A Computational Method for the Analysis of Musical Improvisations by Young Children and Psychiatric Patients with No Musical Background

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ABSTRACT

Improvisation is a common form of musical practice and yet remains the least studied or understood from a music analysis point of view. When populations with no musical background engage in musical improvisation (such as young children or patients in therapy settings) the analysis of the musical aspects becomes more challenging: The possible lack of common learned musical schemata and related technical skills requires the introduction of methods of analysis which can deal with these peculiarities. In this paper we propose a computational method for analysing such types of improvisations and apply it to the analysis of a small number of case studies. The analytical method is a type of semiotic analysis, where repetition, variation and transformation are brought forward. Musical parameters have to be defined, and a computational tool is built to reveal interesting patterns that repeat within the various musical parameters. The method is applied to the improvisations of six eight-year old children and two psychiatric patients with psychotic syndromes. For their improvisations they use the machine-learning based system MIROR-IMPRO, developed within the FP7 European Project MIROR, which can respond interactively, by using and rephrasing the user's own material. The results point towards the usefulness of more abstract types of representations and bring forward several general common features across these types of improvisations, which can be related to gestures.

I. INTRODUCTION

Improvisation is a common form of musical practice across cultures, and yet remains the least studied or understood from a music analysis point of view. To that end, there have been a number of approaches, especially in jazz and folk music (e.g. Berliner, 1994; for computational approaches see Sentruk and Chordia, 2011; Johnson-Laird, 1991). In music therapy, the analysis of improvisations is gaining more ground in recent years, informing directly the therapeutic process (such as Thaut, 1988; Lee, 2000; Erkkila et. al. 2004 for a computational tool). In young children's improvisations, various approaches exist to date, which however focus more on educational, psychological and sociological theories rather than the music per se, and explore the process rather than the product of the improvisation (such as Baldi et. al. 2002; Burnard, 2000; Young, 2005).

Music analysis is the discipline which "takes the music itself as its starting point rather than external factors" (Bent and Pople, 2001). In its formal part, it raises the question how does a piece of music work, what are its constituent parts and how they relate to each other, bringing out specific relations of similarity and difference. Where appropriate, it can provide interesting insights on related human perceptions and understanding.

When populations with no musical background engage in musical improvisation (such as the majority of young children and patients in therapy settings), the analysis of the musical aspects becomes more challenging: The possible lack of common learned musical schemata and related technical skills results in improvisations which do not have the expected musical characteristics and structure, to guide the analytical procedure. In this case, the introduction of particular methods of analysis that can deal with such aspects is called for.

In this paper the method employed is related to paradigmatic analysis as described by Nattiez (1975), also discussed in Monelle (1992) and Agawu (2009). In this method, analysis is carried out with as few preconceptions as possible, and is being based on creating a systematic account of repetitions and variations located in the music itself. In the present study a computational tool is used to locate repeated patterns in the corpus of improvisations.

For our corpus we take improvisations by young children and psychiatric patients, whom we recorded in a number of sessions each. The direct comparison of improvisations of these two populations might seem odd at first. Apart from the fact that all our improvisations are made by people with no musical background, there are no other unifying principles. However, the aim of this paper is to create an investigation on the purely musical level, without engaging with extra-musical associations, such as psychological, cultural, therapeutic and anthropological perspectives.

The rest of the paper proceeds as follows: Section 2 describes the method of analysis, starting from the description of the corpus, moving on to the issue of knowledge representation which is given particular emphasis in this paper, and ending with a description of the algorithm and related analysis methodology. Section 3 presents some sample results of the various representations, demonstrating why some representations might be more appropriate than others, section 4 includes a discussion on the results, while section 5 ends the paper with some general remarks and directions for future work.

