendix D). From responses to question 1, participants described the Ballagumi using various terms such as:

- Sea slug
- Manta ray
- Two turn tables connected
- Butterfly
- Fighter jet

From questions 2,5 and 6, 6 participants described the wings as contributing more to sound modulation than the middle section and described associated gestures that can be performed on them. These participants mention that as a whole the entire instrument contributes to making sound, however the wings have a higher range of bending than the core. 3 participants also mention the role of the middle section in modulating the gain (volume) of the sound. The 3 female participants mentioned that working with the middle is more tiring than the wings and also that they had a harder time manipulating the instrument in general due to its weight. 4 participants also mentioned the role of the legs in the questionnaires. This is an interesting find since in the initial compositions on the Ballagumi, the position of the legs was not taken into account. Indeed the legs can also deform the instrument to the point of influencing the same sensors as manipulated by the hands.

Direct energy input mapping

Participant responses to the closed questions when experiencing the instrument with the direct-energy input mapping are presented in Appendix D. From the 10 participants who took part in the evaluation with the direct energy input mapping, 6 mentioned that the gestures were relatively easy to learn (giving a 3 out of 7 on the Likert scale). 5 participants mentioned that they can control the pitch (giving a 5 out of 7, where 7 indicated complete control of pitch), in the comments however participants mentioned that there aren't many pitches to choose from, making the synthesis less interesting to control. 7 participants gave a score of 5,6 or 7 on the Likert scale (with 7 labeled as "very tiring") when it came to the amount of pressure required for making gestures. In particular, the female participants gave a higher score in this question and commented that the middle section of the instrument particularly needs "a lot of pressure for the volume/gain" and that it "could be hard on the hands/arms". This finding was used after this study to improve the instrument response and effort in order to prepare it for study 2 (Chapter 5).

Continuous energy input mapping

The parameters for the second mapping were adjusted after feedback from a preliminary evaluation yielded that the instrument was too tiring to play. According to the pilot participants, the instrument was playable however too much pressure was needed to change the sound, there was delay in the sound response and properties such as volume were difficult to control. After adjusting the parameters in the continuous energy input mapping, the instrument was tried with 4 participants. The parameter adjustments did not affect the nature of the mapping nor the sounds in the second set; scaling factors and thresholds were used to ensure easier control of sound in different ranges.

The participants' questionnaire results showed that in general, the instrument was still tiring to play however there were "Key movements on the left and right sides" that were responsive and the "Lobe gestures were natural but not so much the center". Participants all ranked between 4 and 6 on the amount of bending required to make sound (where 7 indicates too much bending) showing that effort was still required to manipulate the instrument. 3 out of the 4 participants rated a 3 out of 7 when it came to controlling the volume, indicating that they had less than desired control over the volume. This may be caused by the specific sensor used in the volume signal; this sensor in particular had a larger dynamic range but was also more rapid to lose/gain light, thus making it more difficult to have fine continuous control over it. Adding the latency from the signal processing and parsing algorithms, the effect became even harder to control.

4.2.3 Areas of improvement

In general, the continuous energy input mapping, regardless of the fact of having to move the instrument was deemed tiring to play. Participants did not discover the effect of moving the middle section to control volume since they were trying to manipulate the instrument as a whole. For both mappings, from the composed scores, one of the indicated gestures is pushing in the middle of the instrument. This suggested gesture was least liked by participants overall, with one participant commenting for example that "It didn't feel completely natural when pushing directly on centre lobe". Judging from these comments, the mappings were modified to ease the acquisition of sound for study 2. The middle section was in particular modified to allow easier sound onset and activation by moving the middle ridges (thus not being restricted to push in the middle of the instrument). All the gesture notations are included with the corresponding compositions in Appendix A.

4.3 Summary

This first study was an initial exploration into the workings of the Ballagumi with an initial design for both mappings. A total of 14 participants played the instrument both in an exploratory nature and by trying to play tasks from a composed score. The participants' gestures were extracted from the exploratory part of the practice to find the most intuitive gestures. The participants ratings and comments from the task-based session showed that while participants are able to learn several basic gesutres, the designed compositions with their suggested gestures are not the most intuitive. As well, the results showed the effects of the signal choices and latency in the configuration of the instrument and presented areas of improvement to ensure a more smooth interaction.

Chapter 5

Study 2 : Mapping Exchange and Improvisation

5.1 Study Design

This study was comprised of multiple sessions each focusing on one aspect of the Ballagumi and the chosen mappings. The overall goal of the study was to engage professional musicians (especially those with experience with digital musical instruments) in playing the Ballagumi and observe their creative process. For this purpose the two created mappings were used and each participant was asked to both replicate tasks and improvise on the instrument given each mapping. The participants were not explicitly aware of which mapping they're playing on. For each participant, the study was structured as per Figure 5.1

As can be seen from Figure 5.1, each participant played the instrument with Mapping A and Mapping B (which could be a choice of the direct energy input mapping or continuous energy input mapping). During each session, the participant was first presented the Ballagumi with pre-recorded tasks to play. Based on the most relevant gestures found from Phase 1 of the study, a new composition was created that focused on the available sounds in the synthesizer. This composition was broken down into small excerpts by bars that were recorded, creating the tasks used in the first 15 minutes of each study session. There were 12 audio excerpts per mapping in total. Each participant was given 3 excerpts that each lasted approximately 30 seconds for each mapping. The order of the tasks was changed

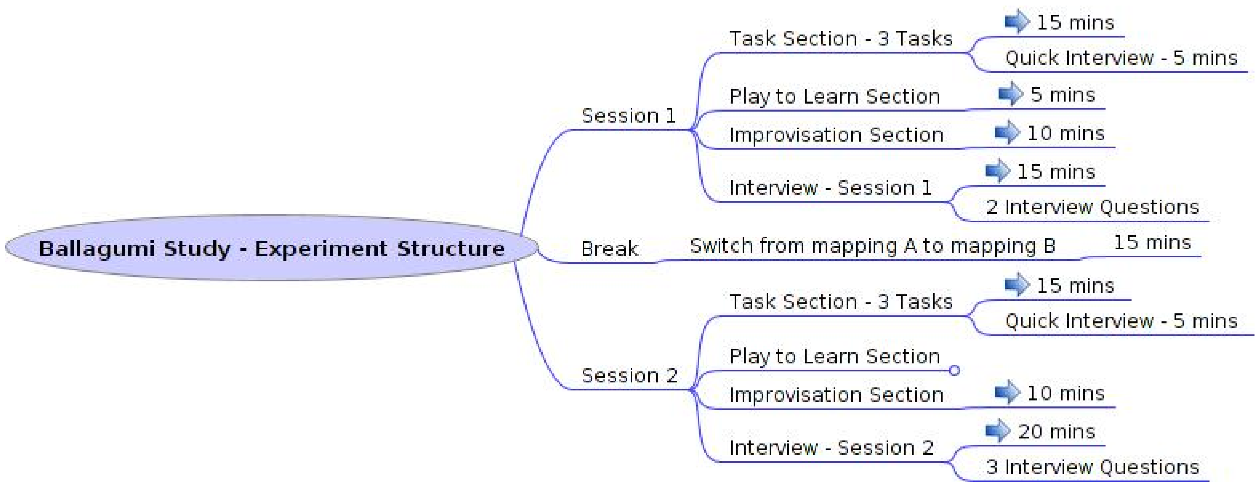

Fig. 5.1 Phase II Study Structure

and a different combination of excerpts was chosen each time to minimize any influence of order. Participants were asked to listen to the recording and re-create the sounds using the Ballagumi. The composition was playable by both mappings although changes in gestures were necessary in order to fully replicate the sound excerpt.

5.1.1 Participants

In this phase, four participants were explicitly chosen who are professional musicians, and have significant musical background with electronic or digital musical instruments. The participants were given a questionnaire to collect ethnographic data. The 4 professional musicians (3 males and 1 female) were invited from the experimental music scene of Montreal. They have an average of 16 years of musical experience (SD = 6). All 4 are improvisers. Three of them had performed with digital controllers on stage for an average of 10.5 years (SD = 7). Trained as a classical violinist, the 4th musician is a member of a contemporary string quartet specialized in expanded music practices, including the use of sensors and real-time electronics, though no experience with DMIs. We hypothesize that this group of professionals with different musical backgrounds and expertise can bring different perspectives to inform our study.

5.1.2 Experimental Procedude

The experiment was divided into 2 sessions corresponding to the 2 mappings. The order of the tested mapping was counterbalanced among participants. The experiment took 2 hours in total, including a 15 minute break in between the 2 sessions. Given their high level of expertise, the musicians received 80 dollars for their participation.

In each session, the participant was first asked to reproduce three short excerpts after listening to their audio recording. This replication task was followed by a quick interview. They were then given 5 minutes to play around with the instrument before being invited to improvise for approximately 10 minutes as if in a performance setting. The improvisation was followed by an interview. The replication task, improvisation and interviews were audio and video-recorded. For the improvisation, the participants could choose whether or not to have an audience and to receive a copy of the audio recording. All participants played both mappings however the order in which they were presented with the mappings differed from one to the other. 2 participants were initially given the direct energy input mapping and then switched to the continuous energy input mapping. The other 2 initially played the Ballagumi with the continuous energy input mapping and then switched to the direct energy input mapping.

5.1.3 Design of the replication task session

As discussed earlier, a new piece was composed by Montreal-based composer Beavan Flanagan, following the recommendations of Butler [11] who created pedagogical material specifically for DMIs. This material is based on notated etudes for which musical parameters such as pitch and rhythm are combined to enhance performers' virtuosity, though are still musically meaningful. The sounds used in the composition were created using on the common gestures found in study 1. The piece was then broken into several minatures to be replicated. Given the specificities of the Ballagumi, the minatures were composed to be at a technical level that does not require multiple hours of practice or extended techniques on the instrument. They specifically focuse on the possible sounds and do not suggest any gestures in the making. The musical notation for the piece is attached in Appendix A. All sections of the piece can be played using both of our designed mappings. We selected 6 miniatures for each mapping that were notated purely from the sound properties and did not suggest any gesture information to the performer. For each replication task session of our experiment, 3 different miniatures were randomly chosen and presented in a counterbalanced order to the participant. The participant did not have any visual feedback from the synthesizer but had to discover the sounds in the instrument and the necessary combination of gestures in order to reproduce the excerpts.

During the replication task, the participants were encouraged to play back the reference sound as much as they needed. A list of hints was prepared describing appropriate gestures to help the participant when he/she had a hard time reproducing the miniature. The hints are ordered and start from very generic descriptions to more detailed suggestions that would almost show a needed gesture if the participant is unable to create the sound. The hints which were presented are as follows:

- In general you need to use both hands to play the Ballagumi
- Try moving your legs to get silence when not touching the instrument
- Try Playing with the middle of the instrument
- Combinations of gestures work differently than individual ones since the sensors are interconnected.
- Try squeezing the curves of the middle
- Wings have a large range without needing to bend the base too much. Try a lighter bend on the wing

5.1.4 Design of the interview guide

For each session, a set of questions were designed in order to obtain information about the general interaction with the instrument and the discoveries though the improvisation session. The questions of the interview guide were designed with word-by-word attention in order to avoid influencing an answer on the participant or biasing their experience.

After the replication task in each session, we asked the participants the following question: How would you describe your progression throughout the three tasks?.
This question allows feedback on the difficulty of the replication tasks, but also on the order

in which the mappings are presented without giving explicit information on the mapping or instrument configuration.

