Master thesis on Sound and Music Computing
Universitat Pompeu Fabra

Analysis of the skills acquisition process in musical improvisation: an approach based on creativity

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Acknowledgement

First of all, I would like to express my gratitude to the UPF Music Technology Group, and specially its coordinator, Xavier Serra, for giving me the opportunity of being part of the Sound and Music Computing master program, and opening the doors to a new adventure, both at a professional and personal level.

Likewise, I would also like to thank my supervisor, Josep María Comajuncosas, for his time, support and dedication with this project. His office was always available, as well as his advices, whenever I ran into a trouble or question. One simply could not wish for a better or friendlier supervisor.

My sincere thanks also go to Prof. Enric Guaus, as the detonator of this thesis. I still remember that Friday when he proposed this project as a somewhat crazy but rewarding and thoroughly fruitful initiative. His contagious motivation and advice have translated into this final document.

I thank my fellow mates for their support, from the assistance with coding to the overnight visits to the beach. Sharing this experience with you has turned into a building block of my personal life, which will probably germinate in what the future holds for me from now on.

And last, but not least, I must express my very profound gratitude to my family. Their unfailing support and continuous encouragement throughout my years of study have been the key of my professional success. However, all this would be worthless if it had not been accompanied by the affection and education that have made me the person I am today. To be part of this madness that we call family has been, and is, the impulse that I need every day.

Abstract

The aim of this thesis is to investigate and identify a relationship between musical ability and creative musical thinking in free-improvisation by means of a digital instrument. So that, a set of learning metrics have been designed where the technical skills are computed as the product of the spatial, frequential and cinematic analysis of each performance, weighting the final value according to its error, and the creative skills are computed as the product of the variables novelty, surprise and value. This last parameter is calculated according to the coherence, fluency and error correction of the segment being studied.

In order to evaluate the learning metrics, two experiments were designed and carried out. The first one, which was score-based and executed by the author, helped in proving the orthogonality between the variables through a statistical χ^2 test, as well as evidenced the optimal translation of the gestural data into low-level descriptors and its progress to high-level descriptors through the metrics. The second experiment was carried out by a group of ten people, five musicians and five non-musicians. An affirmative correlation between the Technical Skills and the Creativity variables was determined by means of the statistical Spearman Coefficient.

In addition, some tendencies were shown in the experimental results, as the preference of participants to explore effects on frequencies rather than long distance scans. Likewise, a clear learning curve was revealed in what respect to the technical skills for both groups, as well as in the error correction analysis demonstrated by the non-musicians.

To sum up, some contributions and improvements are included in the last chapter. One of those is the necessity of improving the fluency calculations, where the window shifting seems to need some recalibration.

So that, this document arises from the seek of a quantitative relationship between the musical ability acquisition and the creative musical materials, succeeding in finding an affirmative and detailed answer to the research question, an proving the potential of the proposed metrics.

Keywords: Technical skills; Creativity; Assessment metrics; Musical ability; Computer music; Improvisation apprenticeship; Gestural analysis;

Chapter 1

Introduction

When I was nine or ten years old, I started to play the trumpet. I played in a band until I entered the conservatory and I got bewitched by the whole world of music. During that time, I loved to attend concerts where the students older than me used to perform scores that, in my opinion, where masterpieces played gorgeously. I was always amazed and could not get out of my astonishment. Likewise, I remember an audition in particular where a trumpet teacher played "Fantaisie and Variations on The Carnival of Venice" by the french composer J. B. Arban. It is a piece full of virtuosity and technically demoniac. After that, I have not stopped listening to different versions of this piece, including, of course, the ones played by old school trumpet players, such as Maurice André; classical performances with fresh nuances, as it is Winton Marsalis' one; or, new generation approaches, like Ruben Simeo's. However, every performance is unique. Someone could now said that this happens with all music but, in what respects to myself, maybe this piece has turned special to me.

On the contrary, unique is not always good. This specific piece demands a superior technical ability as well as a highly developed musical creativity, in order to achieve a performance where good taste is balanced with virtuosity, and, furthermore, not to exceed a critical edge where the performance turns somehow into something mechanical and, even seeming impossible, boring. Nevertheless, this is not the first time in the history of music where a musical piece does have virtuous content combined with some contribution comming from the performer. Let's just think on the classical and romantic tradition around cadences and there is not more needed to be said.

As a totally different example, but extremely related with the previous idea, I remember when I attempted to taste the jazz world with my trumpet. I was trying to adapt my technical ability to this new domain, but I was not the best in doing it. Then, one of my friends gave me a piece of advise to understand what it has to played, when and where, (although I still think at present that it is rather a 'who' could play it); he just told me: *"practice, try and fail until you improvise like Miles [Davis]. You will be good when you feel confident enough to play a single note when everybody else is improvising by playing the most amazing, astonishing and hard material ever. And, what is more, your solo would be as incredible as their solos"*. And I have been thinking about that until today. What is behind the technical ability when playing and instrument and the capability of being creative at the same time? Does having the most incredible technical skills implies being extremely creative? And what about the other way around? Isn't a single note the least creative proposal in a performance? Or, could it be amazingly creative?

1.1 Motivation

As a musician, and after spending some years in the improvement of my playing technique, I want to understand the processes involved in creating original material, in order to get better when giving my own interpretation of a piece, but always within its style; either my own cadences of a classical score, a solo during an improvisation or the first performance of a new musical piece.

Likewise, creating or finding original material is not an easy task. The common way of proceeding arises from the need of developing something unknown and astonishing. However, not all the new and surprising ideas you may have could be considered as good ones, even though they are original. So that, in addition to being original, the created material has to be, let's say, good enough. And, in terms of linguistics, whatever is original and valuable is defined as Creative.

But now, how can I improve my instrumental technique in any of these dimensions? The key behind mastering a musical instrument is based on practice, in order to acquire the applicable and necessary technical ability. Nonetheless, once those technical skills are gained, the development of the creative thinking needed to take off during music performance would not appear from nowhere, and it would need to be supported onto a specific learning system. This would probably be influenced by the theoretical background, the rhythmic, melodic and harmonic resources, the capability of group adaptation in musical creation and, why not, the technical skills previously acquired with the instrument.

However, was I not able to grow at the creative level before an improvement of my technical skills with my instrument? At least, within a certain margin? Or, what is more, what is the relationship between the acquisition of technical skills and my creative development?

As I said, as a musician I am interested in a process of practical and objective evaluation that analyzes the development of my technical and creative skills and helps me in my learning stages. But in turn, as a physicist, I look for mathematical certainty through computational methods that defines my parameters of study in an objective way and generates a framework of truthful study with which to evaluate my technical and creative progress.

Therefore, looking for a symbiosis between both proposals, is it possible to translate a musical study of acquisition of technical and creative skills in physical-mathematical variables through computational means? And if so, how is the degree of technical resources of interpretation of a musical instrument measured? And its evaluation? How do you measure the level of creativity in a musical performance? And the creative evolution of an interpreter? How do all previous analysis translate into computational processes?

Thereupon, in my opinion, there is no better motivation, even more so when confronting a research process, than a set of questions raised within a deductive framework. Also, these questions are in turn the reflection of the objectives that drive this work and that will be transformed into means and resources for its correct study and analysis.

1.2 Objectives

Taking into account the motivation that drives the development of this thesis, the proposed objectives are the following:

(i) To create a set of analytical metrics of the musical creativity by means of computational methods.

(ii) To design an evaluation metric of the technical abilities in musical performing.

(iii) To base my proposals through the existing methods introduced and exposed in the relevant literature references.

(iv) To conceive, and carry out, an evaluation of the proposed metrics by means of an experimental process within the domain of study framed in the technical and creative skills.

(v) To analyze and discuss the results, both qualitative and quantitative, and estimate the possible relationship between the dimensions of the technical and creative skill in the practice of musical improvisation.

1.3 Structure of the Thesis

After introducing this piece of research and its objectives, the rest of the content is organized is six more chapters and one appendix. Chapter 2 presents a review of the state-of-the-art literature. It has to be taken into consideration how detailed are the objectives to achieve, which forces us to conscientiously extend ourselves in the development of a set of well-founded references, thus giving us the possibility to justify a particular study of the evaluation of technical and creative skills, from a computational point of view. Chapter 3 introduces the theoretical approaches concerning the learning metrics. The experimental stage is explained in Chapter 4, including the procedure and analysis. Fifth chapter contains the experimental results, which are discussed in Chapter 6. Finally, last chapter gives a set of conclusions and points out future work.

Chapter 2

State-of-the-art

During the past years, most of music computing research has been focused on the extraction and analysis of some specific features which were measurable through physical parameters [1]. Nevertheless, a musical performance analysis should take somehow into account more than the encoded musical descriptors within audio [2]. In fact, subjectivity plays an important role in music cognition [3] and, so that, all the subjective music features must be well-defined a priori, when possible, from a physical and computational point of view, in order to carry out a more reliable analysis [4]. In fact, to particularize on a specific subjective descriptor, let's take into consideration that, analysing how creative a musical piece seems to be, is a common task when listening to music, both on the formal music computing research and in our daily exposure to music [5]. Nevertheless, setting the computational basis to automate the analysis of creative processes is not an easy task when defining creativity [6], and even more once we get into the psychological domain. Thereby, the obvious starting point should be to take some time to write down a simple, or even personal, definition of creativity; however, let me tell you that we are dealing with a not easy concept that could be approached from different points of view; because, what is creativity in fact?

2.1 Creativity

According to Amabile, creativity is generally defined as the generation of products or ideas that are both novel and appropriate [7]. However, after a literature review made by Hennessey et al. in [8], it could be seen that the conception of creativity within psychology is harmed by the diversity of opinion and the lack of consensus, especially when choosing the most significant contributions to the creativity literature. Likewise, in this previous study [8], it was believed that a new perspective of creativity is necessary, recognizing that creativity arises through a system of interrelated forces that operate at multiple levels. As a starting point, from the A.I. perspective, talking about creativity means talking about Margaret Boden and her contributions. Boden is interested, above all, in understanding human creativity. For her, creativity is reflected in each and every aspect of life: it is not a special capacity, but remains in the daily skills of human intelligence, such as conceptual thinking, perception, memory and reflexive self-criticism. In [9] Boden describes a theoretical framework to encompass creativity, approaching this idea from different panorama. Thus, a brief summary of her ideas is now provided, in order to start setting up an overview of creativity.

2.1.1 What is creativity?

In Boden words, “Creativity is the ability to come up with ideas or artifacts that are new, surprising, and valuable” [1], where, new could refer to what she calls “psychological creativity”, related to unknown information for a particular individual; or, “historical creativity”, related to an idea that no one had before. Likewise, surprise could refer to something unfamiliar, an unexpected idea in the current way of thinking on a particular situation or, also, when an idea turns impossible.

Likewise, Boden distinguishes between three forms of creativity related to the idea of conceptual spaces: “in the same way as spaces exist in land, they exist in mind” [10], she states. They could not be seen but cover all domains of thought. So that, creativity could be manifested as: an exploration of those conceptual spaces, where the ideas already are, but creating new possibilities or perspectives of those ideas, mostly related with the way of thinking of a particular social group; a transformation of those conceptual spaces, or, novel combinations, using different ways of moving within the mind, sometimes with unfamiliar and rare combinations of common ideas.

After Boden's descriptive hierarchy of creativity, several ideas were deeply debated, focussing criticisms on the lack of details of her perspective and the absence of an explanation about how to fit all the components together to create a real model of creative behaviour. However, in [11] Wiggins proposed a formalization of Boden's ideas, moving towards a model that allows comparison of systems which exhibit behaviour, helping in understanding artificial and natural creative systems. Thus, a new framework was presented where the transformational creativity referred to the conceptual spaces is shown as an exploratory creativity at a meta-state, within six different classes of creative behaviour.

Finally, it has to be said that recent research focussed on creativity and innovation is currently emphasising on how the community in which a person is located affects their creativity and innovation [12]. In fact, this approach is based on the first proposals of collective creativity of the seventies. These include the contributions of Csikszentmihalyi, collected in [13], where the author draws attention to the social and cultural context within the processes of being creative and innovative, moving away from the most common perspectives proposed by psychology, where creativity is, exclusively, a mental process. Therefore, creativity is now a product of social systems.

At this point, and having ascertained how elusive, subjective and even polysemic can the concept of creativity be, designing methods to evaluate it must be the next step in any 'creative' research. In addition, if the idea of creativity is framed in a mixture of variables and attributes that can be considered as essential factors when evaluating something as creative, which is the best method to assess creativity?

2.1.2 Assessing creativity

During the past years, the assessment of creativity has based on the consensus of a set of experts. In fact, the gold-standard technique of creativity evaluation was “The Consensual Assesment” [14], considered as one of the most effective tools for measuring creative work. Basically, this method is based on the overall rating of collections of views from some judges who assess creative works on their own. However, this technique is not connected to any particular theory of creativity, and its validity is not related to the success or collapse of any theory [15].

Furthermore, many other evaluation measures have been proposed related to a specific topic. For instance, according to Sakar and Chakrabarti, creativity should be measured directly in terms of novelty and usefulness of the outcomes, requiring therefore the assessment of those ideas [16]. Likewise, several approaches have been studied by Oman, Tumer, Wood and Seepersad when analysing new perspectives on assessing and encouraging creativity in engineering, education and industry designs [17].

Finally, at present, some new techniques have been used for evaluating creative computational behaviour based on data processing approaches. This does not mean wondering if a computer program is behaving creatively, which would entail a whole new paradigm on the creative research, but moving to a computational framework in order to facilitate the creative assessment task. In this sense, some hints on computational creativity are now provided.

2.1.3 Computational creativity

Computational creativity is defined by [18] as “the study of building software that exhibits behaviour that would be deemed creative in humans”. The goal of computational creativity is to model, simulate or replicate creativity using a computer, to achieve human-level creativity, to help in understanding human creativity, to formulate an algorithmic perspective of creative human behaviour and to enhance human creativity [18]. It was during the last decades of the twentieth century when computational creative research began [19, 20] based on an individual perception of creativity. After some years of exploration, Gero presented in [21] several computational models of creative designing, moving through creative designing from the perspective of individuals, communities and cognitive features.

In the same way as Wiggins went minutely into Boden's creative approach, Maher has focused on evaluating whether a creative artifact is potentially creative, proposing a formal evaluation metric onto Boden's ideas, from the computational point of view [22]. A creative artifact is in fact described as "the result of creativity in any field, whether artistic, design, mathematical or science", considering that it can be described as a set of attribute values. Furthermore, Maher recovers Boden's conceptual spaces [10] and her philosophical and artificial intelligence perspective, as well as Gero's science design point of view [23]. Finally, the evaluation metric presented by Maher in [22] for assessing creativity is based on the assumptions of the artifact being novel, measuring how different is it from known artifacts in its class; valuable, measuring how the artifacts compares in its class referred to utility and performance; and unexpected, measuring the expectation of a new artifact in a class.

So, once the concept of creativity has already been introduced, in order to carry out a study in the field of Music Technology, it is necessary to conduct the dissertation to the scope of music. Because, how is creativity conceived and understood from the musical analytical point of view?

2.2 Creativity in music

The celebrated Robert Schumann once said, "in order to compose, all you need to do is remember a tune that nobody else has thought of". Likewise, in [24], Emma R. Martin states that "the musical language has a place in a space of creativity with no fixed limits". In fact, we are now dealing with something susceptible of being considered as a general truth, when matching being creative with music. Nevertheless, discussing the creativity overview has not been easy so, what could be said about creativity in the musical domain?

Currently, music cognition studies based on brain-imaging have focused on the neurobiology of music processing and the ways of perceiving emotions [25]. López-González and Limb are using these techniques to study artistic creativity through music performances [26], finding that the dreaming and meditation brain areas deactivated while the language and motor skills activated when playing different music scales. From a different point of view, Einstein recognized an unexplainable connection between music and science, often attributing his scientific insight to music. Likewise, Chordia [27] understands music as an essential contributor to the development and cultivation of creativity. Therefore, it is necessary to describe a specific framework for creativity within music, taking into account all the previous research referred to the psychological, philosophical, social and cognitive processes involved in the emergence of creativity. According to Merker [28], musical creativity is placed on the top of a historical and evolution process referred to changes and diversifications of musical patterns, based on musical traditions and impulsed by the innovative musical imagination. Likewise, Reybrouck introduces a theoretical framework in [29] that provides an operational description of creativity from the cybernetics and systems theory perspective. In this piece of work, musical creativity is conceived as an adaptive behaviour at the input, output and central processing levels, in terms of epistemic control systems. Moreover, this approach highlights the flexibility of our cognitive system what gives the idea of working with music in terms of thinking and knowledge acquisition. In [30], Clarke studies music performances from a creative point of view, trying to put together the psych-cognitive orientation and the ethno-social dimension. As it has already been mentioned in this text, Clarke conceives the existence of creativity within a complex physical and cultural environment where the interaction between the music producer and the listener is essential in the creative phenomenon. In the same direction, Williamon proposes a model of creativity in music performance [31] where originality and value are studied under cultural and social perspectives, giving as well a detailed analysis of rare and stylistically well-informed performances.

In [32], Sawyer and DeZutter study the interactional mechanisms that take place in a group, in terms of musical creativity through a specific theoretical framework of distributed creativity. Their starting point is based on the visible emergence of cognitive processes when working with groups, focussing their analysis on the verbal and gestural interactions among the participants. Moreover, Sawyer analyses jazz democracy in terms of the evaluation made by the performers about other musicians' ideas as a collaborative process based on the individual freedom.

2.2.1 Models of musical creativity

Once musical creativity has been introduced, and in what respects to the formalization of its aspects, it is possible to computationally model processes involved in the development of creative thinking and its implementation and performance. As declared by Widmer and Goebl in [33], "computational modelling is an attempt at formulating hypotheses concerning expressive performance in such a precise way that they can be empirically verified (or disproved) on real measured performance data". In this way, generative models of creativity in the music domain are based on features correlations involved in music performances after a previous analysis, giving descriptive and predictive values as output. They also consider the prediction of creative activity and the relation between musical score and the final performance as problematic, delving in the idea that musician's personality is not the go-between music and listeners, supporting their statement on the different performances of a specific music instance carried out always by the same musician subject of study. This leads to the already mentioned issues really involved in the creative process such as context, artistic intentions, personal experiences or listeners' expectation, among others.

Furthermore some other projects and models have been proposed, from the psychological point of view, focussing especially on modelling expressive performances. Juslin's GERM project is based on the conception of performance expression as a multidimensional phenomenon that consists of five components: generative rules for the musical structure, emotional expression, random variations, motion principles which become descriptors of a musical performance and stylistic deviation from traditional conventions [34]. The specific purposes of this model are to describe sources of variability in musical performances, to show that it is necessary to integrate several aspects of a performance for a correct modelling, and, to present some preliminary ideas for a computational model. Likewise, the KTH system-rule model for music performance was proposed by Friberg in [35], based on semantic descriptions and a set of rules selection so that emotional expressions can be modelled. Finally, a new creative framework was proposed by Todd and Miranda in [36] where some aspects from several biological methods from artificial life are used as inspiration, which led to the ALife systems. The approaches to ALife and music research are generative, concerned with mapping its algorithms onto musical processes; engineering, referred to the optimization of software for musical applications; and, musicological, based on the development of music theories [37].