II. METHODOLOGY

A. The Corpus

The corpus to be analysed is comprised of a number of improvisations made by six eight-year old children and two psychiatric patients. In their improvisations they use a MIDI keyboard and the *MIROR – Impro* system. This is a machine-learning system based on the older Continuator (Pachet and Addessi, 2004), which has been developed further during the European FP7 Project MIROR (Musical Interaction Relying on Reflexion, http://www.mirorproject.eu see also Addessi and Volpe, 2011). During the session with the system, the user plays a melody and the system responds by rephrasing and by using similar material to the user's input. This results in a musical dialogue between system and user, which is based on the user's own musical style. This follows the concept of

Interactive Reflexive Musical Systems, where musical concepts are taught by the interaction between system and user, mirroring the user's own ideas and pace.

The system has several settings which can be used, defining the various musical parameters and the degree of similarity between input and output. The system's answers range from identical responses, to very distant variations of the input. During our experiments each user had several sessions with the system, each session usually lasting between 5 and 30 minutes, and using a variety of settings, ranging from identical answers to distant variations. In our analysis we look only at the melodies produced by the users, and do not analyse at this stage the system's responses and the effect they potentially had on the improvisations.

The children had a total of 59 sessions, and the psychiatric patients a total of 19 sessions, each session including several improvisational melodies.

B. Knowledge Representation

The collected improvisations make out a corpus of melodies in symbolic format since they are played on a MIDI keyboard. The concept of a symbolic musical corpus raises the issue of the appropriate music knowledge representation. Having in mind the data manipulation task, the multiple viewpoint formalism is chosen (Conklin and Witten, 1995; for segmental viewpoints see Conklin and Anagnostopoulou, 2006), as it offers great flexibility in surfacing the attributes of the musical objects (notes, phrases, melodies). It also offers a direct and easy representation on corresponding data structures. A viewpoint sequence can be thought of as a sequence of values of a specific musical attribute, for example a sequence of intervals, pitches, contour directions, rhythmic values, and so on.

For the present study we take four different viewpoints which are related to pitch, each one progressively more abstract than the previous one. These are:

A. Pitch (MIDI number,)
B. Melodic Intervals (Number of semitones plus direction)
C. Interval Classes (Value of 0 when unison, 1 if small interval =< 5 semitones, 2 if big interval >5 semitones. Direction not taken into account).
D. Melodic Contour (Value of 1 if rising, -1 if falling, 0 if static)

We look for patterns in all these viewpoints sequences separately, and at the end we evaluate the results for each, checking to see which level of abstraction might be appropriate for this type of musical corpus.

C. Algorithm and related music analysis methodology

The algorithm proceeds by reading one by one all MIDI files in a directory and building from the corresponding MIDI events a sequence of viewpoints. Consecutively, all repeated patterns within each viewpoint sequence are extracted. The identification of repeated patterns can be seen as a problem within the stringology domain. As such, in order to identify common patterns, suffix arrays are employed (Manber and Myers, 1993). Suffix arrays provide an easy to implement and fast way to locate each and every common substring within a string. For constructing the suffix array, the well-known QuickSort comparison sort algorithm (e.g. Sedgewick, 1990) is used in this work. All common patterns of length less that 2 are ignored as trivialities. The suffix array is then scanned and the common patterns are reported, along with their frequency, their length and their locations. Patterns found are allowed to overlap.

In music analysis terms, the discovery of repeated patterns in a corpus can be seen as a type of paradigmatic analysis, in that repetitions of specific patterns are made apparent and located within the piece or pieces of music under analysis. The added advantage here is that each musical parameter is processed separately, and repetitions are located within each parameter (or viewpoint sequence), making thus explicit the type of repetition. We can therefore observe repetitions at different levels of abstraction.

III. RESULTS

We performed experiments using each of the four musical parameters described above, and using firstly all the corpus (A), secondly the corpus of children alone (C), and thirdly the corpus of psychiatric patients alone (P). A large number of patterns was collected, and below we summarise some of the most frequent and interesting results. For each pattern, we note its frequency, the number of different sessions found, and the corpus it came from.

1) Pitch

Pitch is the lowest level representation used in this study. A large number of short patterns was found, which did not have high frequency numbers. Amongst all patterns found, we notice several patterns of stepwise motion, going either up or down, and some patterns of repeated notes in the children's corpus. In Table 1 we quote some of the most frequent ones.