After the improvisation session, 2 questions were presented that focus on the musical experience and creativity. We believe that during improvisation, the musicians are more likely to focus on the musical result than on the technical aspects of the instrument, so it was important to obtain their feedback regarding the music as well as the instrument. The two questions are as follows:

- How do you feel about the music you just created?
- How was your experience playing the instrument?

These two questions encourage emotional and artistic feedback right after the performance when it's most fresh in the performer's mind, thus opening for more technical insights when the participant answers the 2nd question.

To evaluate the effect of the mapping on the performer's experience when discovering the Ballagumi, we slightly changed the questions in the 2nd session after the improvisation. They are as follows:

- This time, how do you feel about the music you just created?
- How would you compare your experience playing the instrument in this session versus the last session?

These two questions were followed by a final question that would allow to explicitly compare the two mappings.

- Which set-up would you like to spend more time on in the future?

This last question also encourages the musician to provide us with ideas about how to improve the instrument and both mappings.

5.1.5 Analysis method

As described above, we conducted the second study with professional musicians each playing both the the direct energy input mapping and the the continuous energy input mapping (requiring constant movement of the middle curve). The musicians' verbal descriptions that we have collected during the interviews contained valuable information that can be looked at using qualitative analysis. Due to the exploratory nature of our study, a content analysis approach was preferred to a discourse analysis approach that would be more appropriate for an experiment looking at very specific aspects of the instrument. We chose the constant comparison technique of Grounded theory that allows researchers to identify emergent concepts in verbal data, and then to classify these concepts into larger categories.Together with the design of the interview guide, this analysis technique minimized the bias from the experimenters' knowledge about the instrument.

5.2 Results

This study was a carefully designed experiment with professional musicians using tasks and interview questions that were directed at answering the two main objectives of the research:

a) how do musicians learn to play a new instrument where they have minimal cultural and/or personal reference

b) whether the choice of mapping has an influence on their interaction.

The observations during the study and the interview results after each session are presented below.

5.2.1 Observations during the task completion

Playing the continuous energy input mapping, all four participants needed a direct hint as to which gesture controls the volume. This occurred regardless of the order of mappings presented to the participants. The three sound excerpts were more difficult to recreate with the continuous energy input mapping, regardless of the order in which the mappings were presented though once learned, they could continue playing them consistently. During the second session (regardless of the choice of mapping), at the beginning participants tried to recreate the sound excerpts using gestures learned from the previous session before realizing that a different configuration was in place. Since the sound excerpts were the same between mappings, sometimes the participants obtained the same excerpt to reproduce. Participants in general were more quick in reproducing the sounds when changing from a continuous-energy input mapping in the first session to a direct-input mapping (isotonic) in the second session.

During the task replication session, participants needed the hints for 10 out of 12 tasks[1] for the continuous-energy input mapping vs. 5 out of 12 tasks for the direct-energy input mapping, which suggests that a direct-energy input mapping is initially easier to play. All 4 participants preferred a minimalistic approach to improvisation with slow movements and gradual changes to gestures.

5.2.2 Analysis of the task replication feedback

Using content analysis by Grounded theory [57] on the feedback given after the task analysis part, we identified the following four main categories:

- Instrument
- Learning
- Experimental procedure
- Mapping differences

Instrument

All four participants commented on the design and feel of the instrument as well as its intrinsic haptic properties that affect musical creation. The instrument in general is viewed as unique, interesting and interactive although there are several factors that impede participants from having an instant liking to the instrument. While all 4 participants commented on the shape of the Ballagumi, participant 3 emphasized its symmetry and how the symmetry in the instrument shape initially suggested symmetric gestures. The fact that the two designed mappings for the instrument do not incorporate symmetric gestures thus leaded

[1] 4 participants performing 3 tasks for each mapping

to a challenging first impression. Participants also noticed the existence of latency in the sound compared to the gesture speed; this latency was due to the speed of the USB port and the parsing of ASCII formatted data as mentioned in section 3.2.2. 2 Participants discussed the weight of the instrument and how it seemed heavy at the beginning of the tasks, though the discovery of lighter gestures later on changed this perspective.

Learning

For learning, the feedback mainly concerned the instrument's learning curve; all 4 participants mentioned that the learning curve does not follow a constant path; 2 participants said that there is a faster learning at the beginning since they are just exposed to the instrument, towards the end of their interaction, the pace of learning slows down however certain features of the instrument become more intuitive to the participants. In terms of understanding the learning curve, one participant specifically mentioned that learning the instrument also gives way to more questions being raised, which in turn makes the interaction more complex. This may be why the learning curve is not constant, however a more detailed study will be needed to confirm this finding.

All 4 participants were able to figure out the basic functionality of the instrument fast and confirmed improving throughout the tasks though, since the tasks were counterbalanced, their levels of difficulty were also mixed causing 2 participants to have slightly more difficult tasks at the beginning and easier ones after. Participant 3 also mentioned that seeing someone else play the instrument would give them a lot of contextual information that would help with learning. These observations suggest that, to study the different dimensions of learning an instrument such as the Ballagumi, a longer, longitudinal study focused on the learning patterns is required.

Experimental procedure

"Having tasks helps focus the learning" was a comment made by Participant 1. 2 of the 4 participants explicitly mentioned that the tasks help build an understanding of the instrument and focus the player's attention towards the essential gestures. Regarding the hints provided during this session, 2 out of 4 participants mentioned that having hints to guide the task reproduction was beneficial, both of these participants said this after playing the instrument with the continuous energy input mapping, confirming our observation in 5.2.1. 1 participant also mentioned that for more complex tasks he would potentially need more hints even if he has become familiar with the instrument.

Mapping differences

All 4 participants confirmed instantly noticing a mapping change during the 2nd session. During the second session, 1 participant emphasized that being familiar with one mapping (from the previous session) impedes learning the next mapping right away and thus prolongs the reproduction of the tasks at the beginning. However once he forgets the first configuration then the current mapping becomes as intuitive to play in as the first one.

5.2.3 Observations during the Improvisation

Each of the 4 participants used different gestures to create music, suggesting that the Ballagumi did not encourage a primary set of gestures. While in both mappings the middle curve was designed to control the sound volume, often times other parts of the instrument also contributed to the deformation of the middle thus changing sound. Participants were able to create and manipulate the sound without explicitly determining a gesture that moves the middle curve.

5.2.4 Analysis of the interviews after the improvisation

Using content analysis by Grounded theory [57] on the interview feedback, we identified the following four major categories:

- Instrument and sound properties
- Learning
- Musical interaction
- Mapping differences

5.2.5 Instrument and sound properties

All 4 participants noted the haptic features of the instrument, 2 participants noticed the existence of predefined sounds and 1 noted that the predefined sounds help build a musical framework. Participants were sensitive to the development of musical material during their improvisation and 2 out of 4 mentioned that musical complexities need to be gradually added to the instrument. All 4 participants noticed the existence of latency, again due to the software configuration. The influence of the latency on the musical outcome was discussed in more detail with participant 3 emphasizing as well that the latency complicates the finding of intuitive gestures.

5.2.6 Learning

With regards to learning, several comments were made after the improvisation however as in section 5.2.2 these results indicate the need for a more extensive study. 2 out of the 4 participants mentioned the importance of learning the instrument on an intuitive level or "Mastering the instrument". They also note that having the intuitive understanding of the instrument leads to a more enjoyable improvisation. 2 participants also mentioned the difference in learning between session 1 and session 2. In session 2, being already familiar with the instrument from session 1 changes the musician's experience regardless of the choice of mapping in place.

5.2.7 Musical interaction

Musical Interaction includes several sub-categories that are interlinked and thus can be grouped together. These include:

- Gestures
- Effort
- Energy transfer from gesture to sound
- Improvisation styles

In general, all 4 study participants expressed the need to easily create continuous sounds, regardless of the mapping they were using. It seems that given the physical look and feel of the instrument, being able to hold a sound for a desired amount of time is expected by participants. Participants also mentioned the importance of being able to go to silence when desired in order to shape musical material. The exchange of continuity and discontinuity helps shape a musical thought especially in an improvisation setting. This was specifically mentioned by one participant who at the time of his performance (because of a bug in the system), had a more difficult time obtaining silence with the direct energy input mapping. All four participants also discussed the influence of the position of the legs on the interaction and compared it with the hands.

For Gestures, while each person had their own set of unique gestures, all 4 participants preferred slow and large gestures in general as producing more clear and consistent sounds. Small gestures were also desired but in specific areas such as the thin wings. 1 participant also expressed the need for a gesture that instantly mutes the instrument, allowing to shape sound more easily.

“At one point, a musical decision almost becomes a physical decision”. This comment made by Participant 2 reflects the role that effort or performer energy plays in playing an instrument, especially an instrument such as the Ballagumi which by many participants was referred to as heavy, physical, and haptic. The question of effort also comes into play with different types of participants, and of different physical capabilities. This in turn affects whether the performer is willing to persist with continuous movements on the instrument in order to get continuous sounds; a case which is a necessity in the continuous-energy input mapping. From the interview feedback, the female participant in the group focused extensively on the instrument’s physical demand, and the fact that the physical gestures, while interesting are also very tiring for her level of strength. The 3 other male participants mentioned that they feel the strain after playing for a long time especially with the continuous-energy input mapping, almost as if they have to wrestle with the instrument. This is important to consider in future designs of mappings for the Ballagumi: ”how do we modify mappings such that less effort could create the same sounding effects?”.

As for energy transfer from Gesture to Sound, 2 out of 4 participants noted that the quality of gestures were not always evident in the sounds, for example a fast movement did not result in a fast change in sound, this was especially mentioned for the continuous-energy input mapping and can be due to both latency and the fact that in this mapping the signals are being filtered and integrated again, making the processing time slightly longer than the direct energy input mapping.

5.2.8 Mapping differences

When it came to the choice between the two presented mappings 3 out of 4 participants preferred the direct-energy input mapping. The participant who preferred the continuous-energy input mapping noted that being able to more easily obtain silence (a bug in the system resolved for the other 3 participants) would alter his preference. The main reasons behind the decisions were as follows: with direct-energy input it is easier to hit loud and sustained sounds, there is more control over the instrument, the mapping has a higher dynamic range and the interaction is more intuitive given the choice of interface. A full list of the concepts that influenced the participants' decisions are presented in Table 5.1.

Concepts that affected the choice of the direct energy input mapping
Ability to obtain louder sounds
Bigger dynamic Range
Instant response
Clearer conception of the performer instrument interaction
Ability to sustain continuous sounds for longer
Quality of gesture is better transferred to the quality of sound

Table 5.1 Mapping Difference - Concepts

All 4 participants mentioned that they definitely feel a difference in their interaction with the instrument, confirming our hypothesis that a mapping change does influence the overall interaction. In addition, 2 out of 4 participants said that the direct-energy mapping is more dynamic, and that it has a clearer transfer of gestural energy to sound. Given that participants are also discovering new gestures while improvising, this helped their intuition more than having to constantly think about moving the middle curve of the instrument. This finding contrasts (to an extent) Hunt's suggestion that incorporating energy in mapping would make for a more engaging interaction [28]. The finding emphasizes the design of the input device as an important factor to consider in the mapping design. Given the input device's haptic features and hard physical build, holding a position for sustained sounds requires physical energy as well and perhaps too much energy. Therefore, both mappings demand performer energy, but each in a different way. This may explain the contrast with Hunt's suggestion. As well, all participants mentioned their desire to create and maintain continuous sounds with the Ballagumi, something which is more difficult to accomplish with the continuous energy input mapping. Another factor in energy requirement is the need to use both hands; for the continuous energy input mapping that gives less freedom to the performer and also forces him/her to focus on both hands at all time.