And again, we face the necessity of defining a specific framework in which to assess musical creativity.

2.2.2 Assessing musical creativity

In 1968, Torrance, one of the most influential theorists on general creativity and faithful follower of Guilford's hypothesis (which considers creative thinking as the operation of twenty four divergent production abilities [38]), presented a test of creative thinking (TTCT) [39] based on measuring: fluency, the number of relevant ideas in response to a stimulus; flexibility, the number of categories of responses; originality, the statistical weirdness of the responses; and, elaboration, the detail in the responses. This model turned into a main reference in assessing creativity. As reviewed in [40], Vaughan proposed a method in 1971 to test musical creativity on fourth- and fifth-grade students based on Torrence's model. Moreover, Gordon and Baltzer proposed as well some tests based on using specific musical instruments in young children. Likewise, during the last decades of the twentieth century, many methodological and technical challenges related to valid assessments of musical creativity were proposed [41].

Currently, the state-of-the-art methods of creative musical assessment usually present a general overview of the creativity approaches before deepening into one of them, for instance the psychological, the cognitive, the socio-cultural, etc. Thereby, a computational method could be proposed according to a standard definition of a certain model of creativity. For instance, the Musical Expression Test (MET) [42] is a multi-method assessment of creative thinking in music focussed on instrumental exploratory behaviours that combines a systematic observational approach with product-based assessment of musical pieces. On the other hand, Hickey introduced in [43] a new model addressed to children in the improvisational and compositional domains. His model follows Torrance's TTCT measurement factors of fluency, flexibility and originality comparing scores written by children with creativity scores taken from Webster's Measurement of Creative Thinking in Music model [44]. Likewise, children's contributions are also used for evaluating the improvement in composing as a result of a regular practice. Furthermore, in the musical creativity literature, when discussing the cognitive processes involved in innovation, improvisation is a common concept that tends to appear more and more. Improvisation can thus be defined as “the spontaneous generation, selection, and execution of novel auditory-motor sequences” [26]. Since musicians must generate a potentially infinite number of contextually meaningful musical phrases by combining a finite set of notes and rhythms, researchers consider musical improvisation an optimal way to study the neural underpinnings of spontaneous creative artistic invention [45]. So that, the apparent next step should address the world of improvisation.

2.3 Improvisation

George Lewis has referred to improvisation as "the ubiquitous practice of everyday life". In [46], after a literature review, musical improvisation is defined as "an act that takes place in real time where the composition and interpretation skills of the musician are combined and during which the musician must be able to anticipate the sound consequences, (...) improvisation does not arise from nothing, since its development is based on the musical knowledge previously acquired by cultural immersion and through instrumental practice".

It is widely acknowledged that through the history of music there has been a huge improvisation culture, from the medieval liturgical music to live electronics, moving across really specific tendencies in every period, music category or culture [47]. Moreover, improvisation can be presented as an archetypal example of the study of musical creativity. Already in the first models of creative evaluation in the musical field, which date back to the first half of the twentieth century, improvisation was considered as one of the main frames of reference.

To start with, research carried about from the point of view of musicology and history of music pointed out the appearance of improvisation in classical Greece musical performances. The evolution of this classical trend besides the development of the Greek Byzantine tradition meant the evolution of the Western music, constituting what at present is known as the Church liturgy that began on the fourth century, what, additionally, established the foundations of the Western Renaissance music. In fact, in [48], Cumming collects evidences from different authors of the emergence of the role of the composer at the end of the fifteenth century. Before that, all musicians were improvisers. Thereby, it is thought that the first idea of renaissance counterpoint was not written composition but improvised polyphony. Then, improvisation was everywhere in the Renaissance, including the vast majority of the well-known polyphony heard in Philip II's chapel from the Spanish master choirs [49]. That is to say, improvisation has been going along with music creation since the very beginning of the foundations of the theoretical music framework. Addressing improvisation is then not an easy task, being possible to focus on different perspectives. In Bailey's well-known "Improvisation: its nature and practice" [50], the approach to improvisation is separated into Indian music, Spanish Flamenco, Baroque tradition (with special attention to the organ), Jazz, Rock and Free improvisation. Furthermore, Bailey adds some special considerations referred to the relationship between improvisation and the audience, composers, recordings and solos. So that, getting a general idea of the concept of improvisation would mean to briefly discuss the musical analytics processes within improvisation, the social and cultural influences and opinions, the differences practices into which improvisation could be split, and, finally, consider the creative dimension involved in improvisational practices.

2.3.1 Improvisational analysis

In Bailey's opinion, "for the description - or evaluation- of improvisation, formal technical analysis is useless" [50]. However, according to Sheehy, even considering improvisation as a structure that could not be separated into its constituent parts, in order to analyse them, it could be said that improvisation is a mode of action or an attitude that involves degrees of spontaneity as well as implicit or explicit valuation of the level of freedom with respect to improvising [51].

Steinbeck's approach [52], clearly influenced Guck's 'analytical fictions', tries to find which fictions are told when musical improvisation is analyzed and how these fictions are connected to the emerging field of improvisation studies. The starting point of the fictional analysis is to consider improvisation as composition, assuming that improvisers use style systems, formulas, referents, schemas and models in the same way composers do. A second statement is to think of improvisation as a social practice, involving relationships through sounds, verbal and non-verbal communications; thereby, a story could be told based on the relations between musicians, including some social subtexts and cultural intertexts [53]. Furthermore, the fictional analysis could also tell a third story where improvisation is about critique and opposition where a narrative is constructed by challenging and subverting others.

On the other hand, a different approach was recently proposed by Goehr [54], distinguishing between two types of improvisation: impromptu and extempore. The first one, improvisation impromptu, refers to an improvisatory adjustment of a musical planned action because of the emergence of an unexpected event; that is to say, to improvise looking for a solution. The second one, improvisation extempore, is a pre-established musical innovation framework where the final goal is the improvisation per se.

Thereby, it is now necessary to take into consideration the different improvisational practices that have been developed during the whole trajectory of the history of music and, moreover, briefly dissect which are the analytical properties that shape and characterize each of them.

2.3.2 Improvisational practices

As it has already been mentioned, improvised practices have been on the musical agenda since the ancient traditions. Without emphasizing too much in this aspect, with regard to the Western repertoire, improvisation has moved from medieval liturgical music to the most contemporary vanguards of today, going through a huge amount of different conceptions of improvisation.

The first evidence of European musical improvisation appears in the medieval period where a new melody was improvised on top of a pre-existent one [55]. Likewise, this technique was improved until the Renaissance contrapuntal improvisation over a cantus firmus. In the sixteenth century, going along with the formal musical instruction, the improvised melodies extended over ostinato chord patterns, written schemes and, somehow, freely performances [56]. Along with the cultural revolution, Baroque's improvisation started to include the period's ornamentation strategies, without forgetting the apogee of the basso continuo and the common keyboard writing style, where musicians were supposed to partially or completely improvised over a well-known established musical theory [57]. Classical period transformed the improvisation tradition into a more flexible form, clearly distinguishing between block-chords voice conduction and simple phrases [58]. Furthermore, writing the out cadenzas became a very common strategy in order to illustrate the composer's original idea on which to improvise. The Romantic period continued using improvisation as an introductory and linker technique but it lost some power with the growth of recordings [59]. In addition, the operatic tradition was a new conception of improvisation of soloist's performances. Finally, improvisation within Contemporary music disappeared, in general, in the classical branch [60]. However, it was also the birth of some improvisation-based music, such as jazz, swing or electronics, among others. This is why a special emphasis is now done in terms of these styles.

During the late nineteenth and twentieth centuries, jazz has its origins in New Orleans as a new music genre characterized by some blues roots as well as several nuances from swing, ragtime, polyrhythm and classical improvisation [61]. However, jazz tradition spread around the world leading to many different styles within jazz, such as the early Dixieland jazz from the 1910s, where ragtime and collective improvisation was used; the mid-30's Kansas City jazz, which was thought to dance by including swing tunes; Bebop, characterized by complex harmonic progressions, rapid chord changes, a quick step through the tonalities, fast tempo, virtuosity and improvisation along a pre-set harmonic structure [62]; Cool jazz, which was born in contrast to bebop by using relaxed tempos and incorporating techniques from classical music; the 1950's free jazz, where the all the previous fixed rules disappeared returning to the emphasis of collective improvisation; and, some later styles such as smooth jazz, cultural jazz traditions or jazz fusions.

Moving now to the other side of the world, improvisation is and has been one of the pillars onto which the Indian musical tradition has been built. The strict difference between improvisation and composition is a recent concept, partly influenced by Western communities. However, Indian musical practices have been based on extensive memorizations of repertoires and techniques, both in teaching and performing [63]. So that, the Indian performer could be also considered a composer when he or she uses spontaneous inspiration combined with memorized and fixed pre-composed materials. In [64], Viswanathan and Cormack, discuss about the interpretation of ragas, a central melodic structure of classical Indian music, providing examples and well-founded analysis of how South Indian tradition (Carnatic) leans on carefully prepared and studied improvisation techniques. Likewise, in [65], Slawek offers us the vision of the presentation of unmetered melodies of the North Indian tradition (Hindustani), framing an analytical approach based on the musicians' considerations of rhythm and phrasing over an unmeasured musical construction.

To conclude, we want to take into consideration the effect and role of improvisation on contemporary music. However, it has to be noted that there are lots of different vanguards of practices susceptible of being analysed, such as swing, flamenco, African tradition, or Gamelan, among others. Nevertheless, we do not want to make a dissertation about improvisation, its origins and practices, but gather the most influential, or best known, genres that evidence the importance of improvisation, and in consequence creativity, within the music performance and creation. So, through the evolution of the history of music, the twentieth century experiences the most deterministic period when talking about how to perform a score, coinciding also with the apogee of the Integral Serialism [66]. However, after this period, a tendency could be perceived on many composers to give performers an increasing share of compositional responsibility, especially in open musical pieces, graphic scores or text-based and symbolic music. It is finally worth mentioning the current impact of improvisation in Live Electronics. This recent genre encompasses a huge amount of different perspectives and styles itself, mainly focused on electroacoustic improvisation [67]. In [68], Stroppa analyses the consequences of the computer-music success, not from the late growth in computing during the past years, but according to its musical significance and repercussion on composition and musical aesthetics. However, his perspective is not based on technological constraints, but it is more related to human interaction.

Furthermore, the most remarkable tendencies within Live Electronics music are: Noise music, heiress of the Futurist Movement and of Musique Concrète, based on the usage of extra-musical devices, such as radios or amplifiers; Circuit Bending, which is similar to the previous one but focussing on musical creativity by using self-customized electronic devices; and, Live Coding, based on the interactive process of musical programming, combining algorithmic composition with improvisation techniques [67].

In addition, besides taking into consideration the differences between all the previous improvisational practices, the similarities they have in common would gather again the basic foundations onto which improvisation is based, where, either being score-based or free performance, creativity arises as a fundamental basic mechanism, and so, this makes necessary to study the relation between these two disciplines.

2.3.3 Creativity within improvisation

During 1987, seven prestigious musicians carried out a staged discussion at the BIM House (Amsterdam) with reason of a set of concerts, concerning improvisation. One of the main conclusions that was abstracted, from nearly an hour of chaos and misunderstanding, was the non-existence of such a thing of improvisation, which basically was conceived the same as composition. Regarding this, Derek Bailey stated in [50]: “ (...) there was a view struggling to be expressed [when thinking about the concept of improvisation] which is, I think, a fundamental belief for some people: musical creativity is indivisible; it doesn't matter what you call it, it doesn't matter how you do it. ” That is to say, creativity was conceived, through Bailey's eyes, as a previous and essential stage responsible, in part, of music creation. In fact, it is shared by both, improvisation and composition.

Already in 1988, Johnson-Laird addressed creativity in jazz improvisation by means of computational analysis, proposing in [69] three different models of creativity. In the first one, known as the neo-Darwinian, an automatic process selects, unconstrainedly, music segments to follow a randomly generated primary material. However, even taking into consideration the potential of this proposal over a novelty analysis, the process turned to be really inefficient with respect to a real-time response. In the second model, the neo-Lamarckian, the new material was created according to some criteria based on a previous learning process developed by the system. Finally, the third model was conceived as a combination of former ones by selecting a collection of possible responses but under inherited constraints followed by a second condition of selection criteria.

Continuing with an approach based on jazz improvisation, a behavioural analysis is carried out in [70] by a computational system based on a genetic algorithm for music generation. The method used takes experts' opinions as musical parameters to generate random MIDI music within some constraints. The system's level of creativity is assessed by Ritchie's works [71].

As a completely different approach, there is a common strategy when studying or working with improvisational creativity concerning infants. Children at school have offered a really specific framework, as a case of creativity study in the music domain, since the seventies. For instance, in [72], an experimental study is carried out on the effects of improvisation in children's creative thinking in music. The method used was based on experiencing improvisation through their bodies and musical instruments, and creativity was assessed by Webster's Measure of Creative Thinking in Music [44], according to four musical parameters: extensiveness, flexibility, originality and syntax. The results and their analysis showed a significantly development of creative thinking in those parameters. Likewise, as previously commented in Section 2.4, Hickey's proposal [43], assess, once again, creativity in children's musical improvisations seeking for consensus according to different creative evaluation methods.

From another point of view, maybe more related to on of the current most requested music production styles, there has also been some research about computer-generated music and its implications with respect to creativity. Linking together with an improvisation practice that has already been mentioned in this document in the previous section, Live Coding is defined in [73] as "the writing of rules in a Turing complete language while they are followed, in order to improvise time based art such as music, video animation or dance". As one of the conclusions of this previously mentioned research, the authors identified correlations between expression in formal languages and musical forms in sound. This idea was not interpreted as a new kind of music but as a new way of understanding it; that is to say, a new computational approach with an essential and very special meaning of creativity. However, this shows a whole new world of possibilities full of specific particularities in, for instance, terms of creativity and improvisation. So, we now see ourselves in the necessity of introducing a whole new section about the emerging application of computing technology in music, its history, usage, classification and correlation with creativity and improvisation.

2.4 Computer-based music

After the Second World War, computer technology suffered a rapid development that meant the birth of computer music. Lejaren Hiller, in collaboration with Leonard Issaacson, wrote in 1957 the Illiac Suite, credited as the first computer-generated musical score [74]. Simultaneously, at Bell Laboratories, Max Mathews opened the age of digital sound synthesis by developing the well-known MUSIC software, which was able to generate digital audio through direct synthesis [75]. In order to understand the nature of compute music, Mathews summarises in [76] the main idea behind its foundations, which comprehend precision, exact reproducibility, and the ability to handle extreme complex specifications with sufficient flexibility. Likewise, the analysis of computer music also offers the possibility of exploring the dynamic relations between the player and the musical instruments, going deep into the efficiency, apprenticeship and learning processes [77], what gives the opportunity to set up a musical instrument evaluation method.

2.4.1 Digital instruments

So, having entered the study of music technology, what can we say about digital instruments, very common in the study of musical abilities such as expressiveness or musicality? According to Wanderley, a digital instrument is described as “the one that contains a separate gestural interface from a sound generation unit” [78]. However, this definition could also be attached to electronic instruments, referring us to the ones based on the exploration of electricity, magnetic waves, oscillators, capacitors, inductors or transistors. So that, which are the differences between acoustics or electronic instruments and digital ones? While the first ones could be described from a conventional perspective as culturally rooted, digital instruments are based in less intuitive constituents, which are not always related to physical parameters. That is to say, code as material is not music, as well it does not vibrate. In this sense, a digital instrument is made up of a computer, a monitor, a sound card, an amplifier, speakers and user interfaces. And, what is more, all this rests over programming languages, signal processing, mapping mechanisms and a big etcetera [79]. So, at this point, it would be useful to study the relations between players and digital instruments, what leads us to the analysis of efficiency and apprenticeship, as introduced in [77]. In this paper, Jordà introduces some parameters that should come together in a (new) digital instrument, stressing the importance of being balanced in terms of challenge-boredom and highlighting the value of giving an equilibrated learnability when taking into consideration the needed time to learn the technical aspects. However, designing a new digital instrument is not an easy task. Moreover, it is also necessary to take into account what it will be used for. In this sense, which aspects should be considered in order to design a digital instrument?

2.4.2 Criteria for the design of digital instruments focusing on creativity

"From a design perspective, any interface can be designed for any sound" [79]. According to [78], when designing a real-time multiparametric control system, several attributes must be taken into account. The most remarkable ones are:

- There is no fixed ordering to the human-computer dialogue.
- There is no single permitted set of options 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.

Likewise, in [80], some hints are given when designing tangible interfaces, stating that theses should be: intuitive, giving the chance to the users to easily understand the basic elements of the interaction; unobtrusive, allowing users to carry on their decisions; enticing, encouraging interaction; portable, making transportation and set up an easy task; robust, being able of recover from harsh conditions; and, flexible, being capable of adapting to the environment in which they are used.

In [77], when analysing about what makes an instrument good, Jordà talks about learnability. He sets the example of the differences found, in terms of playability, between musical instruments: "An absolute non-musician can still improvise some beautiful piano music, we argued, but still, the piano is a really intimidating instrument and the kalimba is not". Thus, he also launches the question "what happens during the learning path?". In this sense, it now seems obvious to deeply study the learning processes involved in musical practice.

2.5 The process of musical learning

To continue, we now introduce the second fundamental foundation, in terms of contents, of this thesis. To study the acquisition of skills in musical improvisation through the analysis of creativity, it is possible to initiate the same research from two starting points, which, however, can really, and would help to, be studied in parallel. Thus, this document presents literature relevance about creativity and its computational models, as well as their implications within the musical field. All this, moreover, is guided through a conductive thread that ends in the improvisatory practice as a tool of evaluation of the models proposed and studied. In this way, the idea behind musical creativity and its implications is covered. On the other hand, this same study could have started through the analysis of the concept of apprenticeship. Obviously, the field of study should be closed with a view to musical learning, due to the great scope that the subject in question can reach, from pedagogical, psychological, sociological points of view ... and a large number of "ogicals". In this case, the starting point was creativity; now, turns to the acquisition of musical skills.

In [81], Sawyer proposed musical performances, among others, as a "set of opportunities (...) to work collectively to create a shared, improvised creative product".

However, analysing the implications of acquiring musical ability in, for instance, improvisation, could mean the necessity of defining learning from a cognitive, psychological and pedagogical point of view. So that, we will just focus on the acquisition of skills an on the models to assess them. In fact, Sawyer also finds a gap in this sense [82], focussing on how people learn to accurately reflect the current skills-creativity conceptual understanding. Likewise, in [83], it is highlighted the little interest shown in the development of construct-validated tests capable of diagnosing individual differences in musical ability. In this sense, proposing new evaluation methods in this specific domain would mean an interesting and even highly requested contribution.