Table 1: Example patterns of pitch for the three corpora

Pattern	Frequency	Number of sessions	Corpus
[D3,F3,E3]	59	10	A
[E4,A4,E4]	37	10	A
[F4,G4,A4]	214	25	A
[C2,C2,C2,C2,C2,C2,C2,C2,C2,C2]	107	2	C
[B2,A2]	134	22	C
[C3,D3]	145	8	P
[D3,E3]	183	7	P
[G4,F4,G4]	34	6	P

2) Intervals

A large number of interval patterns was found, from very short to very long ones. These included straight movements across the keyboard, either ascending or descending, oscillating movements (the alternation of two notes on the keyboard), some unison patterns, and others. Table 2 shows some characteristic ones. The second pattern, which is found in the A corpus, that is both in children and psychiatric patients, [-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1], presents a diatonic stepwise downward movement (for an example see Figure 2), probably using all the white keys of the keyboard. The third pattern [0,0,0,0,0,0,0,0,0] (Figure 1) denotes a repetition of the same note, and although it was very frequent, it was more common on the children's improvisations. The next two patterns found on the Children's corpus, [-2,2,-2,2] and [-27,27,-27,27], the first one much more frequent than the second, denote oscillating movement between two notes. The first one includes a tone, whereas the second one a very large interval of more than two octaves. The next two patterns by the psychiatric patients include another oscillating pattern of a tone, and a stepwise diatonic downward movement.

Table 2: Example patterns of intervals in semitones for the three corpora.

Pattern	Frequency	Number of sessions	Corpus
[-3,-2,-0]	23	7	A
[-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1]	16	6	A
[0,0,0,0,0,0,0,0,0]	376	7	A
[-2,2,-2,2]	266	29	C
[-27,27,-27,27]	16	1	C
[-2,2,-2,2,-2,2,-2,2,-2]	14	4	P
[-1,-2,-2,-1,-2,-2,-2,-1]	32	6	P
[-53,-2,52,-53]	5	5	P

Figure 1: Example of interval pattern [0,0,0,0,...]

3) Interval Classes

The representation of interval classes was decided in order to achieve a representation more abstract than intervals and less abstract than contour. It also seemed useful to be able to distinguish between smaller and larger intervals. Many patterns, short and long were found, and some results are presented below.

Table 3: Example patterns of interval classes for the three corpora.

Pattern	Frequency	Number of sessions	Corpus
[2,2,2,2,2,1]	757	37	A
[2,1,2,1,2,1,1,2,2,2,1,2]	16	7	A
[1,2,1,2,1,2,1,1,2,1,1]	26	11	C
[2,2,2,1,1,1,2,2]	89	17	C
[2,1,1,2,1,1,2,1,1,1,2]	106	3	P
[1,1,1,2,2,2,1]	149	7	P

4) Melodic Contour

Patterns of melodic contour found had high frequencies as they were the most abstract (and therefore most common) ones. As with intervals, we observe the same movements (oscillating motions, straight ascending or descending movements, unisons, and others). Here we present a few instances: The first pattern [1,-1,1,-1,1,1,-1, -1,1,1] is an example of a pattern moving in changing directions, the second one is a very common pattern which was found in all sessions – and thus perhaps trivial as it did not characterise any of the corpora. The first pattern on the children's corpus [1,-1,1,-1,1,-1,1,-1,-1] is a typical example of an oscillating motion (though the exact intervals in each direction might vary), whereas the second one, [1,1,1,1,1,1,1,1,1,-1] includes a long upward motion. The first pattern of the psychiatric patients, [-1,1,-1,1,-1,-1,**-1,-1**,1,-1,**1,1**,-1], is a good example of an almost oscillating motion, while the second one, [0,0], is a short example of the unison pattern found more often in the children's corpus.

Figure 2: Example of melody containing the pattern of stepwise downward movement.