The Ballagumi as a whole is a complex yet continuous instrument and consists of multiple layers. According the Hunt et al. "mapping is an integral part of the instrument" [27] and as an abstract concept could extend from various points in the gesture to sound process and could also be divided into multiple layers. If the acquisition of the signals, the usage and mapping and the addition to the synthesizer are all considered as part of the mapping, for both of the two inner mappings that were explicitly designed, the mapping block as a whole will be considered as complex. The choice of the physical interface and the transmission of the signals from the point of contact to the mapping block and to the sound all constitute the instrument. The fact that musicians preferred a direct energy input mapping than a continuous energy input one then does not contradict the necessity of having energy input in a musical interaction, but highlights the importance of the attributes that exist in the larger mapping block, namely the feedback obtained from bending, the treatment of the signals and the ranges of sound existing in the synthesizer.

These results can also be compared with the results obtained by Jacob et al. [30], adding to their hypothesis that "performance is improved when the perceptual structure of the task matches the control structure of the device" [30]. In essence given that the Ballagumi was tested as a whole for full improvisations using both hands and legs, perhaps adding a separate abstraction layer in the mapping changes the control structure of the instrument to a more separate/percussive control while the task remains integral: improvising with mainly "continuous-timbre" sounds to create music.

5.3 Summary

This study was carefully designed to benefit from a creative and musical context in evaluating the Ballagumi. 4 participants who were professional musicians with experience with digital instruments were chosen to play the instrument, each with both mappings in random order. Comments from their follow-up interviews were analyzed used qualitative analysis by grounded theory leading to the discovery of 4 major categories where the interaction is described: Instrument, Learning, Musical Interaction and Mapping Difference. Within each category, participants commented on both the physical features of the instrument and the improvisation process. The most important comment finding was that the direct energy input mapping was preferred by 3 out of 4 participants to the continuous energy input mapping. The reasoning behind this decision comes from the fact that the instrument is very physical and thus adding an additional layer that demands physical energy is less intuitive and makes it harder to learn the instrument.

Chapter 6

Conclusion and Future Work

Musically informative evaluations of DMIs are slowly becoming more common among researchers however given the lack of historical background and pedagogy, they are complicated to design. There is then a need to devise methodologies to study learning on DMIs. HCI is a research domain that shares the basic criteria needed to study DMIs as some configurations regarding general computer interfaces also apply to DMIs, however evaluation methods from HCI need to be altered to take into consideration the musical context in which DMIs exist.

The Ballagumi is an alternative DMI with unique properties that minimize its resemblance to existing instruments, going as far even as having no buttons or strings. This makes the Ballagumi ideal for conducting studies that look at learning and creativity on DMIs and that don't need to consider musical bias as a major factor in the interaction. At the same time, the Ballagumi is a new instrument, never played before and thus participants who took part in its evaluations are literally the first musicians ever to play the instrument. After setting up the instrument with two distinct mappings, a new synthesizer and novel compositions, new evaluation methodologies were applied to evaluate it in a musical context.

The two objectives of the research were: whether the Ballagumi can be learned and enjoyed by musicians, and whether the choice of mapping influences this experience. To answer these questions two studies were conducted. These studies contributed to expanding evaluation techniques on DMIs and also helped to look at musicians' changes of perspective when there is a change in the mapping layer of a DMI.

From the two studies conducted on the Ballagumi, the first study was a preliminary step to discovering the gestural possibilities of the instrument. The gesture results from this study permitted to compose a piece of music which was subsequently used in the second study to assess professional musicians' capabilities of learning the instrument. Questionnaire results from this study gave feedback on improving the instrument, but were not coherent enough, therefore requiring a second study.

The second evaluation study was designed to minimize bias from cultural experience and background while taking advantage of the fact that the participants are improvisers, professional musicians and familiar with DMIs in a performance setting. This study included a task replication session and an improvisation session followed by interviews.

The results from the second study not only gave important insights on the Ballagumi itself and the state of its mappings, they demonstrated the important role of the physical interface when studying mappings. The fact that the study participants preferred a constant energy input mapping to one requiring continuous energy and movement contrasts to an extent, the findings by Hunt [23]. This extent being again the significance of the properties of the physical interface in the experiment set-up (determined from content analysis of the participants' feedback). The Ballagumi is unique in the sense that even without sound, the instrument is "interactive" and requires physical effort to be manipulated. The Ballagumi's physical characteristics made it require more effort to manipulate, at least until more subtle gestures are discovered. The interface is elastic and resistant to bending; thus even small manipulations of the core require energy. This requirement of energy was deemed by participants enough to make for an interesting musical interaction with direct sound-generation. Additional requirements for energy input were more seen as frustrating than interesting (In contrast to other conventional instruments that require continuous energy such as the violin). The participant was also forced to use both hands in the continuous energy input mapping and had to continuously think about moving the left hand in order not to lose sound. Perhaps once reason why the extra energy requirement is not desired is because the same hand that is locked into moving the center piece to maintain sound could be used elsewhere in the direct energy input mapping, giving more freedom to the musician.

These results also highlighted the different perspectives achieved when the study moves beyond task-completion and allows for creativity. As an example, the preferences in mapping on the instrument are confirmed once participants are given time to be creative with the Ballagumi and really try to create music with it. In essence, while the field of HCI has the necessary groundwork to do DMI evaluation [45], more effective results are shown to be achieved by incorporating a creative context in the evaluation.

These two evaluations allowed for an initial assessment of the Ballagumi itself but also resulted in important insights about performer instrument interaction. From the final results analysis of participant interviews, it can be concluded that the fine control of an interface requires that the value of the gesture be intuitively linked to that of the sound, and for that purpose an instrument with haptic features such as the Ballagumi has more initial clarity when the abstract mapping layer is kept as a direct-energy input mapping, thus allowing for the intuitive link to be made quickly without having to think of other abstract layers.

The insights from these evaluations also presented the areas of improvement for both the instrument and future experiments. In the future, we plan to firstly improve the signal acquisition method on the instrument. This includes modifying the parsing script to read directly from binary data, changing the data printing rates to avoid a bottleneck at the USB input, and stabilizing the optical fibres themselves to have more control. Changes to the instrument structure include making it slightly lighter, moving the optical fibres from under the instrument to have better control with the legs and adding more flexibility to the core to reduce the physical demand on the musician. If bending the silicone becomes slightly easier, perhaps a continuous energy input mapping would have more potential for being an engaging mapping as the gesture to create sound would become almost automatic. In terms of future experiments, a study with a longitudinal design would benefit the research in providing more insights on the learning aspect of the instrument. Further analysis of the current evaluation data (analysis of gestures from the second study or a discourse analysis method) could also be applied to extract more results.

References

[1] J. Accot and S. Zhai. Beyond Fitt's Law: Models for Trajectory-Based HCI Tasks. In *Proceedings of the 1997 SIGHI conference on Human factors in computing systems*, pages 295–302, 1997.

[2] J.-M. Adrien. The missing link: modal synthesis. In G. De Poli, A. Piccialli, and C. Roads, editors, *Representations of musical signals*, pages 269–298. MIT Press, Cambridge, MA, USA, 1991.

[3] A. G. Almeida. Methodologies for Design and Evaluation of Interactive Musical Interfaces. In *Proceedings of the 3rd Brazilian Symposium on Computer Music*, pages 68–72, 1996.

[4] C. Antaki, M. Billig, D. Edwards, and J. Potter. Discourse Analysis Means Doing Analysis: A Critique of Six Analytic Shortcomings. *Discourse Analysis Online*, 1(1), 2003.

[5] F. Baldé. junXion, 2005. Available: `http://steim.org/product/junxion/`.

[6] F. Bevilacqua, R. Müller, and N. Schnell. MnM: a Max/MSP mapping toolbox. In *Proceedings of the 2005 conference on New Interfaces for Musical Expression*, pages 85–88, 2005.

[7] S. Bilbao. *Numerical Sound Synthesis*, chapter Sound synthesis and physical modelling, pages 1–18. Wiley, Chichester, 2009.

[8] I. Bowler, A. Purvis, P. Manning, and N. Bailey. On mapping N articulation onto M synthesiser-control parameters. In *Proceedings of the 1990 International Computer Music Conference*, pages 181–184. International Computer Music Association, 1990.

[9] G. A. Bowley. The Fiber Optic Guitar. In *Audio Engineering Society Convention 70*. New York, NY, USA, October 1981.

[10] D. F. Buchla. System and method for detecting deformation of a membrane. Patent application, June 1999. United States Patent 5913260.

[11] J. Butler. Creating Pedagogical Etudes for Interactive Instruments. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 77–80, 2008.

[12] C. Casciato. On the Choice of Gestural Controllers for Musical Applications: An Evaluation of the Lightning II and the Radio Baton. Master's thesis, McGill University, August 2007.

[13] D. Chapuis, R. Gassert, L. Sache, E. Burdet, and H. Bleuler. Design of a simple MRI/fMRI compatible force/torque sensor. In *International Conference on Intelligent Robots and Systems*, volume 3, pages 2593–2599, 2004.

[14] J. Chowning. The Synthesis of Complex Audio Spectra by means of Frequency Modulation. *Journal of the Audio Engineering Society*, 21(7):526–534, 1973.

[15] M. Collicutt, C. Casciato, and M. M. Wanderley. From Real to Virtual : A Comparison of Input Devices for Percussion Tasks. In *Proceedings of the 2009 International Conference on New Interfaces for Musical Expression*, pages 1–6, 2009.

[16] S. Fels, A. Gadd, and A. Mulder. Mapping transparency through metaphor: towards more expressive musical instruments. *Organized Sound*, 7:109–126, August 2002.

[17] P. M. Fitts. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 74:381–391, 1954.

[18] M. K. Geoffrey Morris, Sasha Leitman. SillyTone Squish Factory. In *Proceedings of the 2004 Conference on New Interfaces for Musical Expression*, pages 201–202, 2004.

[19] B. G. Glaser and A. L. Strauss. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine de Gruyter, New York, NY, USA, 1967.

[20] C. Goudeseune. Interpolated mappings for musical instruments. *Organized Sound*, 7: 85–96, August 2002.

[21] A. Hollinger. Design of fMRI-compatible electronic musical interfaces. Master's thesis, McGill University, 2008.

[22] A. Hollinger and M. Wanderley. Optoelectronic Acquisition and Control Board for Musical Applications. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*. University of Michigan, May 21-23 2012.

[23] A. Hunt. *Radical User Interfaces for Real-time Musical Control*. PhD thesis, University of York, UK, 1999.

[24] A. Hunt. *Radical User Interfaces for Real-time Musical Control*. PhD thesis, University of York, 1999.

[25] A. Hunt and R. Kirk. Mapping Strategies for Musical Performance. In *Trends in Gestural Control of Music*. IRCAM - Centre Pompidou, Paris, 2000.

[26] A. Hunt and M. M. Wanderley. Mapping performer parameters to synthesis engines. *Organized Sound*, 7(2):97–108, August 2002.