Concerning improvisation, Després and Dubé reviewed in [46] the most remarkable literature on improvisation learning. In their analysis, they identified seven factor that play a crucial role in musical improvisation: time, memory, the knowledge base, motor skills, the instrument morphology, the musical referents and social interactions. Finally, based on Kratus contributions, the authors put together the seven phases into which the musical improvisation learning process is divided:

- Exploration: preparatory stage where sounds are experienced.
- Improvisation based on the process: the repetition of coherent gestures and movements.
- Improvisation based on the product: usage of structural principles such as pulse, tonality or meter.
- Fluid improvisation: the creation of music is based on automatic technical skills.
- Structured improvisation: based on a repertoire of strategies that makes possible to give a formal structure to the improvisation.
- Stylistic improvisation: a certain style is represented according to harmonic, melodic and rhythmic characteristics.
- Personal improvisation: an own system of rules is created transcending the current known styles.

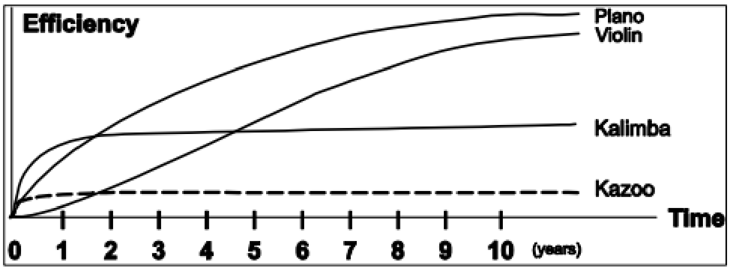

Figure 1: Approximate learning curve for the kazoo, kalimba, piano and violin, from [77], page 3.

So that, in order to relate improvisation and its implications from a learning point of view, it is now necessary to start from the concept of musical ability, to talk about the role of creativity in this process, and to review the most remarkable models of assessment developed during the past years.

2.5.1 What is musical ability?

In [83], Law and Zentner try to give their own point of view after showing the absence of agreement of an objective proposition involved in defining musical ability, launching the idea of "potential for learning music before formal training and achievement". Likewise, this issue comes together with the evaluation of musical ability. So, in [77], Jordá reviews the concept of learning curve, first described by Hermann Ebbinghaus in 1885 concerning the psychology of learning, by describing the contributions on the musical domain from Levitin to Wanderley. In this sense, Jordà talks about learning curves from what intuitively can be grasped; that is to say, the obvious relation between a player, the instrument and its performing evolution. However, there is not a clear definition nowadays and, much less, a way to evaluate it, in what refers to the acquisition of musical abilities. Nevertheless, they do exist certain main ideas that should be taken into consideration, such as an asymptotic behaviour shown by the learning curves, a clear dependency of this behaviour and the specific instrument is being analysed, a faster growth in the novice stage compared to the expert's one, or the existence of the "rewarding point", known as the spot when the experience of playing becomes rewarding. See figure 1.

The classic approach to analyse the acquisition of skills was first proposed in

1967 by Fitts and Posner in [84], describing a three-scenarios system, formed by the cognitive stage, where the task is broken down into individual components of action which are not conceived as a whole; the associative stage, originated by practice, where relevant aspects of the task environment are associated successfully turning into the correct actions; and, finally, the autonomous stage, where the components of the skill are carried out faster, being the performer able to focus on higher order aspects of the task. However, while the three stages are conceptually different, the transition between them, experienced when practising, is not obvious. In fact, this transition is often non-linear according to the dynamic systems underlying coordination [85].

A different and complementary approach was proposed by Dreyfus based on the phenomenology of skill acquisition [86], where how acting on a task, in different levels of competency, is experienced in first person. However, some similarities are shown on the general structure. Thereby, in the first stage, the task is understood by breaking it down into independent pieces, following generic rules for action. To continue, in the next stage, performers would be capable of picking up regularities in the task from those small units. Finally, a proficient stage can be reached by abstracting to higher-levels of the task beyond the small units.

At this point, it seems necessary to introduce the differences and similarities between perceptual-motor skills and cognitive skills. In his PhD. thesis [87], Rodger faces this discussion conceiving two kind of skills, the ones involved in the coordination of perception and action (according to Holding's approach from 1989), and the ones related to an intellectual ability (according to VanLehn's approach from 1996). And, even taking into consideration the enormous distinctions between the two types, general patterns of skill acquisition are applied to both groups, showing, somehow, similarity. The author also finds evidence in Newell and Rosenbloom's (1981) contributions on their research about the practice effects, highlighting a clear evolution in the cognitive and perceptual motor skills, which has also been demonstrated by showing how they share common underlying neural mechanisms in different studies. So that, these similarities can be conceptualised in a unified account by combining anthropological and ecological approach to skill, as follows Ingold's proposal [88], where it has to be taken into consideration that skills are not just bodily activity but part of an embodied agent and environment, that skills do not mean just the motion to the final goal but need from monitoring of the task, and finally, that the result of skills is shaped by the activity itself and not the intellectual goal.

2.5.2 Creativity and apprenticeship

Once again, Sawyer collects from the literature, in [89], evidences to reveal the importance of creativity to individual fulfilment. However, he could not find a complete understanding of how to design creative learning environments that foster learning in creative thinking and behaviour. Likewise, he studies creativity in education from a close association within music, in particular, based on a cognitive approach. In this sense, Sawyer highlights the effectiveness of creativity training when it focuses on a specific domain (we could now start seeing a possibility in focussing on computer-based improvisation).

From another point of view, a common strategy to assess learning is centred in what is called self-regulated learning (SRL) and meta-cognition, during and after any learning activity. Thus, in [90], SRL is defined as "an active, constructive process whereby learners set goals for their learning and attempt to monitor, regulate and control their cognition, motivation and behaviour, guided and constrained by their goals and contextual features in the environment". From this point, several methods have been designed and used to assess SRL, mainly based on controlled surveys, questionnaires or interviews. However, even taking that into account, in our case, free improvisation without external feedback would mean the influence of self-learning, all the SRL evaluation methods are based on the active participation of the subjects of study who must analyse, from their point of view, their own skills acquisition processes, which, nonetheless, is not the main intention of this piece of research, so going through all those methods would just blur the idea of creative-learning evaluation.

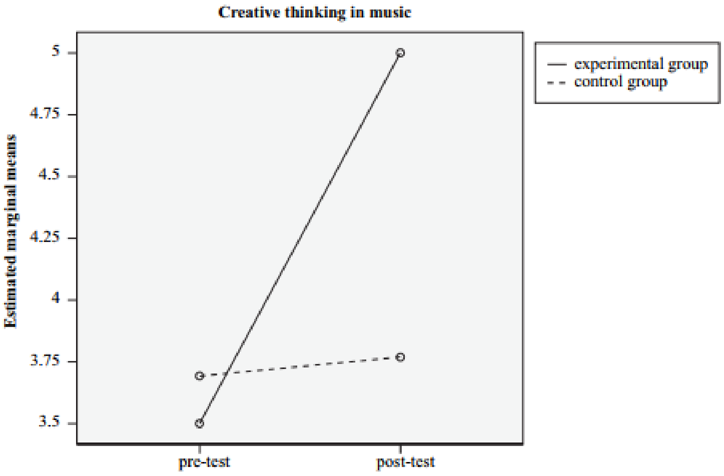

Figure 2: Porgress in creative thinking after an improvisation learning stage, from [72], page 13.

Finally, a quasi-experimental study carried out in [72], reported the effects and correlations of the improvisation learning process and the development of creative thinking in music, revealing significant relevance in the promotion of musical flexibility, originality and syntax in music-making. Analysis revealed that improvisation affects significantly the development of creative thinking; in particular, it promotes musical flexibility, originality, and syntax in children's music-making. The conclusive results can be seen in figure 2. The experimental method was based on Webster's MCTM-II [44], previously commented.

2.5.3 Models to assess creative learning

To continue, it is already clear that some assessment tools are needed to evaluate the progress referred to the evolution of acquirement of skills in the process of musical learning. In fact, it has also been seen that all these methods would be attached to, and maybe conditioned by, the specific domain in which they are being applied. Thus, in [83], the most remarkable musical aptitude tests are reviewed, emphasizing in turn several recurrent problems. This brief analysis included research proposals such as: Wing's measurement, distribution and development of musical capability analysis, tested with eight to fifteen year old children (1948); Seashore's et al. measures of musical talent, tested with ten to sixteen year old children (1960);

Bentley's musical ability analysis, tested with nine to eleven year old children (1966); Gordon's measures of music audition, tested with nine to eighteen year old children (1990); Gordon's musical aptitudes profiles, tested with seventeen to nineteen year old teenagers (1995); Karma's musical aptitude measurements, tested with ten to eighteen year old children (2007); and, Wallentin's et al. tests for measuring musical competence, tested with adult population. However, according to Law and Zentner, those test batteries used to measure a combination of skills rather than a specific skill, which, in their opinion, is a main problem. Likewise, another issue was found when the audio samples sounds used were related to specific musics styles or vanguards, regarding limitations in recording techniques of the time, or audio quality, most specifically in those related to contemporary music. Finally, the procedures used for display test validity and reliability were based on obsolete indicators (with the exception of Gordon's batteries) or were not sufficiently explained. Thereby, the state-of-the-art test batteries are more based on sound principles of test construction, capturing deficits instead of differences in musical perception skills. Therefore, the proposals that stand out are, for instance: Peretz's et al. Montreal Battery Evaluation of Amusia (MBEA) studies, developed to assess musical disorders (2003); Kang's et al. Clinical Assessment of Music Perception (CAMP), designed to evaluate the music perception of adults with cochlear implants (2009); Müllensiefen's et al. Goldsmith Musical Sophistication Index, developed as a tool that measures musical skills in the normal population (2012); Fabiani's et al. analysis of music perception of instrument dynamics (2011); and, Geringer's ratings of duration, tempo and performance level (2007).

A totally different perspective was proposed by Sloboda in [91] where the aspects of musical performance were divided into technical and expressive. The former ones were related to motor skills which would produce sounds. The latter ones refer to the creation of an individual performance characterized by a personal interpretation, mostly based on deviations of the common standards. Sloboda's work was founded onto several ideas. The main one was to consider music as a biological constitutive of early human functioning. Going deep into the performing analysis, his research showed how expressive expertise has rationality and develops through prac-

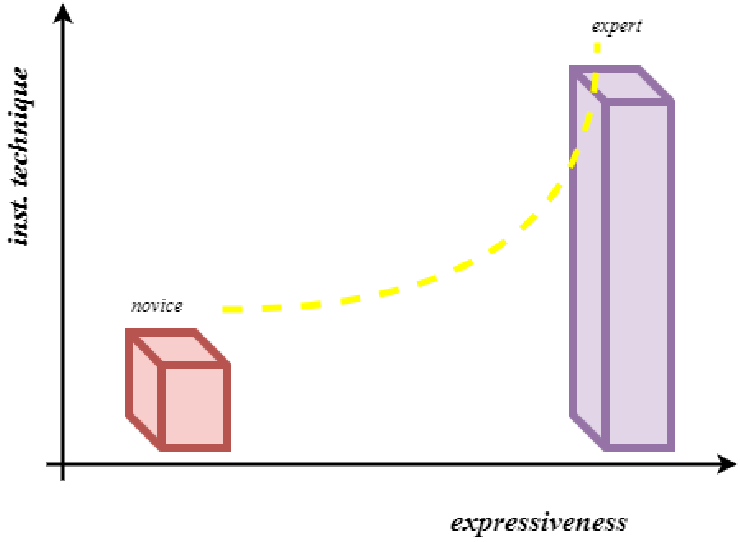

Figure 3: Model based on Sloboda's qualitative proposal.

tice. Likewise, expression showed similar characteristics to extra-musical activities, such as bodily and emotional gestures. See figure 3.

In this sense, Rodger's proposal [86] takes Sloboda's as a starting point, analyzing performances according to vertical skills: generic ones referred to the instrument technique, independent of the piece and, normally, heavily time consuming in the improving and process; and, horizontal skills: interpretative ones referred to the expressiveness, dependent of the piece and, normally, light time consuming in the improving and learning process. This latter skills must be specified in each analysis, regarding a singular aspect that must contain, or be the continent, of expressiveness.

To conclude, the proposal to evaluate the learning processes, introduced by Sloboda and Rodger, may be applicable when studying the relationship between the acquisition of technical musical skills and creativity. Thus, the computational approach to assess creativity described by Maher can be used on a computer-based musical instrument, designed according to the parameters established by Sheridan and Bryan-Kinns, and bearing in mind that the improvisation must be able to follow the process previously described by Després and Dubé. So that, this proposal seems to be the best approach to answer a research question that could be deduced from all the previous information:

Is there a relationship between the acquisition and development of the technical and creative skills in the practice of musical improvisation?

Chapter 3

Methodology:

Analysis, computation and development of the technical skills and creativity metrics within a common framework

As it has already been said, in 2010 Rodger proposed in his PhD. thesis a metric for assessing skills in musical performances based on gestural analysis, establishing a relationship between the analysis of technical ability based on gestures and some musicality perspectives, as seen in figure 4.

According to Rodger's proposal, musical performances could be analyzed over time in order to study the behaviour between the different stages in musical learning. The vertical skills *(VS)* were defined as the gestures related to the sound production, specific of the musical instrument itself and conceived as time consuming when talking about their acquisition. The horizontal skills *(HS)* were defined as expressive features, specific of the musical piece and conceived as an interpretative descriptor of a musical performance. Likewise, the horizontal skills focus on expressiveness due to author's decision. However, if a different conceptual space needs to be analyzed, the process would be very similar, if not the same.

In this sense, instead of just analyzing one single dimension of creativity, as is expressiveness, there are many possibilities when trying to develop a new piece of research; that is to say: what about originality, musicality or fluency in musical

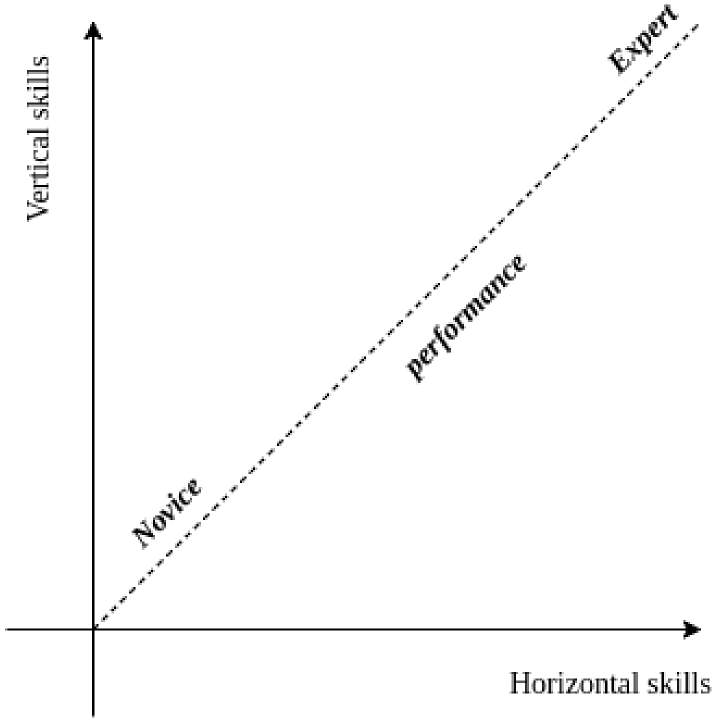

Figure 4: Rodger's gestural metrics in musical learning.

performing? All those dimensions are grouped together in the literature in a broader concept that is Creativity. Thereby, it seems natural, as well as challenging, to define creativity as the main corpus within the horizontal skills to be analyzed in a new research proposal focused on musical skills. So that, we could start the conception of a novel system of musical learning metrics by studying musical performances according to sound-gestural analysis, which could be set as the Y-axis, and musical creativity, as the X-axis.

To continue, to define a scope of study is now necessary. According to the literature, musical improvisation was the main musical framework when studying the theoretical approaches proposed during the XXth century in what respects to creativity. In 1998, Nunn identified multiple processes that take place during free-improvisation. In fact, Nunn introduced the idea of identities as the melodic and rhythmic elements, gestural shapes, timbre and articulation nuances that are established by a performer in free-improvisation. Likewise, Nunn's approach focused on the gestural continuity which seems to be an optimal perspective when combining with computational creative analysis. In this sense, free-improvisation seems to be a good framework in which comprehend a creative-learning study. However, it could also seem obvious to propose score-based performances as a different, or even better, domain to study subjective dimensions of music, as it is creativity. But, before setting the whole group of metrics, we have to take into consideration their implications towards performers (or subjects of study in a not too distant future). That is to say, we have to look for the minimum possible constraints. Just the fact of proposing a musical instrument can be considered as an axiom per se that will define and influence our metrics development, results and analysis. In this way, we should seek the most ideal proposal, which means, the one with the fewest possible restrictions when performing music. Although this forces us to elaborate a study of creativity closer to a subjective point of view, the idea of acquiring technical skills is purer because the degrees of freedom imposed a priori are the minimum. So that, we prefer and choose free-improvisation over any other musical system.

Likewise, because of the conception of Maher's creativity metrics [22], the main reference to be used when computing creativity, the simplest of the design, the best, and the more reliable.

In order to carry out the experimental analysis, each improvisation would be considered as a set of gestures. Gestures are then defined as music excerpts separated by silences or pauses. Moreover, each gesture would be formed by events, conceived as the smallest constituents within every gesture. That is to say, those events could be described by different descriptors such as duration, pitch, or spatial location, among others. Finally, to set up every metric, the idea of error needs to be defined. It could be due to wrong pitch, wrong rhythmic pattern, wrong location, etcetera, but it would depend on the system's design.

Let's then take an example. Imagine we are playing a circular musical interface where one musical dimension is controlled by the angle. We could then tap several times through the circle discontinuously; that is to say, as if we were jumping. Or we could drag our finger across the surface. The angular output would probably something like figure 5.

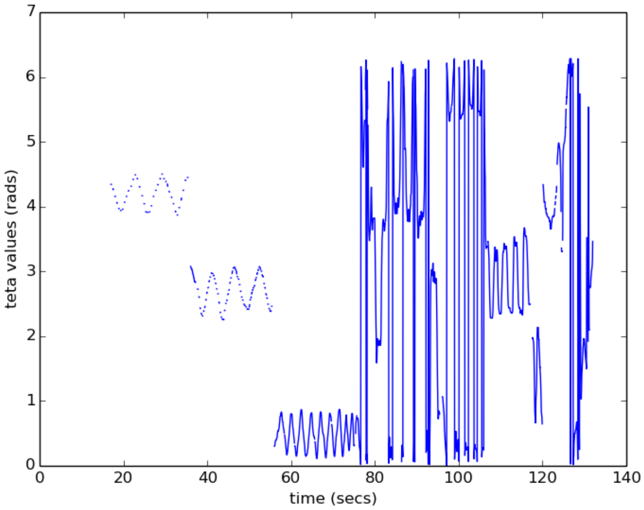

Figure 5: Performing example in a circular digital surface.