Table 4: Example patterns of melodic contour for the three corpora.

Pattern	Frequency	Number of sessions	Corpus
[1,-1,1,-1,1,1,-1,-1,1,1]	152	25	A
[1,1,-1,1]	1402	ALL	A

[1,-1,1,-1,1,-1,1,-1,-1]	62	19	C
[1,1,1,1,1,1,1,1,-1]	37	9	C
[-1,1,-1,1,-1,-1,**-1,-1**,1,-1,**1,1**,-1]	16	5	P
[0,0]	181	8	P

IV. DISCUSSION

- As expected, the most common patterns (with the highest frequencies) are the shorter patterns. The longer the pattern, the less likely to be repeated in other sessions.
- As explained above, most of the discovered patterns tended to fall in one of the following categories: denoting a straight upward or downward movement, oscillating motion between two pitches, repetition of the same pitch, and other patterns. In terms of paradigmatic analysis, these can be thought of as the main paradigms of a paradigmatic chart.
- In pitch patterns we had many of the instances of patterns found in more abstract representations. For example, the patterns [C3,D3, E3] and [D3,E3, F3] which were found, are both instances of the contour pattern [1,1]. Pitch patterns tended to have lower frequencies, since they were more specific patterns.
- In that respect, pitch patterns did not prove to be very interesting, as not many conclusions could be drawn from them.
- The similarities between interval patterns such as [-27,27,-27,27] and [-2,2,-2,2] (found in C) can be captured by the contour representation [-1,1,-1,1], whereas they can be distinguished in the interval class representation.
- The long pattern of repeated unison intervals is found mainly on the children corpus. In the psychiatric patients the longest repeated unison pattern with notable frequency was of length three ([0,0,0]).
- The pattern of oscillating movement (contour getting alternating values of -1,1) was found mainly in children. There were a large number of patterns in the psychiatric patients which were *almost* oscillating, e.g. pattern 5 in contour above ([-1,1,-1,1,-1,1,-1,-1,1,-1,1,1,-1]).
- The pattern of stepwise downward movement was very common in all corpora. However, clearer instances were found in children, as patients occasionally introduced intervals with opposite directions in their downward movement.
- Upward movements through the whole range of the keyboard were also found in all corpora.
- Although the melodic contour representation seems to capture all interesting patterns, there are also patterns that appear in all sessions and therefore might be considered trivial to mention (such as the pattern [1,1,-1,1]).
- The interval class parameter – viewpoint did not give any interesting results, and no further conclusions can be drawn from it. Perhaps this is due to the arbitrary choice of deciding which intervals are large (and thus have value 2) and which intervals are small (and thus have value 1) in the definition. A more informed representation is needed.
- Simultaneities of notes, that is clusters played by the whole hand, were also encountered in the data sets, but here they have not been analysed further. A vertical viewpoint representation (Conklin, 2002) is needed to capture these types of textures.

V. CONCLUSIONS

In this paper we presented an initial computational exploratory analytical study of young children's and patients' improvisations. In order to explore the corpus, we used a type of paradigmatic analysis, translated in computational terms into pattern discovery, to reveal interesting repeated patterns within the various musical parameters.

In general, patterns found, especially in children, tend to point to specific gestures. For example, the patterns of oscillation found in all representations (up and down interchangeably), the pattern of repeated notes found especially in children, the pattern of long downward and upward movements found mainly in children. In psychiatric patients, these gestural patterns were also found, but they were not always as clear (i.e. they contained a small number of elements which was not in agreement).

These gestural patterns can be well captured by more abstract types of representations, such as melodic contour. In other words, the level of abstraction in the initial representation needs not be very low level, in order to capture the similarities in the corpus. Melodic contour seems to be an adequate representation to capture pitch-related patterns. This observation might link to the fact that there is no musical background in any of the children or patients. More work is needed on this in order to verify the connection.