[27] A. Hunt, M. Wanderley, and R. Kirk. Towards a Model for Instrumental Mapping in Expert Musical Interaction. In *Proceedings of the 2000 International Computer Music Conference*. International Computer Music Association, 2000.

[28] A. Hunt, M. Wanderley, and M. Paradis. The Importance of Parameter Mapping in Electronic Instrument Design. *Journal of New Music Research*, 32(4):429–440, December 2003.

[29] D. Isaacs. Evaluating Input Devices for Musical Expressions. Master's thesis, University of Queensland, Australia, 2003.

[30] R. J. K. Jacob, L. E. Sibert, D. C. McFarlane, and J. M. Preston Mullen. Integrality and separability of input devices. *ACM Transactions on Computer-Human Interaction*, 1(1):3–26, 1994.

[31] T. Jehan, A. Freed, and R. Dudas. Musical Applications of New Filter Extensions to Max/MSP. In *Proceedings of the 1999 International Computer Music Conference*, pages 504–507. International Computer Music Association, 1999.

[32] K. S. C. Kuang, W. J. Cantwell, and P. J. Scully. An evaluation of a novel plastic optical fibre sensor for axial strain and bend measurements. *Measurement Science and Technology*, 13(10):1523, 2002.

[33] Y. Liu, J. Williams, and I. Bennion. Optical bend sensor based on measurement of resonance mode splitting of long-period fiber grating. *Photonics Technology Letters, IEEE*, 12(5):531 –533, may 2000.

[34] J. Malloch. A Consort of Gestural Musical Controllers: Design, Construction, and Performance. Master's thesis, McGill University, August 2007.

[35] J. Malloch and S. Sinclair. The Digital Orchestra Toolbox, 2008. Available: `www.idmil.org/software/dot`.

[36] J. Malloch, D. Birnbaum, E. Sinyor, and M. M. Wanderley. Towards a New Conceptual Framework for Digital Musical Instruments. In *Proc. of the Int. Conf. on Digital Audio Effects (DAFx-06)*, pages 49–52, September 2006.

[37] J. Malloch, S. Sinclair, and M. M. Wanderley. From controller to sound: tools for collaborative development of digital musical instruments. In *Proceedings of the 2007 International Computer Music Conference*, pages 65–72, 2007.

[38] J. Malloch, A. Hollinger, S. Sinclair, and M. Wanderley. Input Devices and Music Interaction. In *Musical Robots and Interactive Multimodal Systems*, volume 74, pages 67–83. Springer Berlin, Heidelberg, 2011.

[39] MIDI Manufacturers Association Incorporated. The Technology of MIDI, 2008. Available: `http://www.midi.org/about-midi/abtmidi.shtml`.

[40] E. R. Miranda and M. M. Wanderley. Musical Gestures: Acquisition and Mapping. In *New Digital Instruments: Control and Interaction Beyond the Keyboard*. A-R Publications, 2006.

[41] A. Momeni and C. Henry. Dynamic Independent Mapping Layers for Concurrent Control of Audio and Video Synthesis. *Computer Music Journal*, 30:49–66, March 2006.

[42] J. D. Morrison and J.-M. Adrien. Mosaic: A framework for modal synthesis. *Computer Music Journal*, 17(1):45–56, 1993.

[43] M. D. Myers. Qualitative Research in Information Systems. *MIS Quarterly*, 21(2), 1997.

[44] P. V. O'Neil. *Beginning partial differential equations*. Pure and Applied Mathematics (Hoboken). Wiley, Hoboken, NJ, second edition, 2008.

[45] N. Orio, N. Schnell, and M. M. Wanderley. Input devices for musical expression: borrowing tools from HCI. In *Proceedings of the 2001 conference on New interfaces for musical expression*, pages 1–4, 2001.

[46] M. Orth and G. Weinberg. Music Shapers. Available: `http://www.media.mit.edu/hyperins/projects/shapers.html`.

[47] T. H. Park. An Interview with Max Mathews. *Computer Music Journal*, 33(3):9–22, 2009.

[48] B. W. Pennycook. Computer-music interfaces: a survey. *ACM Computer Survey*, 17 (2):267–289, June 1985.

[49] X. Pestova, E. Donald, H. Hindman, J. Malloch, M. T. Marshall, F. Rocha, S. Sinclair, D. A. Stewart, M. M. Wanderley, and S. Ferguson. The CIRMMT/McGill Digital Orchestra Project. In *Proceedings of the 2009 International Computer Music Conference*, pages 295–298, 2009.

[50] J. Rovan, M. Wanderley, S. Dubnov, and P. Depalle. Instrumental gestural mapping strategies as expressivity determinants in computer music performance. In *Proceedings of Kansei-The Technology of Emotion Workshop*, pages 3–4, 1997.

[51] V. Rudararaju. A Tool for Configuring Mappings for Musical Systems using Wireless Sensor Networks. Master's thesis, McGill University, December 2011.

[52] S. Sinclair. Mapper Rec, 2011. Available: `https://github.com/radarsat1/mapperRec`.

[53] E. Singer. Sonic Banana: A Novel Bend-Sensor-Based MIDI Controller. In *NIME*, pages 220–221, 2003.

[54] H.-C. Steiner. [hid] toolkit: a unified framework for instrument design. In *Proceedings of the 2005 conference on New interfaces for musical expression*, pages 140–143, 2005.

[55] D. Stowell, M. D. Plumbley, and N. Bryan-Kinns. Discourse analysis evaluation method for expressive musical interfaces. In *Proceedings of the Conference on New Interfaces for Musical Expression*, pages 81–86, 2008.

[56] D. Stowell, A. Robertson, N. Bryan-Kinns, and M. D. Plumbley. Evaluation of live human-computer music-making: Quantitative and qualitative approaches. *International Journal of Human Computer Studies*, 67(11):960–975, November 2009.

[57] A. Strauss and J. M. Corbin. *Basics of Qualitative Research : Techniques and Procedures for Developing Grounded Theory.* SAGE Publications, Sept. 1998.

[58] R. Vertegaal. An Evaluation of Input Devices for Timbre Space Navigation. Master's thesis, Department of Computing - University of Bradford, 1994.

[59] D. Wessel and M. Wright. Problems and Prospects for Intimate Control of Computers. *Computer Music Journal*, 26:3:11–22, Fall 2002.

[60] D. Wessel, M. Wright, and J. Schott. Intimate musical control of computers with a variety of controllers and gesture mapping metaphors. In *Proceedings of the 2002 conference on New Interfaces for Musical Expression*, pages 192–194, 2002.

[61] M. Wright. Open Sound Control Specification, 2002. Available: `http://www.cnmat.berkeley.edu/OSC/OSC-spec.html`.

Appendix A

Ballagumi Compositions

A.1 Study 1 Compositions

The series of compositions used in Study 1 are gesture-based and were used to give participants an idea of the Ballagumi's functions using a mix of overall gestures and traditional western musical elements. They include symbols for each overall gesture, an indication of which hand to use and dynamics and rhythm.

A.2 Study 2 Compositions

For study 2, one long piece of music was composed which was later broken into smaller excerpts and recorded by the author. These excerpts were then presented to participants during the task reproduction session in the study. The full composition is presented in Figure A.6.