So that, each different value of the angle is considered an event. And, as it has been said, a group of these events make a gesture. The concept of gesture here relates the movement of your finger across the surface and the output data.

Taking advantage of this previous example, we could ask ourselves about the technical ability necessary to create the example, as well as how creative the performance has been. According to what it has been said referred to the metrics, to compute the gestural and creative analysis, we need to establish the intermediate parameters which make up the foundations of the metrics.

3.1 Technical skills based on gestural analysis *(VS)*

In order to define the technical skills involved in our metric, we will just focus on the analysis of the gestures responsible of producing sounds. Thus, taking into consideration Wanderley's general theory of musical gestures [78], this means to focus on phenomenological gestures, which defines the metric's attributes as follows:

- Spatial analysis: the distance between events in each gesture and between gestures.
- Cinematic analysis: the number of events per second within each gesture.

- Frequential analysis: the pitch range.

So that, taking this into consideration, the technical skills would be defined by the spatial analysis interquartile, the cinematic analysis and the frequential analysis. Moreover, each gesture error value would be used to correct each skills value. Therefore, for each performance, the vertical skills would be compute as follows:

$$technical\_skills = (spatial\_anal * cinematic\_anal * frequential\_anal) - local\_error. \tag{3.1}$$

3.2 Creative skills *(HS)*

To continue, in order to describe each event, and therefore, each gesture, the information extracted from every improvisation would be translated into a set of gestural descriptors, proposed by Hartman et al. in [92] and adapted by Comajuncosas in [67] when assesing creativity in computer ensembles. In order to understand them without going too deep too soon, remember the circular instrument introduced in the previous example, the one illustrated in figure 5. Therefore, from a performance based on a set of events and gestures on the circular surface we were talking about, the possible descriptors that can be analyzed are:

- duration: segment duration in seconds
- IOI: inter-onset interval between segments
- angle: mean position in radians
- angle range: inter-quartile range related to spatial extent
- radius: mean position related to coordinates
- radius range: inter-quartile range related to spatial extent
- speed: mean angular velocity
- speed range: inter-quartile range for velocity

Thereupon, we are now prepared to create our horizontal analysis, which would be entirely based on computational creativity. So, following Maher's contributions [22], to analyze how creative an improvisation is, each gesture would be given with a weight of Novelty, Surprise and Value, the metric's attributes, which, in this case, are conceived as:

- Novelty: the euclidean distance to the closest centroid of a k-means based clustering of the descriptor's vector of every gesture.
- Surprise: the maximum value of the set of distances of every new event, within each gesture, to the resulting linear regression of the (maximum five) previous events.
- Value: the result of multiplying Gibbs' model of Evaluation Features of Musical Improvisation [93], which are: coherence: calculated as the unity minus the distance from every event within each gesture to the centroid of the cluster computed by adding the events one by one. It is analyzed over the effect, freq, freqn, teta and diameter descriptors; Fluency: the unity minus the number of the boolean click equal to zero, in a period of ten seconds, starting after the first click; and, Error correction: the unity minus the current local error value divided by the previous local error. In case the local error of the improvisation is zero, the error correction becomes the maximum.

So that, the computational creative analysis for each gesture could be summarized as:

$$creativity = novelty * value * surprise, \tag{3.2}$$

where, for every event within each gesture,

$$value = coherence * fluency * error\_correction. \tag{3.3}$$

That is to say, the total value of each gesture would be:

$$value_{gesture} = \frac{1}{N} \sum_{i=1}^{N} value_i,$$

where, $value_i$ refers to the result of each event in a gesture and N is the number of events within a gesture. In the same sense, the final performance value of creativity would be calculated as the weighted sum of the values of every gesture within each performance.

To conclude, the skills acquisition metrics based on a computational creative analysis have just been described. However, we could now ask ourselves to what extend could we be sure that there is not a correlation between both metrics.

A priori, the computational methods described to calculate the intrinsic parameters are somehow similar, however, the technical skills approach analyses each performance as a whole, putting together the information extracted of every event, and, what is more, normalizing according to instrument-dependent, not piece-dependent values. On the contrary, the creative metrics work over each gesture and give a final value for every performance taking by adding the results of all the gestures within the performances. Furthermore, the analysis of the value parameter is made on the event scale, which also discorrelates the creative metric itself. So that, both mathematically and theoretically speaking, the technical skills and creative skills metrics seem to be uncorrelated. However, one of the goals of the experimental stage should be to first give some evidences in order to show this lack of dependency.

Chapter 4

Experiments

In order to evaluate the relationship between the technical skills and musical creativity with the proposed assessment metrics, a set of experiments have been designed and carried out with a computer-based musical instrument. So, in the first one, Experiment 1, I played myself an score-based performance in order to evaluate the suitability of our proposed assessment metrics. Then, in the second one, Experiment 2, a group of people carried out musical improvisations which were analyzed according to the technical skills and creativity.

4.1 Participants and design

Getting back to the previous example, remember figure 5, where the musical interface was a circular surface, we now face a similar scheme in what respects to the actual instrument used in the experimental stage. As it is going to be explained in the following pages, a mouse-controlled computer interface was designed where the gestures of a performer were transformed into output sounds. And, again, the appearance of the interface is a circle with different possibilities. That is why the relevant information to work with could be interpreted by the distance to the centre of the circle (coordinates), the angle or the speed between gestures, among others. Being all this, obviously, correlated with the emerging musical improvisation. But let's go step by step.

The pilot experiment, Experiment 1, was carried out by myself, in order to test the assessment metrics. Thus, instead of performing a free-improvisation, I created a music score, shown in table 1, taking into account the parameters that affect the descriptors to which the metrics are associated. In that score, each part lasts twenty seconds, and the control parameters considered are: Δ space, coulding be short ($< <$), meaning that the spatial range used is too small; or big, ($> >$), meaning the contrary; the clicks, that refer to *click-on = 0* and *click-off = 1* of the mouse.; velocity, which could also be quick ($> >$) or slow ($< <$), as well as steadily or variable; the frequency, which could be progressive, by playing correlated pitches, or non-progressive; and, finally, Δ effect, that corresponds to the amount of distortion of the played pitches.

Table 1: Score for Experiment 1

Time (secs)	**Δ space**	**Clicks**	**Velocity**	**Prog. freq**	**Δ effects**
0-20	< <	∼1	< </cte	yes	< <
20-40	< <	∼1	> >/cte	yes	< <
40-60	< <	∼0	> >/cte	yes	< <
60-80	> >	∼0	> >/cte	no	< <
80-100	> >	∼0	> >/cte	yes	< <
100-120	> >	∼combined	> >/variable	yes	> >

To carry out Experiment 2, ten people, five musicians and five non-musicians, performed ten computer-based free improvisation of a duration of two minutes each. In order to have some demographic information, the subjects of study were asked to fill a questionnaire with the following data: name, gender, age, citizenship, education level, musical knowledge or studies, hours per week listening to music, played musical instruments and musical style preference.

The demographic data is now summarized in the following pictures, from figures 6 to 11, just including the most relevant information.

In order to carry out the experiment, the participants were introduced to the musical instrument and asked to perform a free-improvisation by using the mouse as

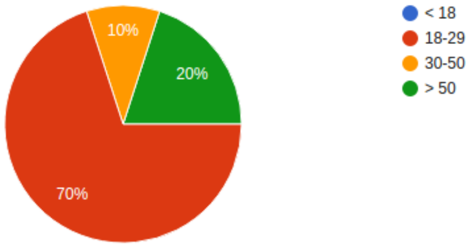

Figure 6: Age.

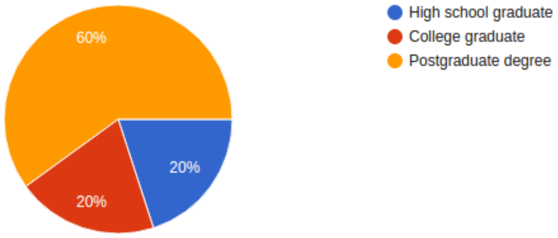

Figure 7: Education level.

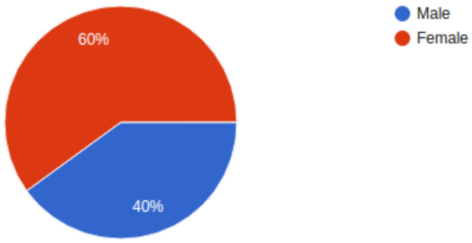

Figure 8: Gender.

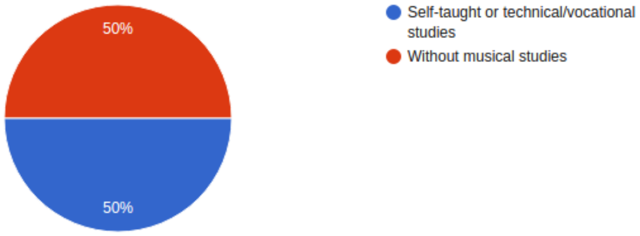

Figure 9: Musical knowledge.

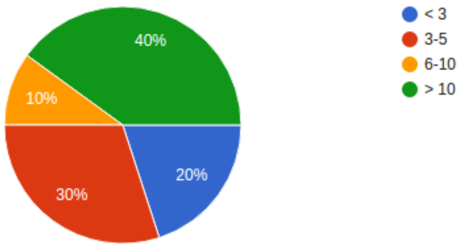

Figure 10: Hours/week listening to music.

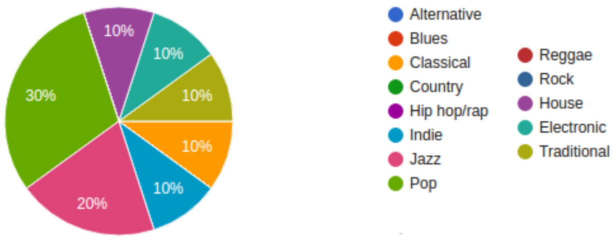

Figure 11: Preferred music style.

a controller and the computer as the interface's support. So as not to influence the participants' performances, no more information was provided a priori, but they were asked to improvise with the given digital instrument by doing the best of themselves. One of our hypothesis included the first performance of each participant as the typical exploration stage that appears recurrently in the literature when learning how to play a musical instrument. That is why there was not an introductory phase with the digital instrument and all the contact participant-instrument was recorded as a real performance.

4.2 Apparatus and procedure

The computer-based musical instrument was based on a custom design just for this particular thesis. It was developed with PureData as two concentric circles divided in twelve sectors, as seen in figure 12. The interface's appearance corresponds to PD GEM (Graphics Environments for Multimedia) onto a pre-saved two concentric circles image, equally divided into twelve regions. Each sector of the outer circle correspond to a predominant frequency of the chromatic scale, displayed in a discrete way over a Shepard tone following an adapted subpatch modified according to PureData's shepard-tone example. Likewise, the inner circle followed the same idea but over a continuous distribution of frequency over a Shepard tone. Furthermore, a reverberator is included inside the inner circle, controlled by the distance to the centre of the surface. The closer you get the more distortion is applied, until the coordinates origin is reached, when there is just noise as output. The reverberation level is set a priori as 80, as well as the revtime equal 74. The fact that the design of the instrument is the one proposed can be justified according to several premises. The two concentric circles offer a clear separation of two timbral dimensions and give us the opportunity to explore and analyze a continuous and a discrete space. In addition, the segmentation is automatic, which facilitates the analysis. The timbral range is sufficiently extensive, from the tone to the pure noise, all built on a continuum based on Shepard tones, which prevents jumps between octaves, thus eliminating the possibility of having singular points of interest that affect improvi-

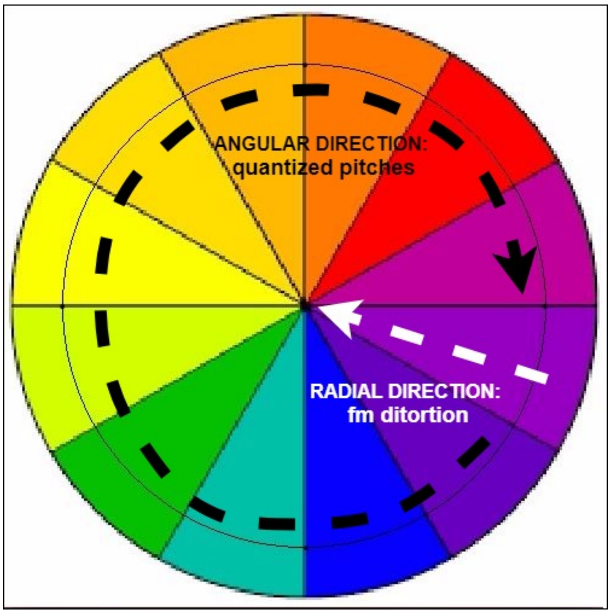

Figure 12: Computer-based musical instrument.

sations. Likewise, the smallest area within each colored sector is the one closest to the centre, that is why the noise gives a natural correspondence between different sectors, where the separation distances are not too big.

Everything which is not within the circles' boundaries, that is to say, the blank spaces, are set as silences. Whether the selected area when clicking the mouse is blank or the mouse goes from a sounding to a blank space, the output sound would immediately cease whenever this region is reached.

There is also and exponential envelope included before letting the sound going out. Likewise, there is an audio ramp generator, whose levels and timing values are controlled by the coordinates parameters.

Finally, there is a toggle set as the ON push-button, in order to send a boolean to the bourne shell patch in charge of the data capture. Additionally, this toggle initializes a timing slider that would turn the data capture process down whenever it finishes.

The musical instrument was conceived to be played with the computer mouse. Whenever the subject clicks within the circles, a sound would output. If the mouse reaches a blank zone, that is to say, outside the circles, the sound would stop until

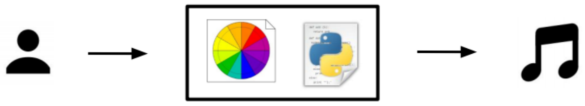

Figure 13: Experiment work-flow.

the mouse is clicked again. By the way, this is considered as an error. Moreover, after some seconds of playing a sound, this would suffer a diminuendo until its extinction. So that, to produce a sound again, the mouse has to be clicked anew. The system includes a slider that works as a timer where the subject can see the remaining time of each experiment.

To start the experiment, the subjects of study were asked to improvise by using the musical interface as best as they can. So, once a participant is sitting down in front of the computer, he or she will click on the ON push-button so as to start the improvisation. That process would also be translated into a boolean response sent to the data collector PD sub-patch in order to start recording the data. By the way, this is done over a Bourne shell script that needs to be executed by the controller of the experiment as the starting point of each improvisation. So that, when the improvisation has started, a timing slider begins its descent in a two-minutes range, reaching a zero value at the end. This zero value is transformed again into a boolean that depresses the ON button and stops the data capture process. But this is just the technical part.

4.3 Data extraction and analysis

During the improvisation, the data is being captured. The skeleton of the process could be depicted as it is seen in figure 13; that is to say:

$$\textit{performer} + \textit{PD musical interface} + \textit{background Python extraction code}$$

$$=$$

$$\textit{musical output}$$

However, although there is a musical output, the data extraction and analysis is just done with the gestural information extracted from the PD interface. That is to say, all the sounding information is read and processed as numerical equivalents, according to certain descriptors. Thereby, the extraction code organizes the data from every performance in a .csv file describing each event by the following information: date, time, mouse clicking, x_{coord}, y_{coord}, boolean outer circle, amount or distortion effect, boolean inner circle, diameter, frequency outer circle, frequency inner circle and angle onto the circular surface. To continue, each column of data is saved into a descriptor vector. Moreover, a whole new set of vectors is created by grouping the data in gestures. For that, a segmentation process separates the data according to the mouse clicking. After that, the metrics are built following the previously commented theoretical approach, computing the technical skills and creativity as the vertical and horizontal analysis, respectively.

4.3.1 Technical skills (vertical parameters)

To compute the vertical skills metric, the three corresponding variables were defined to calculate the total technical skills values for each whole performance. Thus, as it has already been said, the $spatial\_analysis$ is calculated by adding the euclidean distance between each event and the previous one, the $cinematic\_analysis$ is calculated by dividing the number of events by the total duration in seconds and the $frequential\_analysis$ is calculated as the IQR of the distortion effect. Additionally, the $local\_error$ is calculated by grouping the consecutive values where an error is detected and averaging by its duration in seconds. Finally, the $technical\_skills$ are set by subtracting the local_error from the product of the spatial, cinematic and frequential analysis.

4.3.2 Creativity assessment (horizontal parameters)

First of all, for each segment, some low-level features are calculated, known as the gesture descriptors:

- duration ≡ last element of the segmented time vector minus its first one.
- IOI (inter-onset interval) ≡ last element of a segmented time vector $[i]$ minus

the first element of the next segmented time vector $[i+1]$.

- angle $\equiv$ polar coordinate $teta$ in the $[0, 2pi]$ interval.
- angle range $\equiv$ angle's IQR.
- radius $\equiv$ mean radius calculated with the diameter data.
- radius range $\equiv$ radius' IQR.
- speed $\equiv$ angular velocity
- speed range $\equiv$ velocity's IQR

To continue, each descriptor is normalized according to their elements and all them are used to to create the gestures vector:

$$gestures = [duration, ioi, angle, radius, range_{teta}, range_{r}, speed, speed_{var}]$$

After that, following Maher's computational approach, the descriptor has to be clustered. A skcikit-learn model is then fed with the gestures vector and the maximum number of clusters is selected so that $n_{samples} >= n_{clusters}$. To choose the optimal number of clusters for each segment an automatic elbow method was developed. Afterwards, inasmuch as the gesture vector is an eight-dimensions variable, following [67] computational approach, a Principal Component Analysis (PCA) is performed onto the gesture vector, in order to find and define two main attributes with which perform a k-means clustering, by fitting with the the gestures one by one, and, clustering each of them whenever a new gesture is added. Thereby, we are ready to work on the creativity components of the computational metrics.

4.3.3 Novelty computation

So, to start with, the first two gestures of the performance are clustered. After that, the novelty of the next gesture is calculated and saved as its euclidean distance to the previous cluster centroid. Then, a three-gestures cluster is calculated and the novelty value of the forth cluster is now calculated. And so on. Finally, the total performance novelty value would be the sum of all novelty values divided by the number of gestures (without including the first two gestures).

4.3.4 Surprise computation

To continue, following again Maher's computational approach, the *scipy.stats* linear regression is computed onto a pair of events from the gesture vector, as well as the Confidence Interval (CI) of that linear regression. Then, the distance from the next event to the linear regression is calculated, giving this value as the instant surprise, unless it is smaller than the CI value, when, in that case, the surprise value will be zero. So, to finish, the obtained values are normalized for each descriptor, and each gesture final surprise value is set as the maximum one. Finally, the improvisation's surprise value is calculated as the maximum value from the surprise values calculated over the gesture vector.

4.3.5 Coherence computation

In a similar way as is has been done with the Novelty computation, to evaluate how coherent a sequence has been, the distance of a new point of the improvisation to the previous cluster is again calculated. However, this analysis is now done over each event within a gesture. Then, each coherence value would be set as the unity minus that calculated distance to the cluster's centroid, normalized according to all the values of event-coherences inside every gesture.