The topic of music in relation to gesture has received a lot of attention in the literature. Andrew Mead (1999) talks about "some of the ways physiology, the study of bodily function, inhabits how we talk and think about music, both directly and metaphorically", introducing the idea of kinesthetic empathy as a significant contributor to our musical understanding. Discussing improvisation, Ashley (2009) points out that improvisation "connects musical structure, our bodies and our sense of selves as individuals". In relation to young children's improvisations, Young (2003) discusses the gestural ways they improvise on various musical instruments.

Our results are still very preliminary. Further research will analyse a larger corpus where the statistical significance of patterns will be taken into account. A larger number of features and viewpoints will be explored, especially related to rhythm, texture, dynamics, and those musical attributes which can directly be related to gestures in music. At a second stage, the system's input will be taken into account to check how it affects the improvisation performance. Finally, a syntagmatic analysis of patterns found will help towards a structural analysis of the improvisations.

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An exploratory study of young children's technology-enabled improvisations

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ABSTRACT

Improvisation is now recognised as a central component of musical creativity. Although a relatively young area of study, its educational value has been discussed both musically and socially; young children's musical improvisations more specifically, have been explored through a variety of methods and from diverse paradigmatic viewpoints: cognitive, developmental, educational, sociological and others. The aim of this ongoing exploratory study is to enrich our understanding of the variety of ways young children experience musical improvisation, as this is enabled through the MIROR platform – an innovative adaptive system for children's music improvisation and composition, based on the *reflexive interaction paradigm*. In this paper we draw on data from an exploratory study conducted in November 2011 with eight year-old children, which aimed to explore the ways children engage with the MIROR Improvisation prototype. Three types of data are brought together for the analysis: thematic analysis of children's talk, descriptive analysis of children's turn-taking behaviour and computational music analysis. The research findings indicate connections between particular children's (a) turn-taking behavior and their embodied (gestural) understandings of how they played with the machine and (b) type of musical output and the density of their turn-taking behavior, which seem to indicate that the MIROR technology may in some children encourage particular ways of engagement, both musically and kinesthetically. Pedagogical issues arising from the integration of such technology-enabled improvisation in the primary school classroom are discussed.

Keywords: music improvisation, early childhood education, music technology, pedagogy

I. INTRODUCTION: IMPROVISATION AND NEW TECHNOLOGIES

Improvisation is now recognised as a central component of musical creativity (Webster, 2002; Ashley, 2009). Although a relatively young area of study, its educational value has been discussed both musically and socially, as has its collective and collaborative dimension (for an overview see Tafuri, 2006). Young children's musical improvisations, more specifically, have been explored through a variety of methods and from diverse paradigmatic viewpoints: cognitive, developmental, educational, sociological and others (see Azzara, 2002), while the object of research is also varied. For example, researchers have looked at the development of children as improvisers (Paananen, 2007; Brophy, 2005); improvisation as beneficial to the musical learning of very young children (Kratus, 1989); group improvisational behaviours (Burnard, 1999; 2002); and child-adult interaction as a source of children's creative behaviors (Young, 2003). 'Improvisation creates the possibility for children to create imaginative leaps and to be really present to music-making and discursive thinking, both their own and others' (Kanellopoulos, 2007:135). And as Ashley (2009) points out, improvisation is not an isolated element of human music-making; 'it connects musical structure our bodies and our sense of selves as individuals and members of social units in powerful ways' (p.419). Other areas, such as the introduction of new technologies to support children's improvisations, have received less attention.

The role of technology in music education is foregrounded in discussions about teacher effectiveness (Mills, 1997); young people's out-of-school musical lives (Folkestad, 2006); its impact on learner's creativity (Dillon, 2003); its complex relationship with creativity as agents for pedagogic change (Burnard, 2007); and processes of creative music-making with computers, particularly those of composing (Hickey, 1997; Collins, 2005). Addessi and Pachet (2005:14) note how 'new technologies in music education should be considered not only as 'instruments' for didactic support, but also as languages and experiences that affect, form and shape profoundly the processes of music learning and the musicality of children'. From a pedagogical point of view, technology is thought to transformatively change the way we teach by encouraging teachers to question what should be taught, how it should be taught, as well as where, when and why it should be taught (Burnard, 2007).