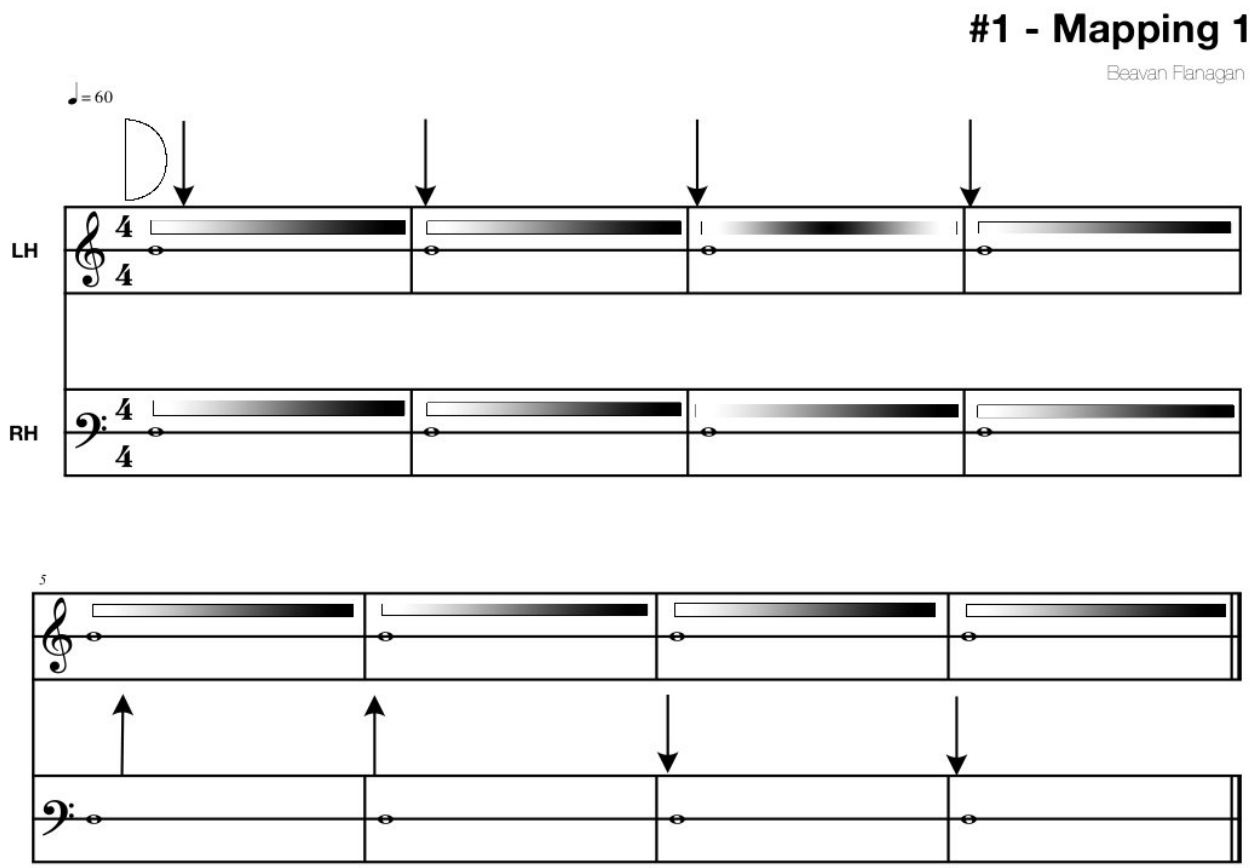

Fig. A.1 Study 1 - Composition 1

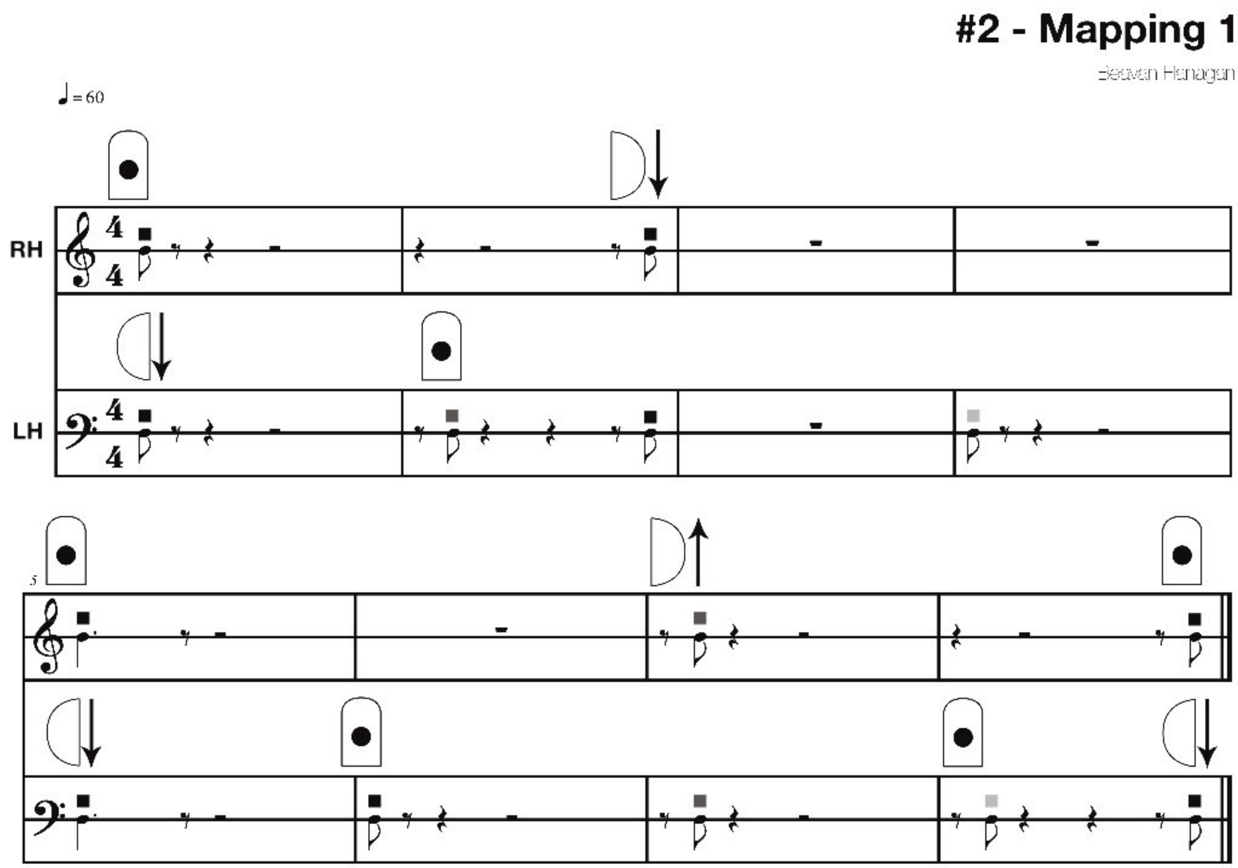

Fig. A.2 Study 1 - Composition 2

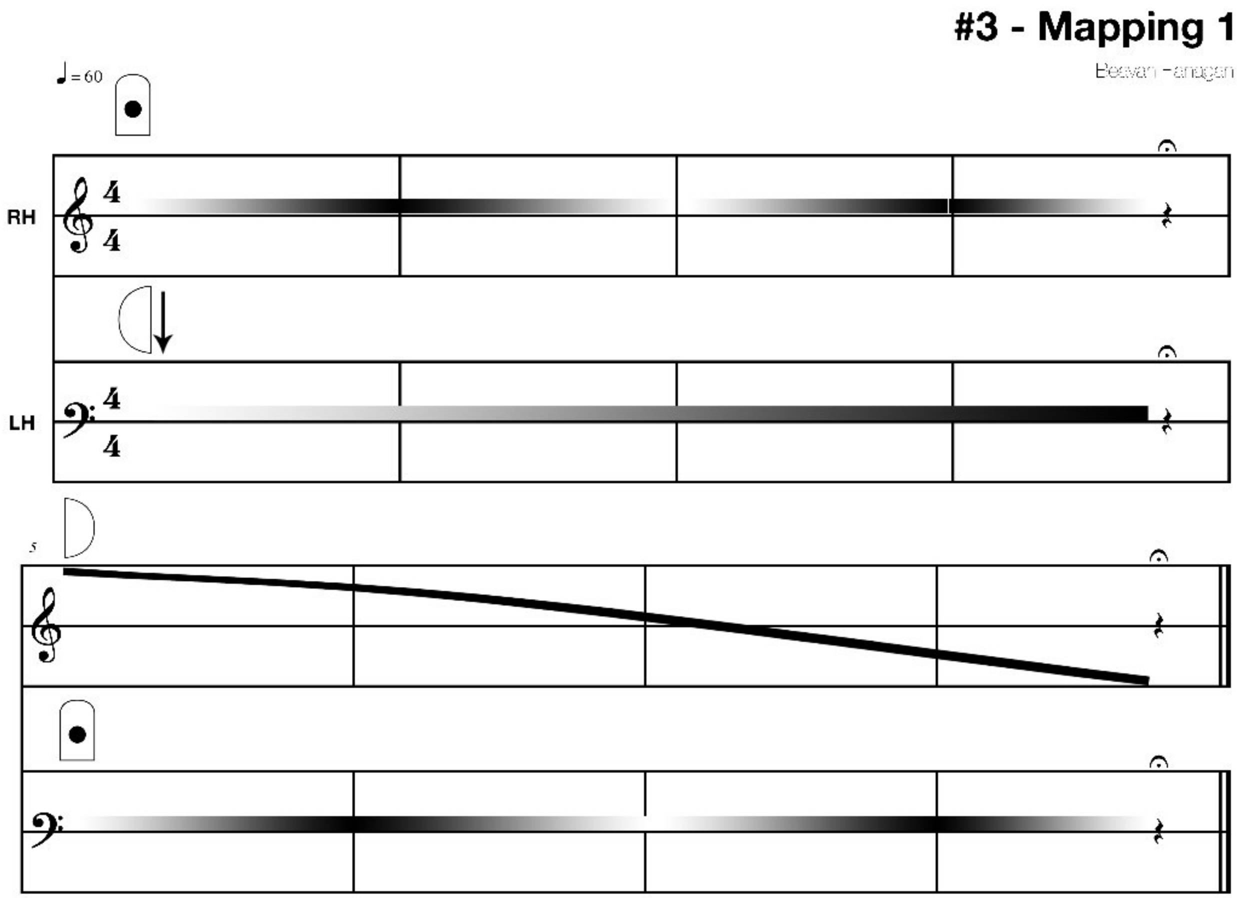

Fig. A.3 Study 1 - Composition 3

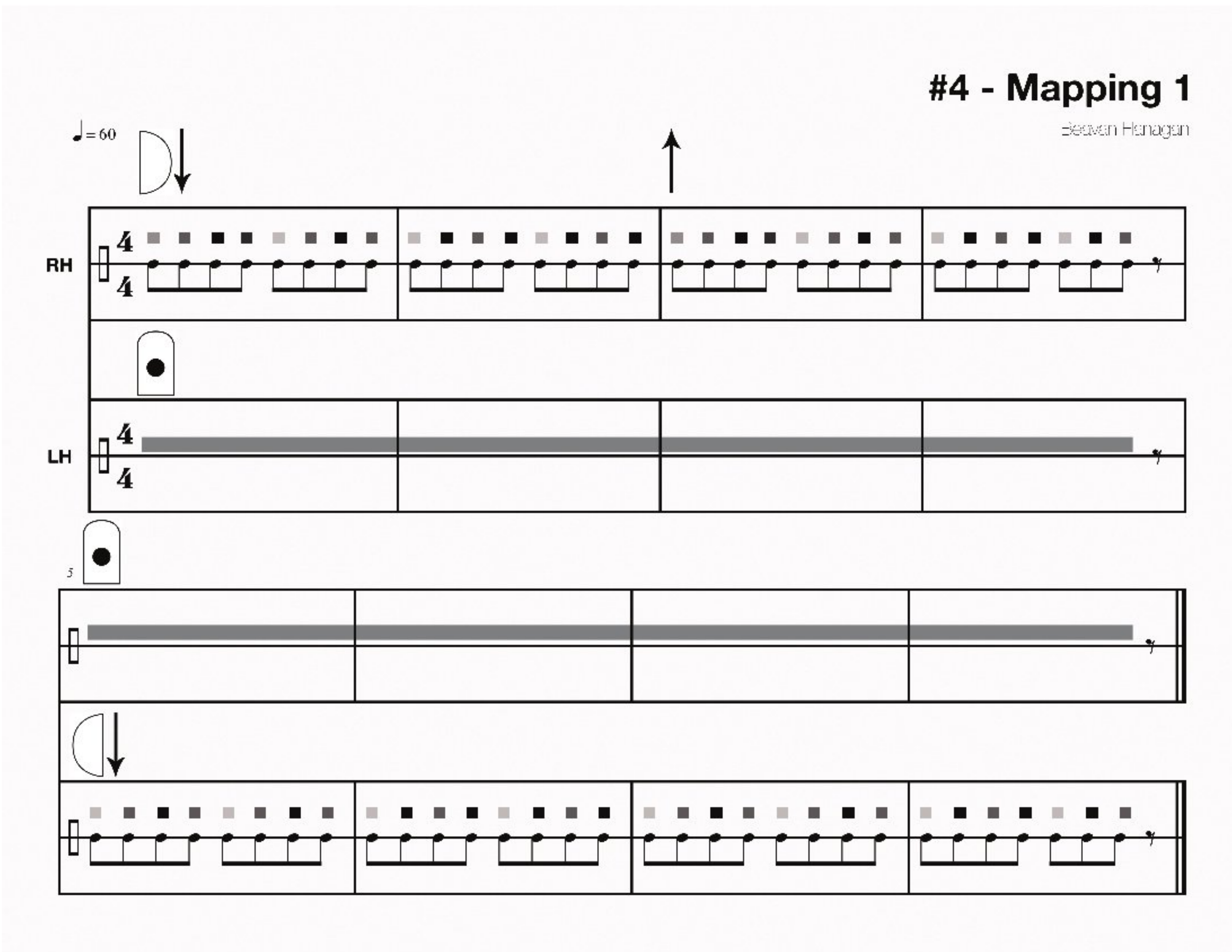

Fig. A.4 Study 1 - Composition 4

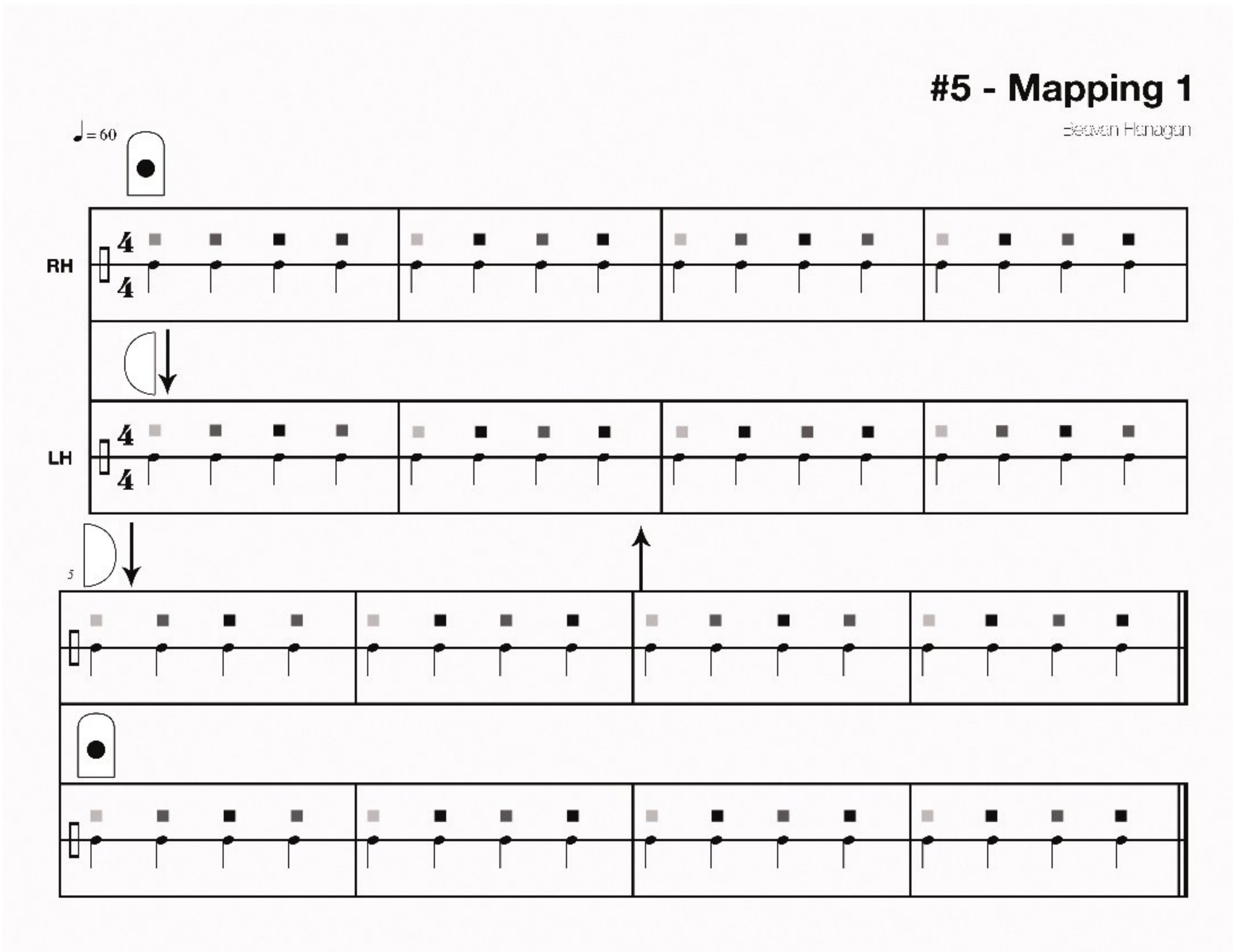

Fig. A.5 Study 1 - Composition 5

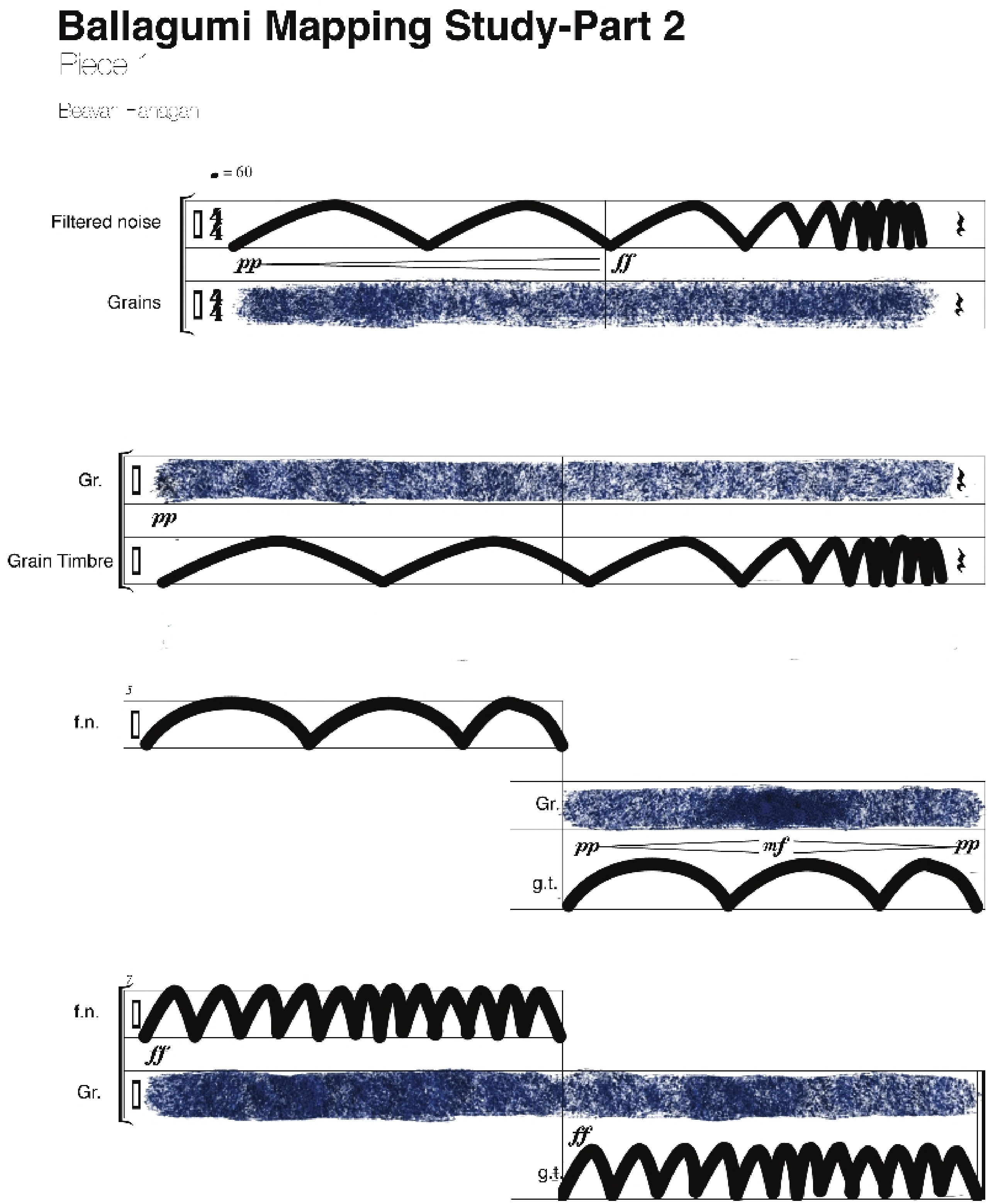

Fig. A.6 Study 2 - Complete Composition

Appendix B

Study 1: Questionnaires

The following questionnaires were handed out to participants during the first study in order to gather demographic information from the participants and to later gather their feedback on their first interaction at the end of the session.

B.1 Participant Information

B.2 User Experience Questionnaire

Participant Information

Practice ID:
Date:
Number of Sessions Played:

---

1. Age:

18 & under	18 – 21	22 – 25	26 – 29	30 – 34
35 -39	40 – 49	50 – 59	60 +	

2. Gender:

Male	Female

3. Do you play an instrument?
   a. If yes:

Name of Instrument							
Years Played (Choose from list)							
	< 1	1 -3	4 – 6	7 – 10	11 – 15	16 – 20	20 <

   b. Are you a professional musician? (Do you have university training in music?)
      i. If yes, which instrument and how many years have you been professionally playing with the given instrument?

4. Do you read music?

5. Do you have any experience with digital controllers? If yes, what have you played, for how long and at what level?

Fig. B.1 Study 1 and 2 - Participant Background Information

User Experience Questionnaire - Ballagumi

Date:

User ID:

Practice Session:

Part 1: Overall Impression

Question 1: What does the Ballagumi look like? Give a few examples

Question 2: Which parts of the instrument are contributing to making sound?

Question 3: How responsive is the instrument?

1	2	3	4	5	6	7

Immediate Response Significant Delay

Comments:

Question 5: How many sound-producing gestures did you find? What are they?

Question 6: Rank these gestures from 1 to 10 (with 1 being the most responsible) based on them being the most responsible for producing sound.

Question 6: How easy was it to learn the above gestures?