4.3.6 Fluency computation

To calculate how fluent a performance is, the number of $click = 0$ is counted in a 10-seconds interval, which would be shifted over each gesture several times. The gestural fluency is calculated as unity minus that value and, the final fluency, is then estimated as the mean value of all those previous ones.

4.3.7 Value computation

Finally, an evaluation gesture vector in then created fill with all the previous calculations:

$$gestures\_value=[coher\_effect,coher\_freq,coher\_freqn,coher\_teta,coher\_diameter,total\_fluency]$$

Thereby, a k-means cluster is fed with the PCA of the *gestures_value* vector, calculating again the optimal number of clusters by using an automatic elbow method. Then, a preliminary value quantity is set as the minimum distance from each gesture to the centroid.

Finally, the *error_correction* value is computed as the unity minus the current local error value divided by the previous local error, what leaves an *error_correction* value equal 1 when the local error of the improvisation is zero. After that, the final value to evaluate a gesture is normalized and weighted by the error_correction.

So that, to conclude, the final creativity is computed as:

$$total\_creativity = total\_surprise*total\_novelty*total\_value$$

The whole process has been summarized in figure 14.

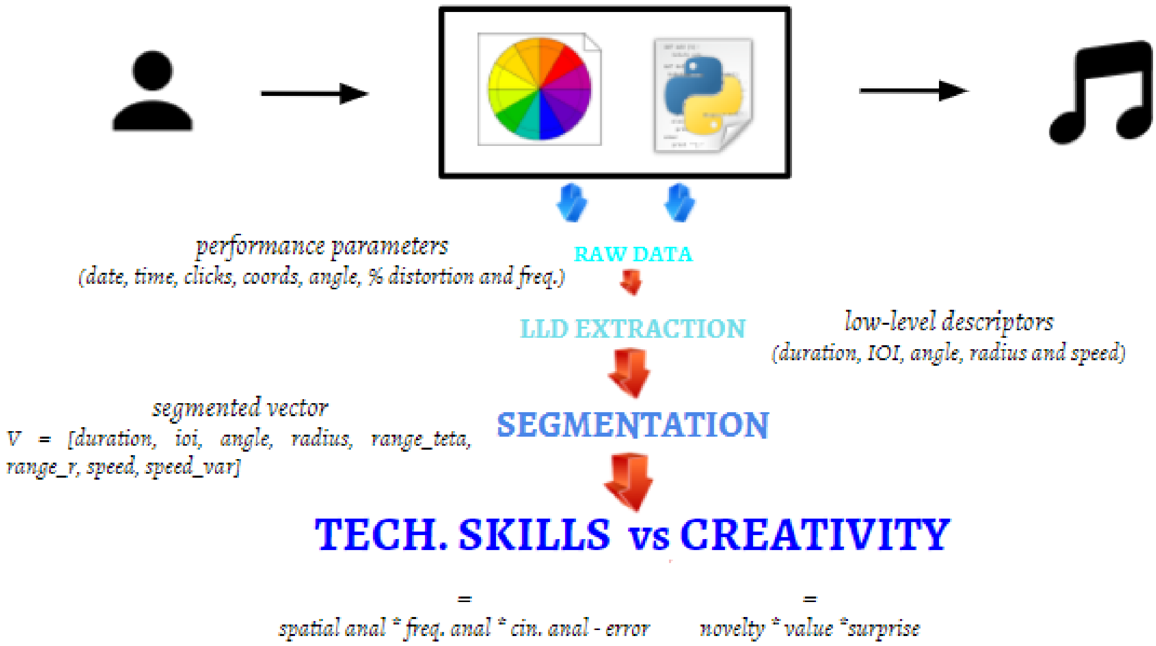

Figure 14: Data extraction summary chart.

Chapter 5

Results

5.1 Experiment 1

The first experiment to be carried out was based on the previously shown table-score 1 in order to test the instrument response, as well as to throw some light into the metrics basic behaviour. So that, taking into account how the score was designed, it could be possible to design a hypothetical distribution about how the response should be.

So that, the score-based performance, which was divided into six intervals, tried to create an improvisation where interest, expressiveness, technical skills and creativity were increasing. Moreover, each period, defined by 20 seconds, included a difference in one control parameter that would remain as changed until the end of the score; that is to say, the performance starts with all the parameters set in a particular position and, in each period of 20 seconds, one of them is changed until all of them are transformed from the least creative stage to the most. The review of the hypothetical output is done based on the following analysis:

- **[0,20) seconds:** To begin with the simplest and least creative improvisation, the scan range is small, the mouse emits clicks constantly, the speed, although constant, is small, the emitted frequencies are contiguous and the distance to the center is very large, so the distortion hardly plays an important role. All the previous values of the control parameters should translate in the smallest components of the technical skills and creativity.

- **[20,40) seconds:** Now, keeping the remaining parameters in their previous state, the velocity becomes greater. This should translate in a greater value of the cinematic variable, as more events per second are being processed.

- **[40,60) seconds:** To continue, the interpretation stops being a set of clicks and happens to be a conglomerate of sounds produced by the drag of the mouse. This would translate into an increase in fluidity (and maybe coherence too), which will give greater value to improvisation. The selected events will be closer to each other, so the surprise values should be smaller. However, new events will appear, because by dragging the mouse between two points, all the frequencies that appear in the middle will also be emitted as output, and these new events would increase the novelty.

- **[60,80) seconds:** Next, the spatial range is greatly increased, initiating a larger exploration process. Also, this exploration is not gradual, jumping to frequencies not contiguous, but very far. This should translate into an increase in spatial analysis. Also, exploring new zones will increase the novelty, as well as the boundaries of the frequency jumps, the surprise.

- **[80,100) seconds:** Following, the jumps between frequencies disappear to give way to an exploration between contiguous zones of frequencies. This should translate into a decrease in surprise as well as spatial analysis.

- **[100,120] seconds:** Finally, the performance combines clicks with mouse drag, as well as variable speed and the use of distortion effect. All this would mean a set of peaks in the cinematic analysis due to the changes in speed and use of the mouse, as well as a sudden increase of the variable frequential analysis. Also, coherence and fluency will undergo very abrupt changes, which should also leave large variations in the final value.

In general terms, the improvisation was designed so that the value was gradually increased, as well as the results of the general metrics. Table 3 shows a summary of the hypothetical expected behaviour.

Table 2: Hypothetical interpretation of Experiment 1 score.

Time (secs)	**Spatial anal.**	**Cin. anal.**	**Freq. anal.**	**Novelty**	**Surprise**	**Value**
0-20	< <	< <	< <	< <	< <	- - -
20-40	<	>	< <	< <	< <	- -
40-60	<	> >	< <	>	<	-
60-80	> >	>	< <	> >	> >	+
80-100	<	>	< <	>	<	+ +
100-120	>	> >	> >	> >	>	+ + +

In this sense, in figures 15, 16 and 17, the technical skills metric components are shown, spatial, cinematic and frequential analysis, respectively. It has to be taken into account that the original metric described this parameters as just a single value for each performance. However, the code was specifically modified in order to show the behaviour of those variables during the course of Experiment 1. Likewise, in figures 18, 19 and 20, the creativity components are shown, being those novelty, value and surprise, respectively. The results will be discussed in the next section.

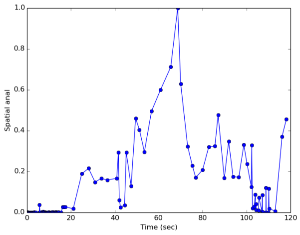

Figure 15: Spatial.

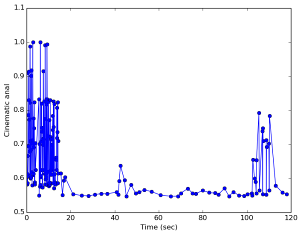

Figure 16: Cinematic.

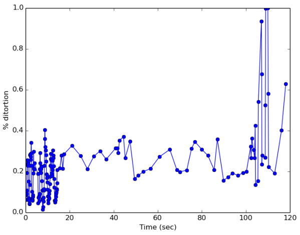

Figure 17: Frequential.

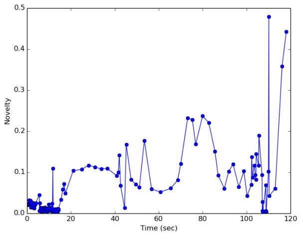

Figure 18: Novelty.

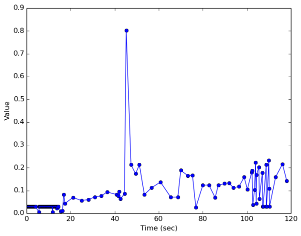

Figure 19: Value.

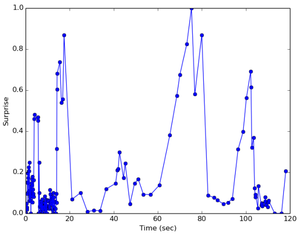

Figure 20: Surprise.

5.2 Experiment 2

To continue, the results of Experiment 2 are now included. They have been separated into two different cases of analysis: all participants and musicians/non-musicians. The plots here shown are just the most relevant ones. The rest of the plots, related to the correlation of intrinsic variables, are included in Appendix A.

5.2.1 All participants

To start with, the first graphic shown, figure 39, corresponds to the distribution of the Technical Skills VS the Creativity values. Remember that this plot could be considered as the main core of the metrics, based on the adaptation of Rodger and Sloboda's learning metrics.

To continue, to make a more exhaustive analysis of the components that give shape and value to the technical skills and creativity, it is essential to add the corresponding graphs of these variables and their constituents. So, graphics 22 and 23 correspond to the more specific distribution of the technical skills and creativity,

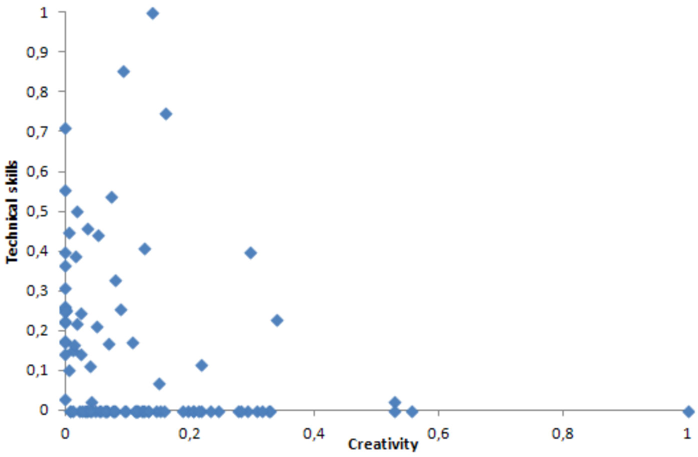

Figure 21: Skills vs. Creativity analysis.

respectively, according to every single performance. To understand those graphics, the legend is now explained:

- Technical-skills components graphics (figures 22, 26 and 30):
  (i) Dark blue dot ≡ spatial analysis.
  (ii) Green dot ≡ cinematic analysis.
  (iii) Red dot ≡ frequential analysis.
  (iv) Bright blue line ≡ total technical skills.
- Creativity components graphics (figures 23, 27 and 31):
  (i) Dark blue dot ≡ novelty.
  (ii) Green dot ≡ value.
  (iii) Red dot ≡ surprise.
  (iv) Bright blue line ≡ total creativity.

And, finally, how could we make a qualitative idea of the learning progress of the participants performances? The easiest way seems to be the exploration of the errors evolution. While it is true that it is possible to include a greater set of results, the most relevant are those collected here. In this way, the rest are included in the

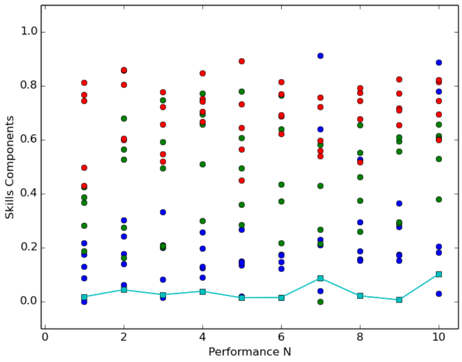

Figure 22: Skills components.

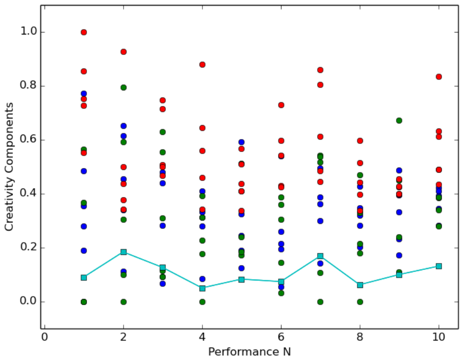

Figure 23: Creativity components.

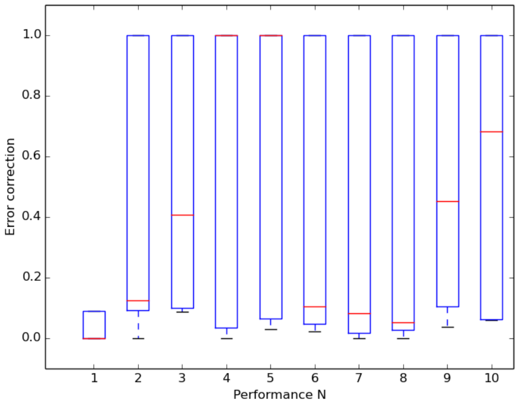

Figure 24: Error correction.

final appendix A. Thus, to conclude the general results that embrace the totality of experiments carried out, a single plot is made on the error correction behaviour. So, in figure 24 a boxplot is shown where it has to be taken into account that the distribution corresponds to a correction analysis and not an absolute error plot. That is to say, the greater the number of errors was, the lower the correction value is. And vice versa.

In order to be able to carry out a comparative analysis between the results corresponding to musicians and non musicians, the previous results are now separated in both categories.

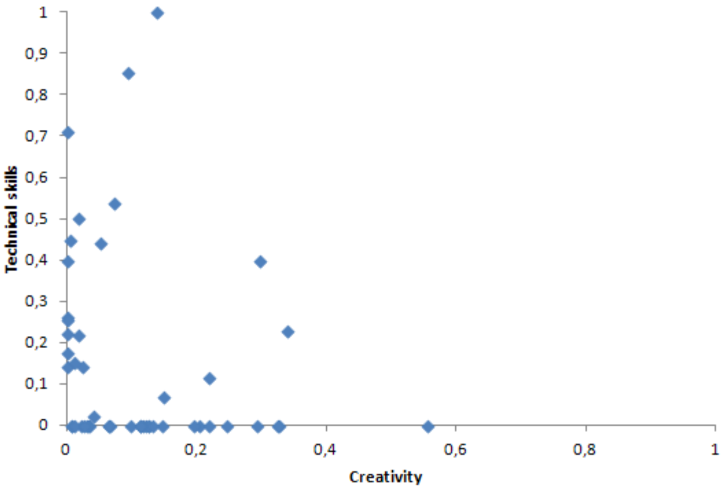

Figure 25: Skills vs. Creativity analysis.

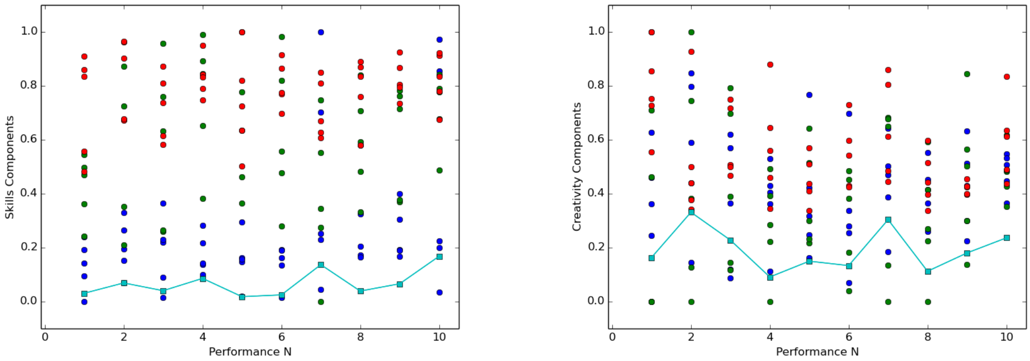

Figure 26: Skills components.

Figure 27: Creativity components.

5.2.2 Musicians

Following the same strategy, the generic plots are now shown corresponding just to the participants with some musical knowledge. Thereby, the first plot to be considered is 25, which corresponds, again, to the metrics' correlation analysis.

After that, the components distributions are also included for both dimensions of study: technical skills, figure 26, and, creativity, figure 27.

To finish, the error boxplot is shown in figure 28.

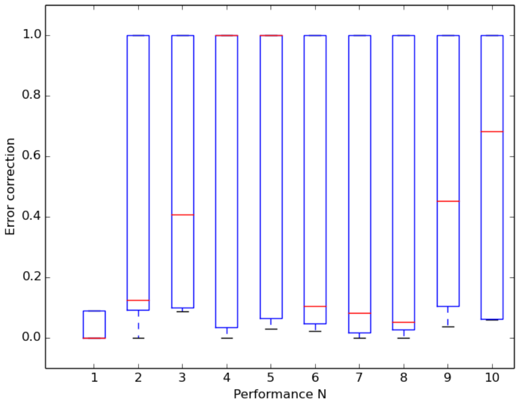

Figure 28: Error correction.

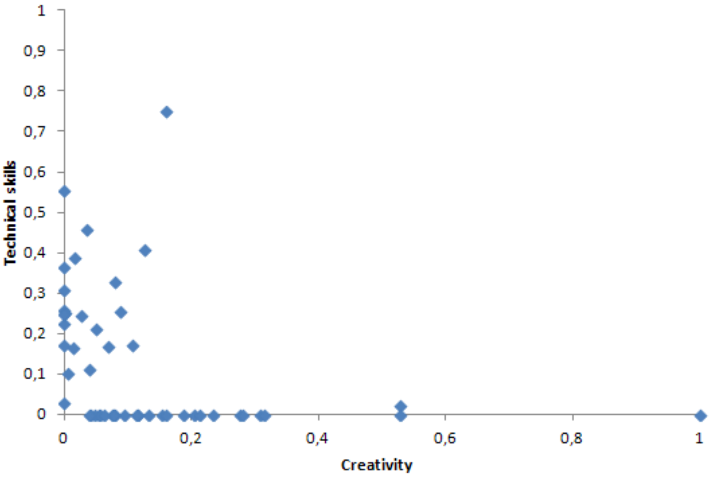

Figure 29: Skills vs. Creativity analysis.

5.2.3 Non-musicians

To conclude, the same distribution is shown referred to the participants without musical knowledge. So, summing up, the following graphics correspond to: the general metric analysis (figure 29); their components distributions, both skills (figure 30) and creativity (figure31); and, finally, the error behaviour (figure 32).