A relative unexplored area in music education technology is that of *interactive reflective music systems*, initially elaborated at the SONY Computer Science Laboratory in Paris, which represent a new generation of computationally augmented musical environments, the effectiveness of which has been largely demonstrated through prior studies carried out since 2003. The concept of this approach is to teach musical processes indirectly by putting the user in a situation where these processes are enacted not by the user, nor by the machine, but by the actual interaction between user and system (Addessi & Pachet, 2005). The idea behind IRMS, in musical terms, is based on the principle of repetition and variation, which are inherent properties in all types of music. The system, in order to produce a response, uses similar musical material of what is entered by the user, while at the same time adding something new to the session. The user, following this, bases his/her interaction on what he/she has already heard, perhaps keeping some musical content, perhaps dropping some, and perhaps introducing something new. In this way, a musical dialogue is created between the human and the system which shares many musical features, attributing various degrees of cohesion and coherence to the session.

The present study explores the use of such an innovative adaptive system for children's music improvisation and composition based on the reflexive interaction paradigm (for a theoretical treatise see paper by Addessi in these proceedings) and developed in the context of early childhood music education (FP7-ICT MIROR Project). The technology employed in the wider project of which the study reported here is part – the MIROR Impro prototype – aims to implement in early childhood settings computer-assisted improvisation.

This paper aims to do the following: (a) to explore children's perspectives on using the MIROR Impro prototype drawing on fieldnotes/informal discussions with children, (b) to supplement this analysis with data from the computational music analysis of children's music and a description of the child-machine interaction, as this was recorded by the MIROR Impro system, and (c) to highlight some implications of employing new technologies in primary music education.

II. METHODOLOGY AND METHOD

A. Research Procedure

The exploratory study was realized in November 2011 with 6 eight-year-old children, 3 girls and 3 boys in Athens. Each child engaged one-to-one with the prototype for 3 sessions across 1 week in a quiet room, following a preliminary meeting to allow familiarization with the equipment and the researcher. The equipment comprised of a laptop with the newest version of the MIROR Impro prototype at the time of the study and a KORG synthesizer connected through USB MIDI with the laptop.

The sample was selected purposely from a pool of around 10 children whose parents consented in their participation in our study, paying attention to select children with no musical background and an equal number of boys/girls.

In each session the child played with and without a visualization screen in front of them (simple representations of pitch, amplitude and tempo displayed on a laptop screen which was placed in front of/removed from children's visual span in each session) (Gromko & Russell, 2002; Gromko, 1994). The adult (researcher) did not interact with the child (as much as was possible). The children were asked to play as much as they liked during each set-up with and without the visualization, stopping when they were tired. The researcher then discussed informally with each child after their session about their experience of playing with the prototype, followed by a more structured discussion after their third session. It should be mentioned that the prototype can be set to respond with more or less variation to the child's input melody. In the particular exploratory study, the MIROR Impro setting was set to 'different', providing an output that was slightly varied to the child's input melody.

The data collected comprised of:

- Musical data from 18 sessions in MIDI format.
- Descriptive data on the turn-taking from 18 output files with statistical data from the system (hereafter named .CSV files).
- 6 Semi-structured interviews: after one week of playing with Impro.
- Fieldnotes: informal discussions with children after each session.

B. Analysis: theoretical considerations

i. *Description of turn-taking behaviours:* In this study we were interested in exploring the notion of turn-taking –i.e. interacting with another person, as an established notion of the process of learning (Rogoff, 1990) and a central component of the reflexive interaction paradigm. The musical dialogue that takes place between the child and the machine could be compared to infant-adult interactions which are based on repetition and variation (Stern, 1985); this interpersonal dimension has been found to potentially contribute to the development of young children's creativity (Young, 2003).