1	2	3	4	5	6	7

Very Easy Very Difficult

Fig. B.2 Study 1 questionnaire page 1

Question 8: How much pressure do you need to apply to the instrument to get the desired sounds?

1	2	3	4	5	6	7

No Pressure — Too Much Pressure
Comments:

Question 9: How much do you need to bend the instrument to get the desired sounds?

1	2	3	4	5	6	7

Not Bending — Bending Too Much
Comments:

Question 10: How difficult is it to go from very soft to very loud and visa versa?

1	2	3	4	5	6	7

Completely Effortless — Very Tiring
Comments:

Question 11: How much control do you have over the volume?

1	2	3	4	5	6	7

No Control — Complete Control
Comments:

Question 12: How much control do you have over the timbre?

1	2	3	4	5	6	7

No Control — Full Control
Comments:

Question 13: How easy is it to quickly change timbres?

1	2	3	4	5	6	7

Very Easy — Very Difficult
Comments:

Fig. B.3 Study 1 questionnaire page 2

Question 14: How much control do you have over the pitch?

1	2	3	4	5	6	7

No Control Full Control

Comments:

Question 14: How difficult is it to make rapid changes to the pitch?

1	2	3	4	5	6	7

Very Easy Very Difficult

Comments:

Question 15: Comment on which gestures you use to maintain the sound while also making changes to timbre and frequency. Which hand (s) do you use and how comfortable does it feel?

Question 15: Which aspects of the musical interaction do you feel facilitates creativity and allows for further performance development?

Fig. B.4 Study 1 questionnaire page 3

Appendix C

Study 1: Captured Gestures

The found gestures from the study participants are summarized in Tables C.1 and C.2. The last column in each table indicates the number of times each gesture was repeated amongst all the participants. As can be noted, bending the Ballagumi's wings and bending the middle curve inwards with both hands occur more often than other gestures.

These gestures contributed to understanding the range of possibilities for the Ballagumi, hence moving towards the conclusion that having tasks created directly from the synthesizer audio to reproduce would be a better approach to evaluating the Ballagumi, thus leading to the design of Study 2 (Chapter 5).