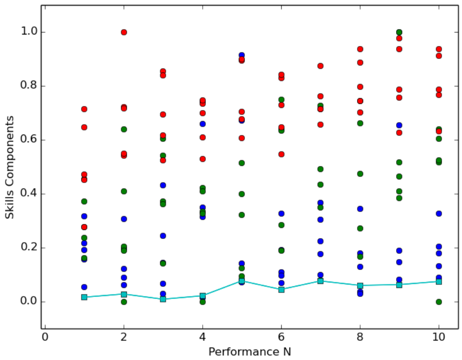

Figure 30: Skills components.

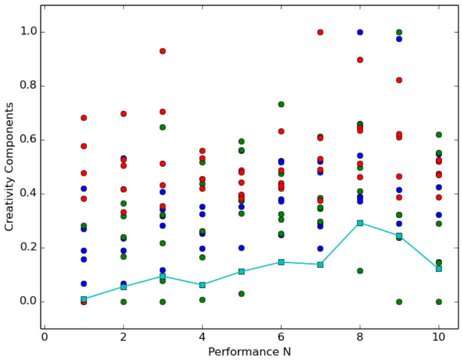

Figure 31: Creativity components.

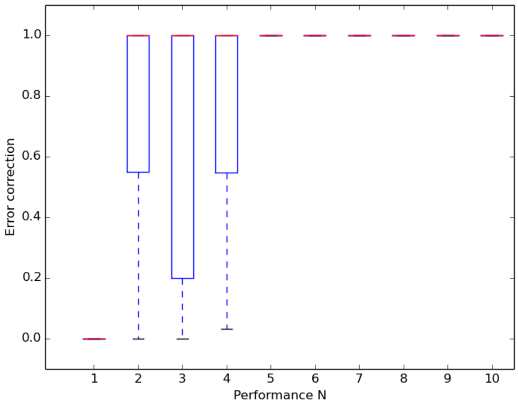

Figure 32: Error correction.

Chapter 6

Discussion

After carrying out the previously commented experiments, 1 and 2, the obtained results have been shown as graphics in Chapter 5. Thus, the following sections discuss and try to interpret those results and their outcomes in what respects to the design and behaviour of the metrics, the corroboration of the hypothesis and, finally, the relation between the technical skills and creativity.

6.1 Experiment 1

In order to analyze the plots referred to the technical and creative components of the general metrics, let's remember how Experiment 1 was designed: onto the digital instrument computational surface, specifically designed for this thesis, a musical performance was played, divide into six intervals of 20-seconds each. The score was written in a progressive way, meaning that every interval would remain as the previous one, except for one parameter that would be changed in each interval until the end. So that, the performance started in a small space range, at small speed, but by selecting contiguous frequencies in a discrete way, in far locations, in what respects to the centre of the interface. In the next 20 seconds, interval 2, the speed increases. In interval 3, the mouse clicking is transformed into mouse scrolling. To continue, interval 4 is characterized by a greater exploration of the spatial range by selecting remote frequencies. In next interval, number 5, the distances between frequencies turn to be smaller. And, finally, in interval 6, the speed is not constant anymore, as well as the mouse, which combines scrolling and clicking.

Taking all these into account, remember that table 3 shows a hypothetical interpretation of the variables' bahaviour (the table shown in the results chapter is now repeated). Thereby, the following graphics include the original results as well as the contours that are expected according to the score.

Table 3: Hypothetical interpretation of Experiment 1 score.

Time (secs)	**Spatial anal.**	**Cin. anal.**	**Freq. anal.**	**Novelty**	**Surprise**	**Value**
0-20	< <	< <	< <	< <	< <	- - -
20-40	<	>	< <	< <	< <	- -
40-60	<	> >	< <	>	<	-
60-80	> >	>	< <	> >	> >	+
80-100	<	>	< <	>	<	+ +
100-120	>	> >	> >	> >	>	+ + +

So, according to the analysis of the used score and the hypothetical results shown in table 3, graphics 33, 34, 35, 36, 37 and 38 are here plotted including the expected behaviour of each variable (in a red discontinuous line), on top of its real distribution (in a dark blue continuous line), referring to the variables spatial analysis, cinematic analysis, frequential analysis, novelty, surprise and value, respectively.

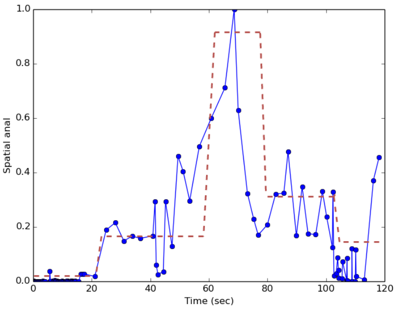

Figure 33: Spatial R&E.

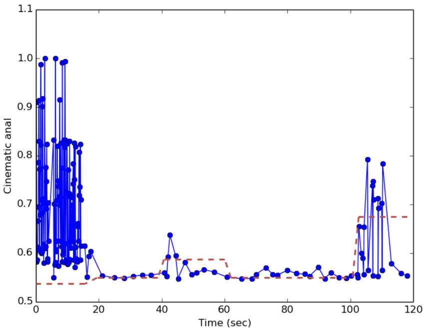

Figure 34: Cinematic R&E.

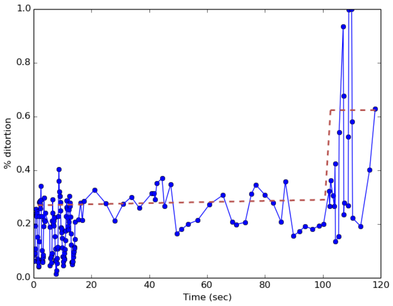

Figure 35: Frequential R&E.

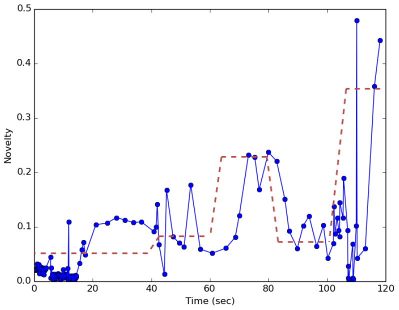

Figure 36: Novelty R&E.

6.1.1 Analysis of the constituent variables.

The Experiment 1 was mainly designed to verify the correct translation of a set of actions in the corresponding behavior of the involved variables through gestural analysis, and thus corroborate the hypotheses that establish the spatial, cinematic and frequential variables, as fundamental components of the analysis of technical skills and, on the other hand, novelty, value and surprise as the constituents of the computational analysis of creativity. Also, we try to study the orthogonality of the metrics and verify that the result of them is not due, locally, to relations of intrinsic dependencies of their constituent variables.

Thereby, the next step needs to be the particular analysis of the expected and real plots, in order to test the desired goals of the experiments. It has to be noted that the scale of the dotted line is merely qualitative, adjusting to the jumps as it

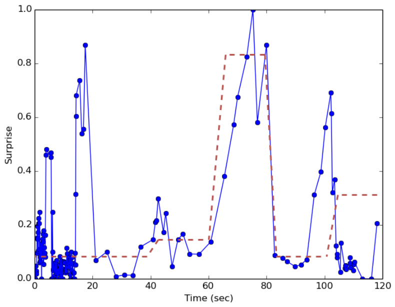

Figure 37: Surprise R&E.

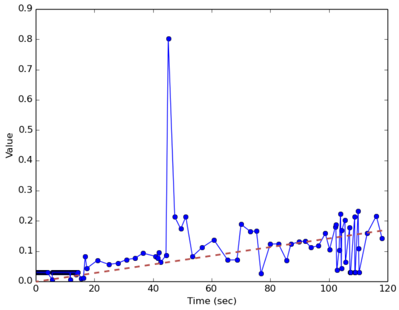

Figure 38: Value R&E.

does the average behavior of the real distribution, but following the hypothetical analysis raised in the table 3. This analysis is now presented:

(i) Spatial analysis: The expected behaviour, plotted in 33, is determined by the following reasons:

- **[0,20) seconds:** The spatial range is small, then the spatial analysis variable, which takes into account the total distance traveled by the mouse in each gesture, will have to capture a fairly low value. This expected behavior fits perfectly with the actual measured distribution.
- **[20,40) seconds:** Although it is true that in this next interval the spatial range must be the same, with, in turn, contiguous frequencies, is very possible that an increase of velocity will be accompanied by a slight increase of the general variable of spatial analysis. Think of moving the mouse faster, it is easier that the new selected frequencies are moderately more distant than in the previous case. It can thus be observed how the actual mean distribution of this interval follows this pattern, with slight differences between the different gestures.
- **[40,60) seconds:** As in the previous section, a small increase in the spatial analysis is expected compared to the initial state. However, the change from clicking to mouse scrolling results in a slight increase in the spatial analysis variable. This is in the same way understandable, since

dragging the mouse can facilitate the involuntary increase of the frequency scanning space.

- **[60,80) seconds:** Now, we are in the interval where the main interest is the exploration of more distant areas, with jumps in increasingly discontinuous frequencies. This should be translated into the maximum increase of the spatial variable, which we can see agrees with the real distribution.
- **[80,100) seconds:** To continue, we now search for contiguous frequencies. This should translate into a spatial range greater than the one from the initial interval but smaller than that of the previous interval. Again, the correlation between expectation and reality is affirmative.
- **[100,120] seconds:** And, finally, this last interval is probably the most difficult one to predict. We could argue that the combination of both, clicking and scrolling mouse techniques, as well as the variability in terms of velocity could translate into multiple peaks of spatial analysis variable. The real distribution is smaller than expected, but this is just a matter of the uncertainty over a musical improvisation with so many different control parameters.

(ii) Cinematic analysis: The expected behaviour, plotted in 34, is determined by the following reasons:

- **[0,20) seconds:** In this first interval, where the spatial range is small, and the velocity is low, we can expect a value of the cinematic analysis variable to be quite low. However, this is not what it happens. If we think about the computational process of the components that constitute the final Tech. Skills: cinematic, spatial and frequential analysis, we can see how this first interval (from 0 to 20 seconds) shows a higher data density, in all three cases. And this is the reason that explains the small disparities originated. These variables were conceived globally on each improvisation in the designed metrics, but, as an exceptional case, for Experiment 1, new variables were created to evaluate an average value of the response of these variables for each GESTURE, at the local level.

But, since this first interval is interpreted by means of mouse clicks, all the simple events are considered as global gestures, which gives a smaller weight to the gestural means of the following intervals, thus triggering the cinematic values of this first interval.

- **[20,40) seconds:** In this next interval, an increase of the initial velocity, again towards a constant state, will slightly increase to a place, in general, with stationary mean, which agrees with the distribution of the affected range.
- **[40, 100) seconds:** The change from clicking to scrolling should mean a small increase in the number of events analyzed in each gesture. While it is true that the initial change can be understood as a slight leap between the difference of the mouse technique, the fact that the distribution is so pronounced at $t = 42secs$ is not fully explicable. Now, taking a look, in general lines, the rest of graphs, it could be seen that this point is of singular interest. It can be observed, and predicted, that something must have occurred during the improvisation that did not fit the established patterns, with the rest of the improvisation showing an affirmative correlation with the actual distribution.
- **[100,120] seconds:** To conclude, by keeping the mouse scrolling, as well as the constant scan speed at the previous intervals, a quasi-stationary state is to be left behind. Now, the combination of variable speed with clicking and scrolling of the mouse have to be translated into a set of peaks with an average value slightly higher than the previous states. This all agrees with the actual distribution.

(iii) Frequential analysis: The expected behaviour, plotted in 35, is determined by the following reasons:

- **[0,100) seconds:** Most of the performance is designed in areas away from the interface. This means that, during the first hundred seconds, the distribution of the variable frequential analysis should vary between low values. Again, we find an area with higher data density in the first interval, as has been commented previously. Also, the real distribution shows the maximum differences in the central distribution zone, those areas in which the ranges with greater distribution in frequencies are explored, which makes sense.

- **[100,120] seconds:** In this last interval the effect of distortion is explored, so that, although several parameters are combined, a series of peaks will appear whose global mean is the maximum of the whole distribution. All this shows a strong positive correlation with the real distribution.

(iv) Novelty: The expected behaviour, plotted in 36, is determined by the following reasons:

- **[0,20) seconds:** In this first interval, where the spatial range is small and the frequencies are contiguous, novelty values have to be small peaks with a low average value, due to the discovery of close new events, as seen in the actual distribution.
- **[20,40) seconds:** In the second interval, the increase in velocity to a higher constant value should imply an increase in the novelty values, since the gestural analysis vector takes the angular velocity and its IQR as main descriptors. It is possible to check in the real distribution an appreciable increase in this interval towards an average value of 0.1.
- **[40,60) seconds:** To continue, the change from clicking to scrolling involves the capture of all intermediate data, which should translate into an increase of new events, assuming this in turn the increase of the average value of novelty. The correlation with the actual distribution remains affirmative.
- **[60,80) seconds:** Now, the spatial range is increased and the exploration focuses on frequencies very far away. This involves the discovery of new values of frequencies as well as coordinates, which should translate into a large increase of the novelty variable, as it can be seen in the actual distribution.

- **[80,100) seconds:** Next, the frequency range becomes smaller, moving again between adjacent zones, which would be a decrease of the novelty with respect to the previous interval, but still greater to the initial state, because the speed is still high and the mouse explores by means of scrolling.

- **[100,120] seconds:** Finally, the combined variability of all previous parameters, both in speed, mouse techniques and frequency scanning areas, should lead to maximum novelty, which can be found in the set of peaks of the actual distribution.

(v) Surprise: The expected behaviour, plotted in 37, is determined by the following reasons:

- **[0,40) seconds:** In the first interval, although the spatial range is low and the frequencies contiguous, everything jumping from one zone to another will suppose a peak in the surprise; that is to say, the boundaries between zones. Likewise, in the second interval, the sudden increase in velocity will mean an instantaneous change in the general vector of gestural analysis, which will thus be reflected in the calculation of the distance to the regression line in the internal computation of the surprise value. This all agrees with the actual distribution.

- **[40,60) seconds:** The change from mouse clicking to scrolling should translate into a slight moderate increase in surprise, as the events are closer to each other, at least for each gesture. It would be normal to also find the peaks in surprise between gestures. We again see in the actual distribution the point $t = 42secs$ that is out of the norm.

- **[60,80) seconds:** In the spatial exploration interval between distant frequencies, the jumps will be translated into events with information in their descriptors very far from the regression lines, which should be translated into maximum surprise. The correlation with reality returns to be strongly positive.

  - **[80,100) seconds:** When you close the scan range in this interval, the regression zone becomes smaller, as well as the surprise value.
  - **[100,120] seconds:** Finally, combining speeds, mouse techniques, distortion effects, and new scanning areas will lead to high surprise values, as long as we are at zone ends, which will produce peaks. Contiguous, stable and quasi-stationary movements would lead to areas of low surprise. It is very complicated to know a priori, with so many parameters at stake, what is, even at a qualitative level, the result to expect.

(vi) Value: The expected behaviour, plotted in 38, is determined by the following reasons:

  - **[0,120] seconds:** Taking into account that the score was designed with the idea of crating a gradually improving performance, the value distribution must be increasing. Once again, the value $t = 42 secs$ shows the maximum value. It should not be like this, but it has already been mentioned that this singular point is due to some improviser mistake made during the performance. Likewise, it is worth noting the variability of the last interval, due to the high concentration of changing parameters, including here also the maximum values of the musical improvisation.

So, after this preliminary analysis, we could conclude some issues:

- The constituent variables of the Technical Skills analysis, spatial, fequential and cinematic, were computed over a global scenario, giving a final value for each experiment. Thereby, just for Experiment 1, **the code was modified in order to extract values over time**. However, the analysis is made as mean values over the events on each gesture, what gives some differences when comparing individual events and complete gestures.
- During the performance, **a singular point appeared in** $t = 42 secs$, that has been seen through the different plots. This shows how arbitrary playing

music could be, but also the sensitivity of the metric in perceiving both the expected and the unexpected data.

- After a first qualitative analysis, and also out of scale, it can be said that **there is a good translation and correlation between the preliminary musical information, the transcribed data and the output values**.

- And, finally, **it can be validated a first aspect on the functionality of the designed metrics.**

6.1.2 Analysis of the orthogonality of the metrics. Independence test.

In the next section, for an analysis and general study of the metrics, we will look for the correlation of the GLOBAL variables of Creativity and Technical Skills. However, now, to validate our metrics, it is possible to study the independence between the constituent LOCAL variables, thus verifying the orthogonality of the metrics without compromising the general analysis that is based on the Sloboda and Rodger proposals.

Pearson's χ^2 test is a statistical test applied to sets of categorical large samples of data to evaluate how likely it is that any observed difference between the sets arose by chance. To determine the intrinsic independence of our variables (spatial analysis, frequential analysis, cinematic analysis, novelty, surprise and value) we have to compare the observed χ^2 with the theoretical one.

The statistical formula is defined so that:

$$\chi^2 = \sum_{i=1}^{N} \sum_{j=1}^{M} \frac{(O_{i,j} - E_{i,j})^2}{E_{i,j}}, \tag{6.1}$$

where $O_{i,j}$ corresponds to the observed variable, with

$$O_{i,j} = \begin{cases} i = 1, 2, 3, ..., N \\ j = 1, 2, 3, ..., M \end{cases} \tag{6.2}$$

where N is the number of gestures of the analyzed performance (the score-based one) and, M, the number of variables of study (the 6 constituent variables). And, $E_{k,m}$ corresponds to the expected variable, computed as:

$$E_{k,m} = \frac{(\sum_{i=1}^{N} O_{i,m})(\sum_{j=1}^{M} O_{k,j})}{\sum_{i=1}^{N}(\sum_{j=1}^{M} O_{i,j})}. \tag{6.3}$$

So that, computing the χ^2 over the data obtained from Experiment 1, with a confident level of 90% we got $\chi^2_{observed} = 55.735$ whereas $\chi^2_{theoretical(critical)} = 284.336$. Thus, as $\chi^2_{observed} < \chi^2_{theoretical(critical)}$, it can be stated that the variables are independent. Moreover, the right tail probability (p) of the χ^2 distribution is much greater than the level of significance (0.1), which also shows the independence of the variables.

Therefore, it has been verified the independence of the variables, thus demonstrating their orthogonality and, together with the qualitative analysis of the previous analysis, **it could be considered validated the operation of the computational metrics proposed in this thesis**. Once we reach this point, we can delve into Experiment 2 to respond to the Research Question through the use of these metrics on the obtained experimental data.