Locus	Hand/Leg	Movement	Number of repeats
Right Wing	Right Hand	Bend tip up	4
		Bend tip down	5
		Bend wing bottom up	3
		Bend wing bottom down	1
		Bend bottom corner up	12
		Bend bottom corner down	4
		Bend base up	9
		Bend base down	4
		Bend side up	8
		Bend side down	9
		Push middle of base down	6
		Percussive hit	1
		Tilt up	2
	Right Leg	Bend Up	1
Left Wing	Left Hand	Bend tip up	7
		Bend tip down	9
		Bend wing bottom up	1
		Bend wing bottom down	1
		Bend bottom corner up	9
		Bend bottom corner down	6
		Bend base up	12
		Bend base down	6
		Bend side up	6
		Bend side down	6
		Push middle of base down	6
		Percussive hit	1
		Tilt up	3
	Both Hands	Bend tip up	2
	Left Leg	Bend Up	1

Table C.1 Gestures for the Ballagumi wings discovered by first-time players - 14 players were observed in total with both Mapping 1 and 2

Locus	Hand/Leg	Movement	Number of repeats
Middle	Right Hand	Push right side inwards	4
		Push left side inwards	1
		Push left side outwards	2
		Push right corner inwards	3
		Push middle down	6
		Bend apex up	4
		Push apex down	2
		Squeeze apex	3
	Left Hand	Push ridge inwards	7
		Push left side outwards	1
		Push left corner inwards	3
		Push middle down	7
		Bend apex up	1
	Both Hands	Squeeze curve corners	2
		Push entire ridge inwards	9
		Push entire ridge outwards	3
		Push apex inwards	6
		Push middle down	2
		Push bottom corners out	1
Instrument	Right Hand	Tilt front up	2
	Both Hands	Tilt bottom up	3
		Tilt front up	4
		Lift up entirely	1
	Both Legs	Tilt left and right	2
		Tilt in and out	3

Table C.2 Gestures for the Ballagumi middle discovered by first-time players - 14 players were observed in total with both Mapping 1 and 2

Appendix D

Study 1: Questionnaire Results

D.1 Direct Energy Input Mapping

Question	Likert Scale Descriptors	Mode
How responsive is the instrument?	1: No Delay, 7: Significant Delay	5
How much control do you have over the pitch?	1: No Control, 7: Full Control	3
How easy was it to learn the sound-producing gestures?	1: Very Easy, 7: Very Difficult	3
How much pressure do you need to apply to the instrument?	1: No Pressure, 7: Too Much Pressure	5
How much do you need to bend the instrument?	1: No Bending, 7: Too Much Bending	5
How difficult is it to go from very soft to very loud and visa versa?	1: Not Tiring, 7: Very Tiring	4
How much control did you have over the volume?	1: No Control, 7: Full Control	5
How much control did you have over the timbre?	1: No Control, 7: Full Control	4
How easy is it to quickly change timbres?	1: Very Easy, 7: Very Difficult	3
How difficult was it to make rapid changes to the pitch?	1: Very Easy, 7: Very Difficult	2

Table D.1 Questionnaire Responses - Mapping 1 Trial 1 - The Mode shows the most common response in the Likert scale

Participants' responses to the open-ended questions and comments on the closed questions for the direct energy input mapping are as follows:

Participant quotes

- “Not too hard to discover the gestures but there was still room to explore, leading people to continue to practice”
- “The multitude of ways you can bend the instrument offers a very wide range of change to the sounds, textures, and timbre. Adding more wings to it would also add more possibilities to help the development of musical pieces”
- “Multi-dimensional deformation of each wing, the relationship between simultaneous gestures in multiple places”
- “Intensity of the touch (pressing force) and different points of contact. I’d like to have many ways to touch the instrument (full hand, all fingers, thumb, knife of the hand)
- “Being able to really feel the instrument but also use easily. The heaviness of the Ballagumi is advantageous in this regard”
- “Adjusting the range of each parameter to suit the performer’s position and hand/arm strength would allow them to be most expressive and develop playing techniques”
- “Because there are no keys or strings or anything you just try everything that comes to mind”
- “The malleability allows for open-ended exploration”
- “The design of the instrument is such that it allows for a very natural performance interaction. I found this to be very novel”
- “The middle is not a very good shape for pressing down”

D.2 Continuous Energy Input Mapping

Participants’ evaluation of the interface given this mapping is summarized in Table D.2.

Question	**Likert Scale Descriptors**	**Mode**
How responsive is the instrument?	1: No Delay, 7: Significant Delay	4
How easy was it to learn the sound producing gestures?	1: Very Easy, 7: Very Difficult	3
How much pressure do you need to apply to the instrument?	1: No Pressure, 7: Too Much Pressure	6
How much do you need to bend the instrument?	1: No Bending, 7: Too Much Bending	6
How difficult is it to go from very soft to very loud and visa versa?	1: Not Tiring, 7: Too Tiring	7
How much control did you have over the volume?	1: No Control, 7: Full Control	3
How much control did you have over the timbre?	1: No Control, 7: Full Control	6
How easy is it to quickly change timbres?	1: Very Easy, 7: Very Difficult	5
How much control do you have over the pitch?	1: No Control, 7: Full Control	3
How difficult was it to make rapid changes to the pitch?	1: Very Easy, 7: Very Difficult	2

Table D.2 Participant Responses - Mapping 2 - The Mode shows the most common response in the Likert scale

Participants' responses to the open-ended questions and comments on the closed questions for the continuous energy input mapping are as follows:

Participant quotes

- "The more subtle bending it can process, the better."
- "New gesture is found: bending both sides of the middle section"
- "Getting the whole upper body involved [is helpful] as shoulders rarely get to be musical, this involvement also comes with making more sound"
- "One wing was very responsive but the centre sound source was very slow"
- "There was a lot of lesser bending which didi not elicit any sound"
- "Timbres were quick to turn on and off, harder to know which timbre I was getting with a given gesture"
- "Moving between the centre (unsustained/delayed sound) and wings without losing sound [would help]"
- "Hard bend of middle sections (contributed to making sound)"
- "The torquing of the side lobes was interesting to play with and would be more fun if we were better able to create the sound in the first place"
- "More responsiveness and a higher degree of control on the volume would facilitate the interaction with the instrument"

Appendix E

Study 2 : Interview Quotes

The following sections corredpond to the major categories found during the qualitative analysis of interview results by grounded theory. The direct participant quotes that resulted in the final analysis are provided below as per the main category. The main categories are: *Intstrument, Learning, Musical Interaction* and *Mapping Difference*

E.1 Instrument

Below are the participants' comments regarding how the instrument form affects the musical interaction:

Participant 1

- there's [...] the limitations of the (instrument) let's say; because there's still a musicality that is there already, which are the tones that you chose, so you play with that; and it's how to modulate those tones [that takes learning], it can be a really slow process. The instrument is not limitative in an aesthetic sense but you have a sound that we have to play with [...] it creates already like a framework to modulate. You modulate something that's already there

- I like the shape of it [the instrument], I found that it's really ergonomic, and interestingly ergonomic

- I thought more about what the form of the object itself was suggesting

Participant 2

- What I feel at some point that behind the instrument is is a set of sounds predefined.
- I would probably think that if I go on experimenting for a significant amount of time, it would be interesting to have control over the sounds other than just with this that you can get different sets of sounds like with pedals, that you can change registers or you can change volumes.
- It is surprisingly physical.
- It has this kinds of very natural shaped surface on top but then something very kind of strong static bottom

Participant 3

- What I like of this object (is) it's fairly inspiring musically. It's shaped in a way that there's resistance, it's opposed to any deformation I can make on it, it's very it's very inspiring for that.
- I like the fact that you have to touch it to make sound and I like the fact that it wants to go back to its natural position, you bend it it goes back to this position and it's easy to bend and you don't feel like you're going to break it.
- There are clearly musical characteristics that are enjoyable about this thing
- When I see such a symmetrical thing, it doesn't call for bimanuality, it would have been more obvious if there had been a neck or something if it had been asymmetrical, I would probably have understood that it's expected for me to do different things with my two hands
- The latency . I would say it's more than noticeable. Just and looking at the screen tells me [that] there must be more than 100 milliseconds here. Maybe just fixing that would improve the other problem I was noticing, the problem of repeatability.
- There's something about it that wants to be plucked, like this (demonstrates gesture) and it feels like gello and it vibrates and it has an intertial characteristic

- It's heavy and also the fact that there's this big stake of cables in that and it can be OK if I were to choose an interface to show on stage I would rather not have that.
- The big strength of this thing is its haptic features,

Participant 4

- It's interesting, it's kinda like a sea creature like umm . it reminds me of a Sting Ray body or something, (laughs) and the sounds are watery too so that fits with it too.
- It seems like there is only a few points where if you just touch it something happens.
- It's really a unique form, it's very sort of like a control interface on some spaceship that's half biological 500 years in the future or something you know?? and the sounds are reminiscent of that this kind of like half biological half technological creature which I think is cool, I like that It's not like a hard plastic digital box, it's something soft and it's something that you could relate to.
- Have you thought about putting it on a table? maybe if you could sit down and there's a table that comes out then again when it's on the lap it's more connected to the body so I understand why you want to keep it that way.

E.2 Learning

Regardless of the choice of mapping, 4 out of 4 participants mentioned the fact that having a novel interface can be overwhelming and they have no cultural or musical references to start playing well right away. Learning is a major factor in all experiences and the tasks given to facilitate the learning process are found useful, even though between mappings, participants had more trouble accomplishing a task with Mapping 2 than with Mapping 1.

Participant 1

- if you really go soft, it then you get really beautiful things, because then your ear(s) are getting in tune with the instrument

- it's great though, once you get tuned to it[The Ballagumi] like that then you can really get it
- I could play hours with that .. like it's a thing that the more you play and more you get like a sense of what it can create too
- if you have too many possibilities uhhh . that will be tough to learn the instrument.

Participant 2

- There's still quite a bit of trial and error
- If I would improvise on a violin which I know I can kind of, my approach in a sense would be different so far as I'd know much more what's going to come out
- When improvising with this instrument I reduced my my exploration in a sense
- The longer you work on this the more you can find. Then you also can put it more into categories.
- Like you try to get a basic control of what you can do so if you improvise at least, it's clear that you can't explore the whole the whole range of possibilities
- This instrument somehow has no references

Participant 3

- There is no way I would actually show up on a stage with this level of preparation
- Having no knowledge at all of the mapping that is used or the sound synthesis algorithm I mean I have an idea of what it might be but I don't know how the mapping is done and how you . what was the intention behind it, so it's really hard yeah I'm realizing while I'm saying this . there is a lot of information that we have when we play a musical instrument that ... comes from well culture or even knowledge or personal experience.
- When I got here I already knew what it was the Ballagumi. I knew it was made out of optic fibres and that the mapping strategy that would be used eventually would

involve neural networks or some sort of implicit mapping, so but from that I couldn't extrapolate what it does. That doesn't really tell you about the how the music is going to be made.

Participant 4

- The experience playing the instrument was awkward definitely, because of the size of my hands and because of not really knowing what's going on at the beginning.
- I guess I just haven't had enough time on it to figure out what does what
- And if there was more control units like actually in the thinner wings, you could get more subtlety you know I could be like just twisting it slightly
- It's hard to tell [with session 2] because I'm also more experienced with it now. so I can't tell if i just like this one lot better or if it's because I'm just also getting a little more of endurance ..... ummm I was more aware my legs and i was putting my legs closer together instead of working them the angle when i was bending them, it was responding more and it would have more sensitivity i thought.
- I just feel like I locked into a few things.

E.3 Music and Improvisation Aesthetic

As all participants are musicians and have experience with Digital Interfaces, they each expressed their personal style which affects their improvisation approach even on a new instrument.

"Minimalism" and "Slow Shifts" were some of the trends mentioned by participants in explaining their improvisation style. Similar words were used to explain why participants maintain certain gestures and limit their sound to a framework. The following phrase by Participant 2 is an explanation of how from simple gestures, an improvisation is built.

Participant 1

- I preferred when I was more manipulative and more I was delicate with it [...] but that's my taste also; I like it when it's delicate. Like you just do a tiny thing and then I find that your perception gets tuned with it and then it becomes very interesting, because it's so subtle.
- Like I said for me it was mainly when I was like more minimal and mainly in-tune to it that I was happy with the result,
- The more I was sensitive with how the material was developing and be[ing] quite careful with the object, the happier I was
- I tried something really fast but I went back to just doing little shifts slowing and I found it was for me more aesthetic, or more suitable for my taste and my ear.
- In the first session, I liked the fact that it could be really dynamic.

From Participant 1's comments regarding the Musical Material, the words that are emphasized over and over are as follows: Subtle, Soft, Minimal, and Dynamic.

Participant 2

- For me [Improvisation means] changing the approach from exploring to working with what I have.
- What happens is if you find certain things which you like when you start improvising, then you just try to stick to them.
- I was looking for sustained sounds, I'm coming from a sustained instrument, so I'm working a lot with sustaining sounds rather than percussive single events that certainly influences my style of improvisation.
- I like to have round kind o f sounds and sound-scapes and sound fields which then have relatively subtle changes in the interior

Participant 4

- With digital, digitally controlled things in general, like it's not, it's not what I'm most interested in sonically, it's not my aesthetic. I work more with raw and unprocessed tones, my perspective is completely biased just because of that.
- Well [In mapping 1] just being able to come on to these moments where there is the sharper tones and the more resonant stuff, that was nice to be able to sort of play with that and also to be able to modulate it a bit to modify them that was helpful.
- I prefer focus on the theme and try to make a variation on the theme and try to cook like interesting thing out of simpler structure , so I find that was easier with the second set-up.

E.4 Mapping Differences

In terms of which mapping was preferred (between a simpler mapping with isotonic energy input and a mapping that requires constant energy input), 3 out of 4 participants (Participants 2,3 and 4) preferred a mapping with isotonic energy input. This response was given regardless of the order in which the mappings were presented to the participants. Participant 1 initially preferred the mapping with continuous energy input however his main reasoning was the fact that with the simpler mapping he was unable to obtain silence. The difficulty in obtaining silence was a software bug that was resolved for the remaining participants. Once the nature of the software bug was explained to Participant 1, he also affirmed that taking out the silence factor, a simpler mapping would be more appealing for this instrument. His exact response is as follows:

Participant 1

- "Of course the silence was a big part because I could structure [the music], but if it was easy to get a silence in the first one, I would like the first one just as much. The first one has a dynamic level that is really easy to get, so I think it might be even easier [than the second] because you play and instantly there's a dynamic range that seems way more easy to go from extremes"

- The parameters that were assigned to acceleration were really fitting with the slow movement of the pitch change [In Mapping 1]
- The assignation of the parameters of the sounds were the thing that were well working with it and I like really how you could move a little but and just slowly shift the sound [With Mapping 1] .
- Just learning how to play physicaly [with Mapping 2] ... it's a total different set-up.
- The sound were the same so it's the designation that I had to get so I got more into what I could do with those sounds, because it was the second time around [With Mapping 2] .
- As soon as I forgot about the [first mapping] to really just understand, I got just a feeling of it, [and] it was easier to get into the sound, since I had already heard those sounds and I had the idea of how I wanted to shape them.
- It was easier to control a bit I think [with Mapping 2] because it was easier to go to silence and also because I understood a little bit what were the parameters of the sound, because it's the same parameters that just assigned in a different place in the objects.
- On a musical level for me [the second mapping] was easier to play. Yeah . Weirdly enough, thats the thing I found that, like it was a bit more difficult at the beginning to reproduce the examples but more I was going faster in the development.
- For the first session [Mapping 1], the acceleration was really clear and was really wide, you could go really high with it which was really interesting. And in the second time around [Mapping 2] I found that it was a smaller scale.

Participant 2

- I thought it was very different from the first [Mapping 2]. At least for me for my playing field. I felt more in control of the instrument this time [Mapping 1]
- I thought I could work more subtly right now. [with Mapping 2]. I think I could control it better

Participant 3

- I think I did better the first time [using Mapping 1]. I was in control with the first one.
- It feels a lot like Hunt and Kirk's experiment; maybe you are trying to compare how it feels for performers to, if they have to move constantly to make sounds as opposed to if sound is produced with position. Oddly, at this point I do not concur at all with Hunt's conclusion in that paper. I felt much more intuitive with the first mapping than this one.
- The latency may play a huge role in this [impression of mapping differences], it could worsen the situation.
- The major difference [between mapping 2 and mapping 2] would be this mapping [mapping 2] I found it harder to play than the first one. I had less control. And harder not only in the sense that it requires more effort to create sound in this case uhhh technically it probably does. But this material, the latex used already requires a fair amount of effort just to squeeze it like in the first mapping. I don't think this kind of material requires a mapping that maps amplitude to sound, you already have something here. Well in this case, in this very isolated case.
- I would use the first mapping, if I had the choice only between the two. I was more in control with the first one. Maybe the second one has a greater potential for expressivity, but with this current set-up I don't think it's more expressive. I felt I was able to express, to be more musical with the first one.

Participant 4

- I like this patch [Mapping 1] better than the last [Mapping 2]. I was able to hit more sort of like feedbacky resonancy moments more I'm able to play with the tones a little bit better.
- My experience playing the instrument was better this time [Mapping 1] than the last [Mapping 2].
- I would choose definitely the second one [Mapping 1] to play.

- Definitely the second wiring allow me to access sounds that I couldn't really access before like a few times in the first set up like I would like pinch the middle thing in kind of like wrestle with it I got some louder more resident sounds for just a couple of moments but I found it really difficult to to get them out. But it was much easier with the second set-up.

E.5 Control and Performance

The list of comments on the interaction include both sessions where Mapping 1 and Mapping 2 were given to the particpants to improvise on.

Participant 1

- I like how it was [with mapping 1] quite easy to understand how to modulate sort of things.
- Of course the slight frustration sometime of like OK I'm going to go there and then it's not exactly [what I had expected], but it's a small thing
- I was finding that the slower I was doing a movement the slower I was trying to do something I was happy with what I was producing,
- Once I didn't try to get it on a rational level and just really be on a perceptive level and I found that it was really working really well.
- It took me so long to get to the ... to understand how to get a continuous sound (With Mapping 2)
- I like the fact that because I could go to silence easily it was easier for me to structure it was easier for me to structure my dynamic (With Mapping 2) gestures
- Once you figure out a bit how to do a continuous sound [with the second Mapping], it's an interesting thing because then instead of shaping continuity, you have to shape discontinuity, or create a discontinuity
- There's a physicality thing to maintain a continuous sound [with the second mapping] so I like when you play an instrument it's like you have to play with your bow

Participant 2

- I'm still having a bit of a hard time with the middle part to kind of make that work to my advantage [using Mapping 2]
- The ultimate goal is to make music with and not be stuck in the technical side of producing sound
- I expected at the beginning that it would react to subtle pressures
- There are some areas where I'm surprised, where I do something and I think given the energy I put in something should happen
- I was also tempted somehow to play with my feet but then it kinds is too thick to do that.
- Doing sustained sounds again which I like was significantly easier [With Mapping 1]
- I could find things, that I could sustain sounds, or hold sounds umm by actually not moving, so you find different positions [With Mapping 1]
- In the first session [Mapping 2] I had to move much more to make sound.

Participant 3

- I found it hard to reproduce what I had done in the past while practicing, while trying to find something I found it really hard to reproduce what I had done before.
- The ballagumi when it's on my knees, or my legs, it's very sensitive to where my knees are underneath it it changes a lot of things and any manipulation I do with my hands above is affected by my position of the knees, I'm much more precise with my fingers and my hands than with my knees.
- In trying to make music there was a frustration not being able to do what I had in my head
- I tried to build on a few very basic gestures that I noticed were repeatable
- I can see now clearly that you in the setting of the mapping you're tried to exploit bimanuality, and it kind of works, but not so intuitively

- The thing is when you add latency on top of the instrument, you think you're not doing the right thing, so you try to correct much faster than the computer is reacting to what you're doing, so instead of correcting you're worsening things

- There are lots of things [with mapping 2], I think, the fact that it's not clear that I'm producing the sound when I move and I'm not doing sound when I stop. I think that when Hunt and Kirk did their experience the idea is it feels more natural if you have to put some effort or constant movement or velocity, make sound while being static doesn't make any sounI had to think twice as much to concentrate on move when you told me that, that I had to move to produce sound, so I understood, now I had to understand it intellectually and I did it intellectually all along. I had to think about it that I need to produce sound.d and it THIS case, it wasn't natural at all. Could be because of the latency but the thing is it had the opposite effect.

- The thing is effort or energy of the gesture would help musically. If it were transferred to the sound, If energy of the gesture is transferred to the sound it helps musically all the time, I'm sure of that. But in THIS case, I don't know why but just there is just that the . movement is mapped to amplitude and just that is not enough to convey the energy of the gesture in to the energy of the sound in this case. Basically what I'm saying is If it worked, musically it would be very inspiring. But in this case it doesn't.

- The gesture is not transferred, there's an impact here, there's no impact in the sound, it just fades in. And there is a disconnection even though continuous movements create continuous sounds, there is . .. (GESTURE) , the quality of the gesture does not influence or influences very little the quality of the sound itself.

Participant 4

- I like to work very minimally like just to have sustained tones for a very long time. I found that the way it was designed, it was fluttering a lot which was fine I was trying to work with that but .. At times I felt like I wasn't quite in control of what was happening.

- There are places where I thought it would be responsive like I would sort of push it one way but then If I pulled it the other way it would do something

- As an improviser, I'm really into like when you do something you can see, you see the response immediately from the gestures and a lot of times I was making useless gestures.
- I was able to sculpt the sound a bit better ummm and it was actually it was mostly that i was able to make more sustained tones which is what I prefer in music in general.
- I was definitely staying still more [with mapping 1] and i was also just focusing on holding things for longer durations with subtle, subtle changes and i got more comfortable with my hand position with the instrument as well
- I like soft sounds, I like loud sounds. but I like to be able to easily move between the two to create dynamics in improvisation , so i thought like it was easier with that there are more spots where I can get something that was popped out above the , the sort of watery quiet sounds it was easier to get louder sounds to come out, so I like that more.

E.6 Effort

Below are the Participant comments regarding the amount of effort specifically needed for each Mapping with the instrument.

Participant 2

- It's somehow less physical [In the first Mapping] I felt like I have to work less in order to get what I want. Ummm yeah I'm more refined I felt I could work more refined

Participant 3

- In terms of effort, for me it was OK but ... [comparing with the Sponge []] most people have told well women have told me that's it's too hard to bend [the sponge], and my feeling is the same thing could happen with the Ballagumi.
- For me I have big hands, fairly strong hands I'm used to doing stuff with my hands so I'm absolutely comfortable doing this [bending the middle] and I can hold it for

hours no problem but I guess that the girls I talked to would have the same problem they had with the sponge with this instrument.

- The Ballagumi requires a lot of effort but to me it's quality that requires effort; it doesn't make noise if you do nothing but one thing though. It's cool that it requires effort to make noise but it would be awesome that if we could by putting some effort into this, mute it.

Participant 4

- I like the louder sounds but I found that it hard to get them to happen.
- I also have really small hands, and I found it difficult to manipulate the center piece with just one hand, like I could but it was really kind of straining.
- I kinda felt like I was wrestling with it because it's heavy, it's on my lap and I actually feel kind of fatigue playing it.
- I was able to get louder sounds more easily with less physical effort in mapping 1.
- In this case it's almost necessary to not tie yourself out, like being on the staying and not knowing if it's goanna do much because there are sometimes where, like I said before sometime I push something and won't really do much and I'll be like oh i just made a big gesture for nothing.