6.2 Experiment 2

Going back in the text, the main reference to face the Research Question is based on the qualitative proposal of the study of the Technical Skills versus Expressiveness, in the musical field. Also, taking the qualitative point of view introduced by Rodger, as well as his proposal of a study based on the gestural analysis, the computational metrics presented in this thesis aim to translate a musical input, from

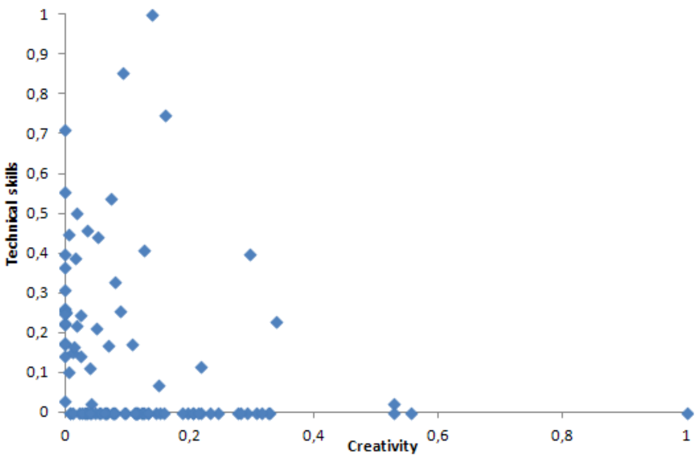

Figure 39: Skills vs. Creativity analysis.

an improvisation, into a set of data referred to the technical skills of the use of the interface by the subject of study, as well as the performing creative level. Therefore, these tools now allow us to graph one variable against the other, as can be seen in the figure 39 that we now could see repeated.

Thus, the next step should be to study the existence of a possible correlation between the obtained values. The first statistical analysis that may come to mind could be the use of the Pearson coefficient; however, the sets of values are random and do not have a normal distribution by themselves, so, it must be discarded. Also, we could consider a cross-correlation study, which is very typical in the field of Signal Processing. Again, we must discard the idea because we do not know one distribution more than another and do not want to offer a priority that can mask our results. Therefore, the most reliable solution seems to be to use Spearman's Correlation Coefficient, taking into account it is designed for random variables, as it could be the case of the parameter results of a musical improvisation.

The Spearman's Correlation Coefficient, r_s is defined as:

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n(n^2-1)}, \tag{6.4}$$

where d_i corresponds to the variables difference of ranges and n, corresponds to the amount of data.

To analyze the final result, the Critical Spearman Coefficient, r_s^*, has to be checked from the Statistical "P" table. In our case, with a statistical significance of $\alpha = 0.01$, $r_s^* = 0.233$. Likewise, after some calculations, $r_s = 0.413$. So, in bilateral test, as $r_s > r_s^*$, it could be said that there exists affirmative correlation. Thereby, after validating the metrics in the previous section, **we could now answer the main Research Question by confirming the existence of positive correlation between the technical skills acquired in a musical instrument and the level of creativity demonstrated through improvisation in that specific interface**.

6.2.1 Deeper analysis of the constituent variables.

To continue, the main metrics variables, technical skills and creativity, are also shown separately, in the Results section, with their respective components. So, in figures 22, 26 and 30, the plots corresponding to the technical skills component of all participants, musicians and non-musicians are shown. It has to be taken into account that the total skills blue line corresponds to a mean value analysis.

The ranges of values of the plot referred to all participants are included in table 4.

Table 4: Total skills components ranges of values.

Spatial analysis	0.0 - 0.9
Frequential analysis	0.4 - 0.9
Cinematic analysis	0.0 - 0.8

However, even having those minimum and maximum values, the general distribution seems to be: *spatial « cinematic « frequential.*

Likewise, in this first plot, figure 22, the two maximum peaks of the distribution coincide with the maximum of the spatial analysis variable, an their behaviour shows some kind of qualitative correlation in those regions.

In regards musicians plot, figure 26, the behaviour is really similar compared to the previous graphic, showing, additionally, some small peaks due to higher values reached by the cinematic analysis variable. Moreover, the spatial and frequential/cinematic variables are more separated in this current case, meaning a small usage of the surfaces space compared to the speed and range of effect used during the performances by the musicians. And, finally, the general appearance of the distribution shows and increasing tendency of the technical skills with the performance. **Some kind of slight learning process**.

In order to finish with the skills component analysis, it has to be said that the non-musicians plot, figure 30, also shows and increasing behaviour of the data, but much less sloped. Furthermore, the final value is smaller than the one reached by the musicians. The general spatial and frequential distributions are again in down and up positions, respectively, according to their values but, in this case, the cinematic distribution shows a more chaotic behaviour. This could mean that **the performances velocities were not really conceived within a small common range by the participating non-musicians**.

To continue, let's make a similar analysis of the creativity data and its components. Those are figures 23, 27 and 31, referred to all participants, musicians and non-musicians, respectively. Again, the creativity line refers to a mean value over the general distribution.

So, the ranges of values reached by the component variables, of the all participants corresponding data, are then shown in table 5.

Table 5: Creativity components ranges of values.

Novelty	0.1 - 0.8
Value	0.0 - 0.8
Surprise	0.3 - 1.0

Some qualitative correlation be also found in this graphic, figure 23, referred to **value**, because this parameter **shows the most variable behaviour, extremely affecting to the final total creativity**. Likewise, the novelty distribution shows

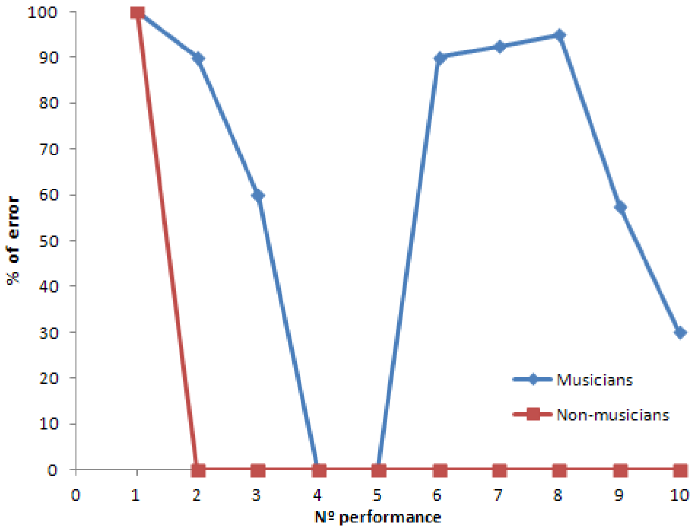

Figure 40: Median error percentage per performance

some kind of convergent behaviour, like a horizontal cone which narrows as the number of performances progresses.

In what respects to the musicians creativity component analysis, the mean creativity looks shifted compared to the all participants' one, reaching the range 0.10-0.35. However, **the general distribution does not follow a gradual increasing appearance**.

Finally, in the case of non-musicians, all the values are shifted down with a general maximum in 0.7 for all parameters, with some exceptions. Likewise, the mean creativity, which now goes from 0.0 to 0.3, follows an increasing learning behaviour.

6.2.2 Analysis of the errors and their corrections.

And, to continue, we now cover the analysis of the Error correction variable. The first graphics to include this analysis are the ones included in the Results section, figures 24, 28 and 32, corresponding to the general error correction plots of all participants, musicians and non-musicians, respectively. Likewise, a summary of the amount of error could be seen in figure 40.

In those graphics, the differences between musicians and non-musicians are very remarkable. **The former ones show a really variable set of values, making even more mistakes, as the number of improvisations progresses**. To explain this we have to consider these people more daring. As they became more familiar with the instrument, demanding themselves more and more, they accepted more risks and looked for improvisations that were increasingly innovative and creative. This, at the same time, would boost the number of errors as the number of improvisations was increasing. On the contrary, **the non-musicians behaviour turns in an increasing appearance**. That is to say, the errors decrease progressively. This could be translated as a learning achievement, giving some evidences about the skills gained during the experimental stage. In order to make a deeper analysis in what respects to the errors during the improvisations, the appendix A includes a whole set of graphics where the errors are analyzed over different intermediate variables. Thus, in figures 47, 48 and 49, corresponding to the coherence distribution vs. the error correction, it could be seen the same main idea: in those cases where the error committed was high, that means error correction ≈ 0, the performance coincides with highly coherent values. This means, according to how the system is computed, that the spatial range used within gestures was always in a common area, but, also within those periods of time, the mouse reached blank zones. To explain this, the more reasonable causes are:

1. The blank zones were pushed accidentally but the improvisation kept on obviating it.
2. The blank zones where used as an effect of turning off the music.

After that, the next figures, 50, 51 and 52, referred to the fluency vs. error correction analysis of all participants, musicians and non-musicians, corroborate the first hypothesis that surrounded the concept of fluency. And, thereby, **its computation needs to be revised** in order to see if that is the main cause of the misunderstanding or if it is just a matter of calculating the mean value of a huge amount of different values.

To continue, the frequential vs. error correction analysis appears illustrated in figures 53, 54 and 55, corresponding to all participants, musicians and non-musicians, respectively. From the analysis of those plots it could be said, first of all, that the number of musician error (14 %) is half the non-musicians (28 %). Furthermore, the range of distribution gives the lowest frequential values to musicians, being the highest the non-musicians'. Taking that into consideration, as well as the fact that the frequential analysis is the IQR calculated over the effect's percentage, those results show how, in the case of non-musicians, the maximum number of errors corresponds to the lower frequential stages; that is to say, the outer areas of the interface's surface. So that, it could then be deduced that, from there, it is easier to, accidentally, reach a blank zone. This also gives some consistency on the idea of programmed performances in what respect to musicians. On the contrary, the non-musicians show great area of errors with also great frequential analysis values, so, their improvisations should had include a broad range of variability in the usage of effects, but covering the maximum number of error all over the performances.

Finally, the last distribution shown in the spatial analysis vs. error corrections, figures 56, 57 and 58, referred to all participants, musicians and non-musicians respectively, presents an arbitrary behaviour in the case of non musicians, but also, a common area of error in the musicians performances, corresponding to the low spatial ranges. This throws again some light on the idea of improvisation over a small region, probably by scrolling or clicking the mouse in launches, what makes bigger the number of local error, and, thereby, smaller the error correction values.

6.2.3 Intermediate descriptors analysis.

Let's then conclude with the result graphics included in appendix A. The first plots are the ones related to the spatial analysis vs. the frequential analysis, figures 41, 42 and 43, corresponding to all participants, musicians and non-musicians, respectively. In those plots we could perceive a really similar behaviour. The distributions show most of the data over the ordinate y = 0.5 and until the abscissa x = 0.4. This means that **the general tendency was to go through the effect range more frequently than playing distant pitches**. In this sense, this could mean a greater value of the surprise component compared with the novelty component, in terms of creativity, what, in fact, has been observed in the previous paragraphs. This could also be set as a conclusion of a general tendency, for all participants, musicians and non-musicians, on the improvisation here captured.

The next set of graphics, figures 44, 45 and 46, that refer to the analysis of Coherence vs. Fluency of all participants, musicians and non-musicians, respectively, show an amazing correlation between both variables. However, the fluency values are strangely high; was there no one who had improvised by means of separate sounds? Thereby, this could mean two things:

1. Although people played sometimes separate notes, the mean value of each performance is high because most of the performance was based on mouse scrolling.
2. **The computation of the fluency parameter takes a wrong value of window when it shifts (!)**, what is translated in a non-reliable value of fluency.

To sum up, the starting point of this thesis was the design and computation of a set of metrics to analyze the possibility of an existent relation between the technical skills and creativity in musical improvisation. After building a digital musical interface, those metrics were elaborated according to main references, as they are: Sloboda and Rodger's expressive analysis and Maher computational creativity approach. So that, after an experimental stage, the metrics' operation was tested qualitatively by means of a score-based behavioural analysis, as well as they were validated after a χ^2 independence test. Furthermore, an affirmative correlation was found by applying Spearman Statistical Correlation with an $\alpha = 0.01$ value. Finally, this chapter has covered some more ideas related to variable constituents and intermediate descriptors, in order to squeeze and understand the metrics's functioning the maximum possible, giving us a more global view of the 'how' and 'why'.

Chapter 7

Conclusions

7.1 Technical skills and Creativity metrics

This thesis arises from the need to find a qualitative and quantitative correlation of the technical skills acquired during the process of exploration and use of a digital musical instrument according to a computational analysis of creativity. The main framework was the learning metric proposed by Rodger and Sloboda, conceiving the analysis of technical skills through the computation of Wanderley's gestural analysis methods and Maher's computational creativity proposal. Thus, for the evaluation of these metrics, a digital instrument was designed and presented to a group of five musicians and five non-musicians, for the exploration, manipulation and usage during a free improvisation.

From Experiment 1, it could be ensured that the learning metrics here described translate the data captured from musical improvisations into the correct analysis of technical and creative skills, which in turn agree with the expected result through manual analysis. Likewise, the internal independence of these metrics during the computational development has been demonstrated by means of a statistical analysis.

In addition, Experiment 2 concludes with the existence of a correlation between technical skills and creativity, as Sloboda and Rodger have already stated, from a qualitative point of view. This, in turn, leads us to ratify the concept of learning curve, framing the study elaborated here at its beginning.

Thereby, the three main conclusions could be summarized as follows:

1. **A set of analytical metrics has been designed by means of gestural analysis during musical improvisation and based on the study of the acquisition of Technical Skills and Creativity**.
2. **The operation of those metrics has been tested by a qualitative analysis over a score-based experiment**.
3. **A positive correlation has been found between the Technical Skills and Creativity**. Even though the correlation coefficient is not very big, a new hypothesis could be born from here, considering our experiment just within the beginning of a learning curve. That is to say, a longer experimental stage might lead the data to a general more regressive behaviour.

It is also important to emphasize from the analysis of the constituent components of the metrics, as far as the Experiment 2 in particular is concerned, a greater preference of the participants in the exploration of modifications of preexisting sounds in comparison with the exploration of new sonorities, and , moreover, when the new possibilities are at great distances from the separation of the current event. It should also be noted that both, the development of creative abilities and technical skills, is greater in the case of musicians versus non-musicians.

On the other hand, from the analysis of the fluidity as an intrinsic descriptor of the 'value' metric, with respect to other descriptors, the necessity of a computational adjustment of the descriptor becomes evident, possibly due to the selection of the temporal window size and its shifting.

Finally, with respect to the correction of errors, we can extract from the general analysis the observation of the existence of a clear learning curve by non-musicians.

However, in the case of musicians, the behavior stops erratic and much more random. In fact, it even increases as the number of improvisations of each participant advances. The hypothesis presented here contemplates the possibility of the acceptance of a greater risk on the part of the musician participants when facing new improvisations, which would be translated in a greater number of errors, as we have verified happens in the reality.

In my opinion, through the experimental method and the discussion carried out, the research question has been answered. However, its scope of application is reduced to the experiment developed here. That is to say, if we ask for the existence of a correlation between technical skills and creativity in their acquisition process, the answer is affirmative. But if we want to specify how or how much, the study has to be defined in different ways, hence it is necessary to clarify that: the technical skills studied here refer to a parametrized gestural analysis according to the dimensions of the digital instrument; the level of creativity refers to the computational study of the parameters novelty, value and surprise; the framework of study is free-improvisation as an optimum medium raised in the methods of evaluation of creative models developed during the twentieth century; and a long etcetera. These limitations, from my point of view, do not weaken the research itself, but rather help the reader to understand the scope of the study and its conclusions.

To finish, the computational resources developed for this thesis have been included in an on-line repository. Check its license and instructions in order to follow all the coding and experimental processes involved in this research:

`https://github.com/GermanRuizMarcos/SMC-Master-Thesis`

7.2 Contributions

Through an overview of this thesis, some possible implications and contributions to the state-of-the-art can be enumerated:

1. The digital musical instrument.

The PD-patch that contains the digital instrument can be reused in new research as well as in music creation.

2. The designed metrics.

   (a) Technical skills metric: conceived from Wanderley's theoretical approach and adapted to computational purposes.

   (b) Creativity metric: as a way of continuing Maher's proposal and supporting the proposed method in the hard task of evaluating subjective musical materials. Likewise, the selection of the number of clusters is based on my own automation of the elbow method.

   (c) Value approach: entirely new proposal based on a theoretical approach introduced by Gibbs in the expert based evaluation of musical improvisation.

   (d) Learning metrics: conceived as a brand new combination of the previous commented metrics according Sloboda and Rodger's previous approaches in the field.

3. A narrowing on the semantic gap that relates the used descriptors.
   The relationship made between the captured data from each performance, its translation in low-level descriptors and the metrics role in shaping this into high-level descriptors, could be considered as a step forward in terms of the analysis of creativity and musical ability within the music technology world.

4. A useful tool for learning applications.
   Taking into account the parameters analyzed by the proposed metrics, those applications focused on helping people in the process of learning how to play a musical instrument can use some of the ideas here presented, both in the technical skills assessment and from the creative perspective.

7.3 Future work

There are several possibilities with which to confront new research through the methodology used in this thesis. The first one is the most obvious one, and it would consist on improving the fluency estimation method and computation in order to improve the analysis methodology. Likewise, a longer experimental stage might throw more light into the correlation issue. To continue, the system can also be improved by adding a feedback system, which would give another point of view about the dimension of conceiving the learning metrics. It is also possible for Self-Regulated-Learning (SRL) resources to fit into this new version of the system. Finally, the same digital device can be calibrated so that score-based performances or conducted improvisation can be performed. Furthermore, it would also be interesting to give the interpreter the possibility of modifying and creating small adaptations of the musical instrument. All this would help in comparing the results obtained and draw particular conclusions according to the musical style in which each experiment is framed.

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Bibliography

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Appendix A

Experiment 2 attached plots

A.1 Skills variables deeper analysis

A.2 Value variables deeper analysis

A.3 Error corrections correlations

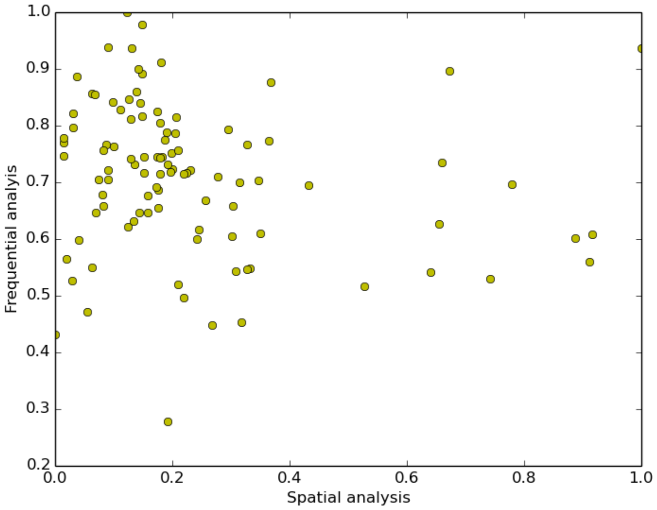

Figure 41: Spatial VS Frequential analysis (all participants).

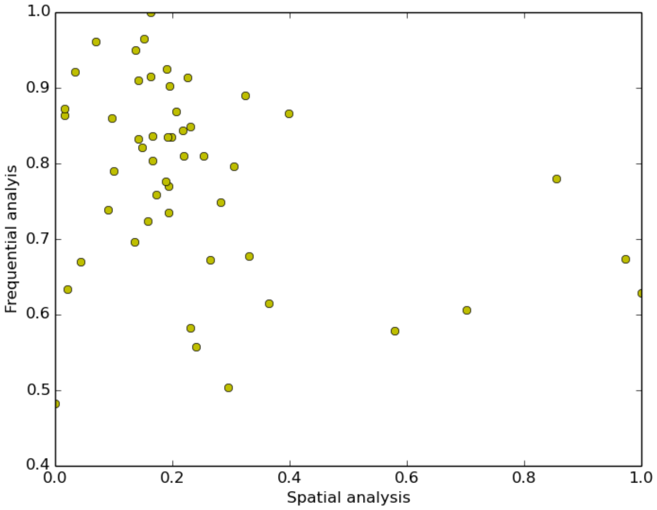

Figure 42: Spatial VS Frequential analysis (musicians).

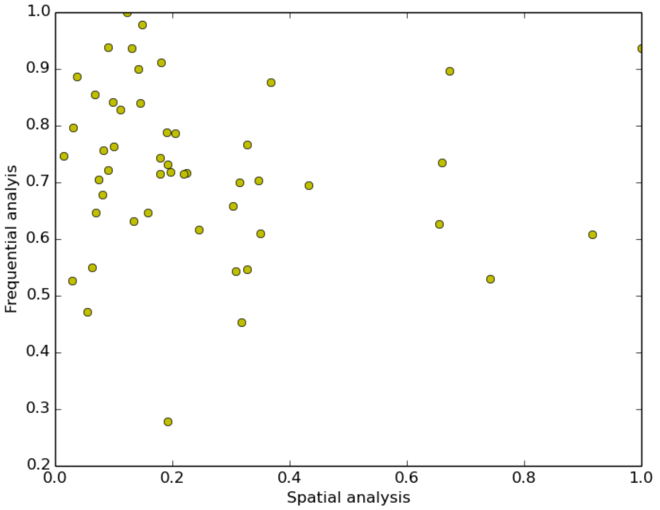

Figure 43: Spatial VS Frequential analysis (non-musicians).

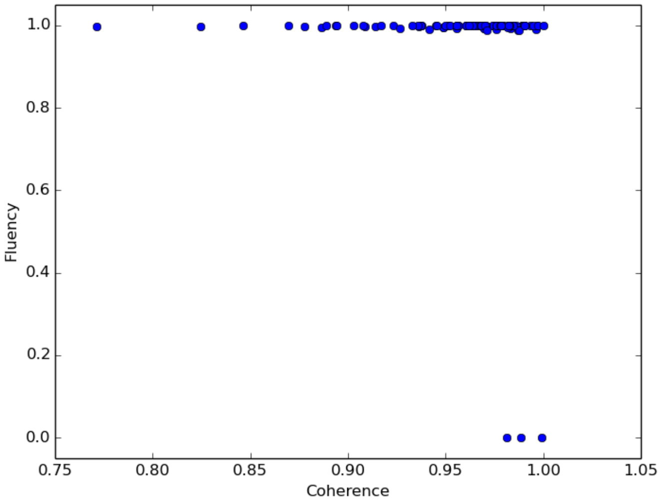

Figure 44: Fluency VS Coherence (all participants).

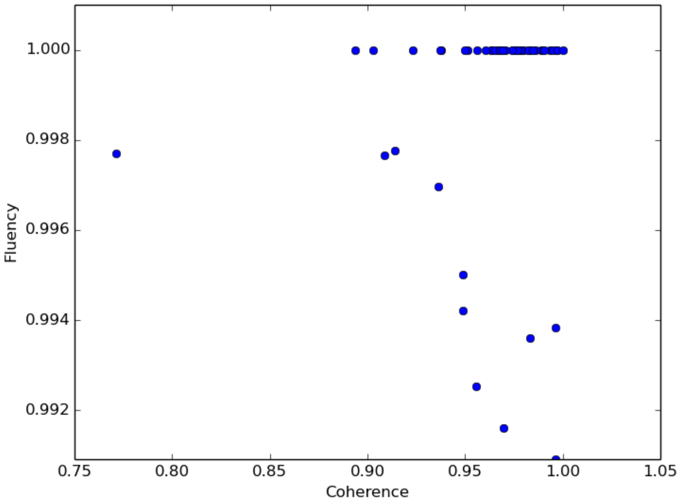

Figure 45: Fluency VS Coherence (musicians).

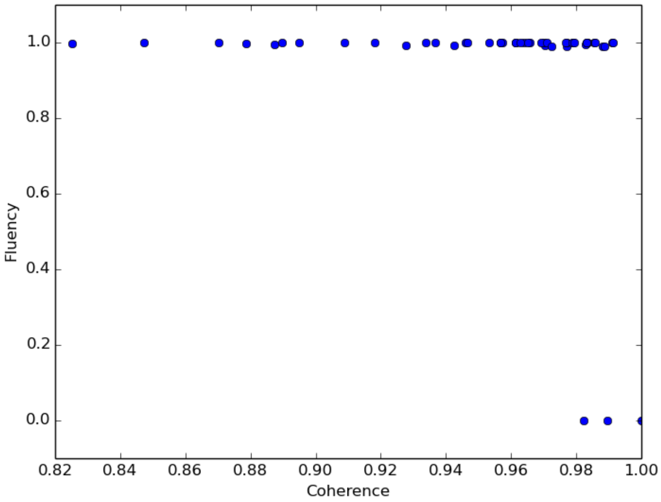

Figure 46: Fluency VS Coherence (non-musicians).

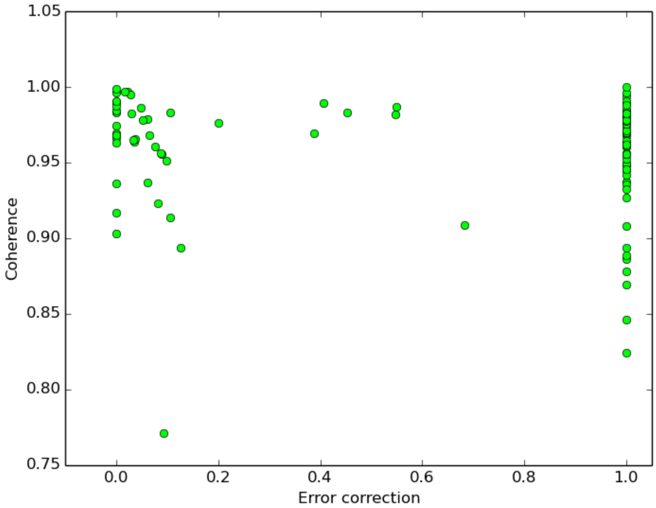

Figure 47: Coherence VS Error correction (all participants).

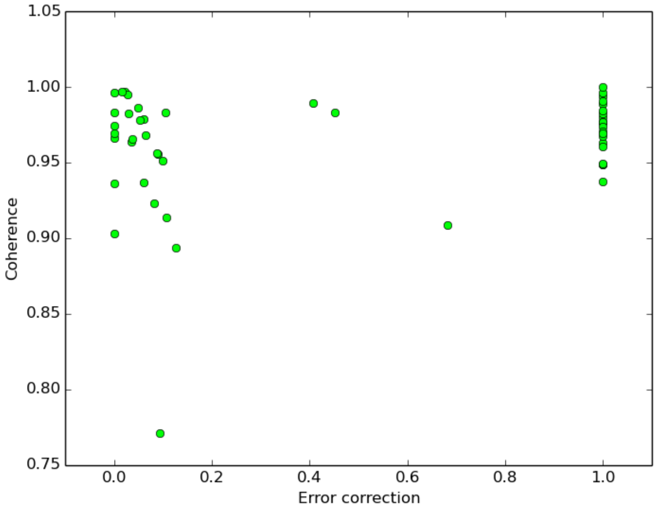

Figure 48: Coherence VS Error correction (musicians).

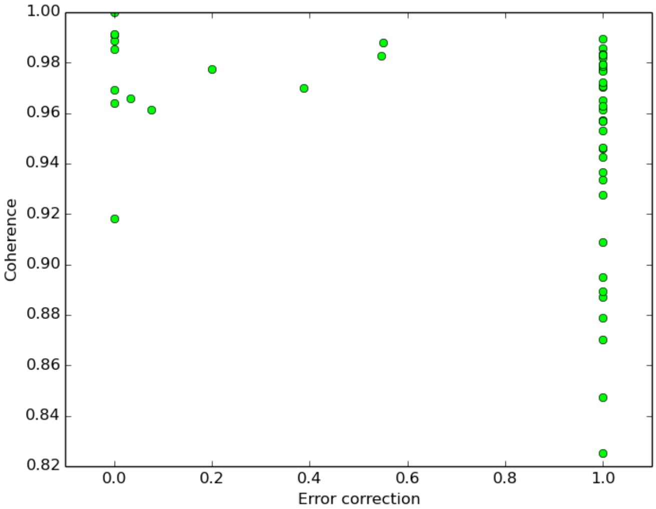

Figure 49: Coherence VS Error correction (non-musicians).

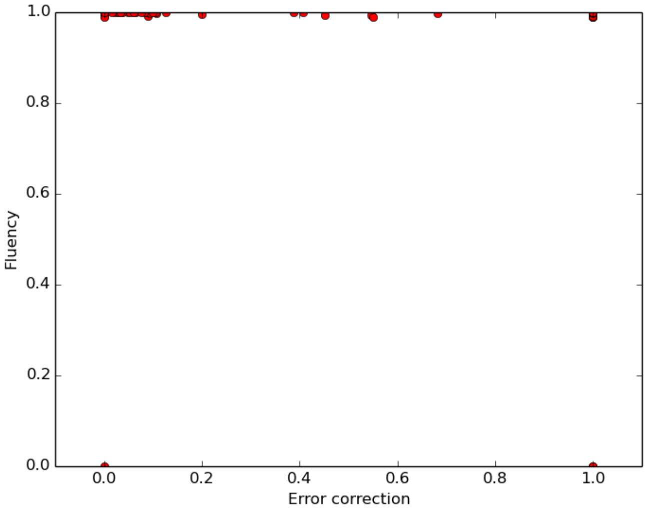

Figure 50: Fluency VS Error correction (all participants).

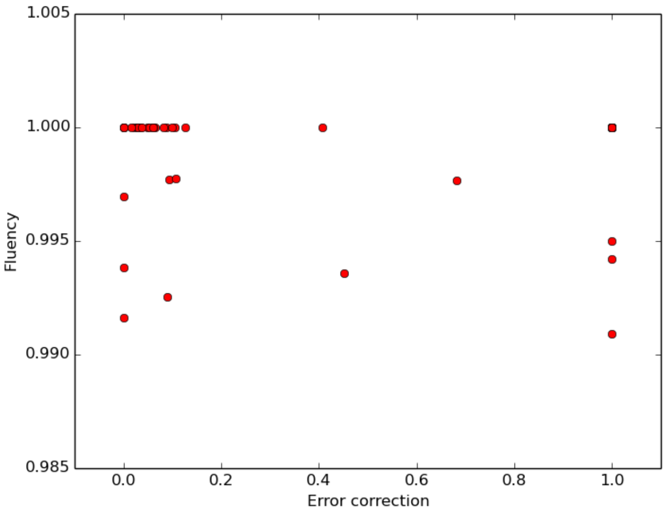

Figure 51: Fluency VS Error correction (musicians).

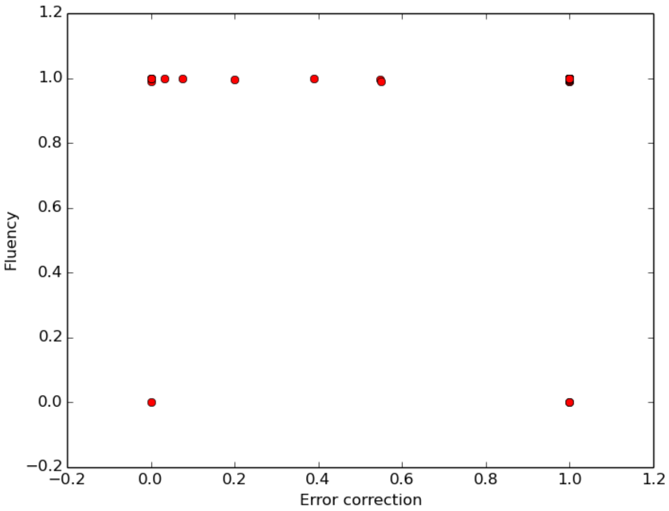

Figure 52: Fluency VS Error correction (non-musicians).

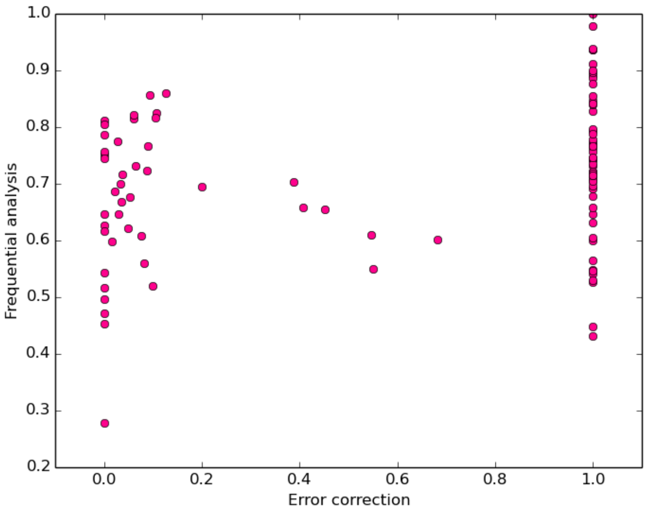

Figure 53: Frequential analysis VS Error correction (all participants).

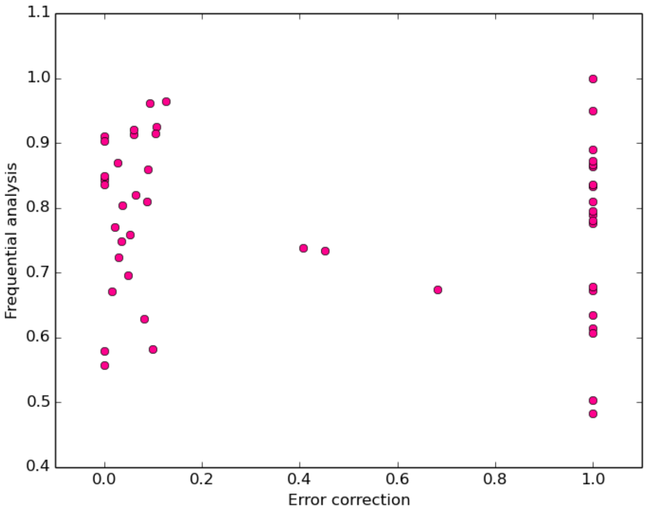

Figure 54: Frequential analysis VS Error correction (musicians).

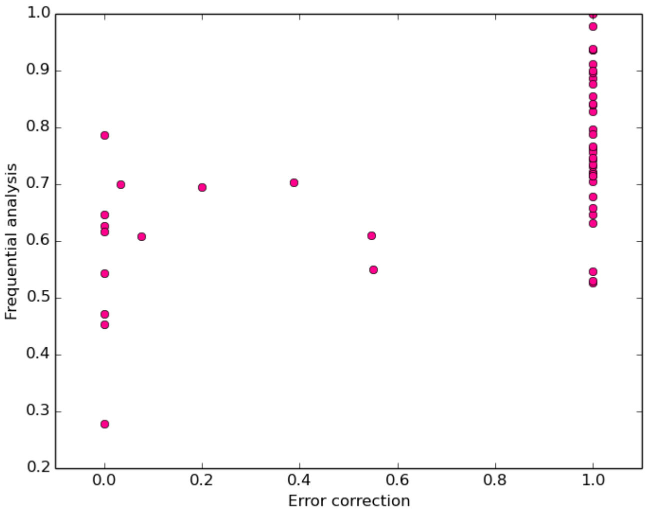

Figure 55: Frequential analysis VS Error correction (non-musicians).

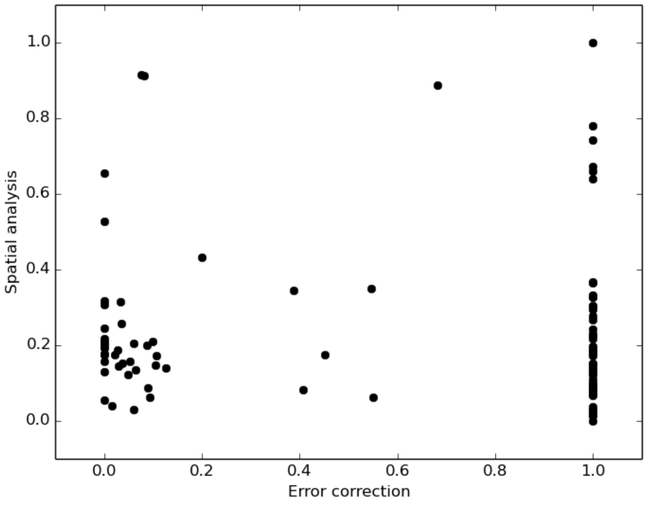

Figure 56: Spatial analysis VS Error correction (all participants).

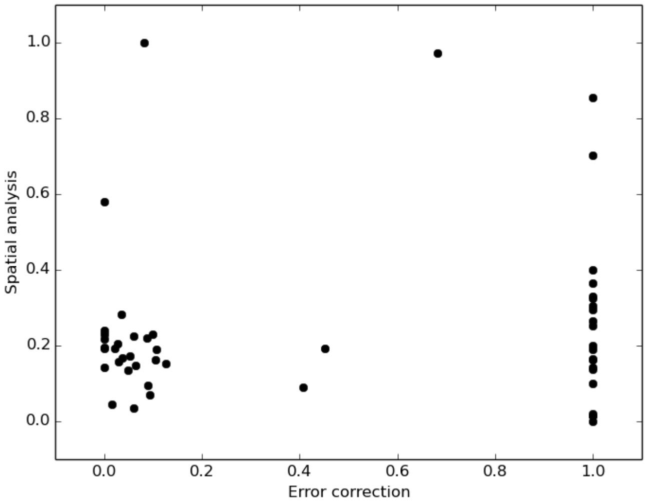

Figure 57: Spatial analysis VS Error correction (musicians).

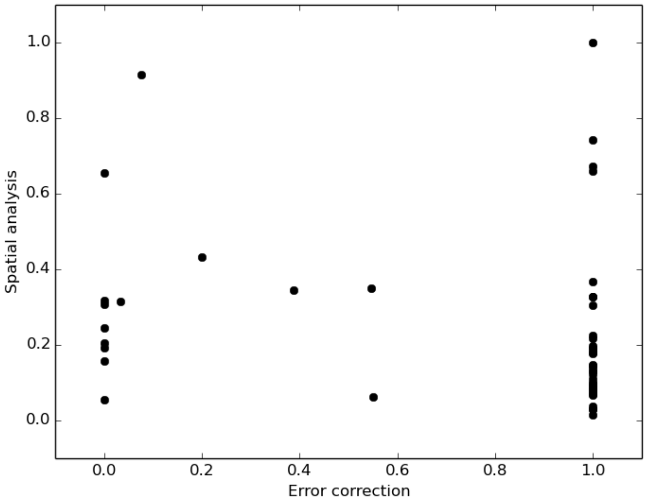

Figure 58: Spatial analysis VS Error correction (non-musicians).