In order to describe children's turn-taking behavior, we drew on the recorded information provided by the MIROR prototype itself in the form of a .CSV file – a system- integrated function that allows the export of all notes played in the session (child's input and machine's output), providing information about the exported session, such as its name and parameters used as well as basic statistics on the session. For our descriptive analysis and in order to develop a general picture of children's turn-taking behaviours we drew on the information that stated the number of answers that the system produced (i.e. the higher the number of answers, the more dense the child-machine interaction). We were interested to identify sessions where the child-machine interaction was particularly dense and relate these sessions also to characteristics of the computational music analysis, as well as to children's perspectives of using the MIROR technology.

ii. *Computational music analysis:* The starting point of any music analysis task is always the music itself. In MIROR, the study of the children's musical output can reveal interesting aspects of their perceptions, experiences and ways the use the system. We concentrate on two distinct types of analysis: The first one is pattern discovery, where repeated patterns in the children's melodies are brought forward, evaluated and discussed, and the second one is clustering of all children's melodies into categories, to see whether there exist specific categories of melodies in the corpus. In our study, children's improvisations made out a corpus of melodies in a symbolic format since they were played on a MIDI keyboard, which were then subjected to computational music analysis in order to explore further children's musical use of the technology (for precise methodology of the pattern discovery technique on a different corpus see paper by Anagnostopoulou, Alexakis & Triantafyllaki, in these Proceedings).

The results of this analysis then fed back to the analysis of children's turn-taking behavior as well as their perspectives of using the technology.

iii. Children's perspectives: Studies looking at children's perspectives of any form of music-making must begin with acknowledging their 'messy, multi-layered and non-normative character' (Spyrou, 2011:151). Further, it must begin with the certainty that exploring children's thinking about their own music relies on the precondition of experimentation, not only with music but also with interpretation of this thinking about music (Kanellopoulos, 2007). Indeed, any interpretation of children's talk cannot be complete without taking into account the larger sociocultural context in which their voice is situated (Wertsch, 1991); and as Bakhtin (1981) might argue in his dialogic take on human communication, children's talk is mediated by the discourses they are able to access and which represent the interests, assumptions and values of particular groups. Such discourses might include in the case of music learning particular assumptions about 'knowing how to make music'; about the 'difficulty' of certain musical instruments; or about how music 'should sound'. When several children in our study initially felt unease when playing with the keyboard (which was used as a medium for the technology), we interpreted their perspectives as situated in the above assumptions, or else, in the dominant ideological and cultural discourses that produced them.

III. RESULTS

A. Turn-taking behaviour

The findings from the CSV function are first presented in order to describe children's turn-taking behavior with and without the visualization screen across 2 different parameters, gender and experience (i.e. across 3 sessions). The turn-taking behavior is calculated on the basis of the number of answers from MIROR Impro during each child's session with and without the visualization, as these were recorded by the program.

Table 1: Turn-taking behavior according to gender

Set-up	With visualisation	Without visualisation	Overall turn-taking
BOYS			
Child 1	34	21	55
2	30	24	54
3	10	19	29
OVERALL BOYS	**74**	**64**	**138**
GIRLS			
4	51	57	108
5	52	54	106
6	75	73	148
OVERALL GIRLS	**178**	**184**	**362**

From these results in Table 1 we can see that children's turn-taking behavior is nearly the same when they interact with MIROR Impro with the visualization and without. Indeed, even within this small sample there seems to be a strong similarity in the level of turn-taking across the two set-ups. Therefore, it would seem that the visualization does not enhance children's turn-taking behaviours. The same finding seems to be the case when comparing levels of turn-taking across boys and girls with and without the visualisation.

However, when examining the levels of turn-taking across boys and girls regardless of the visualization parameter we see that girls seem to interact with MI more than boys. Indeed, their interaction with the prototype seems nearly doubled (362 number of answers from MI) to that of boys in the sample (138 number of answers from MI).

Table 2 examines how the children's experience of engaging with MI with and without visualization might shift across sessions. In this table we highlight in bold where there seems to be a decrease to a greater or lesser extent in the level of turn-taking behaviour across sessions 1 & 3, regardless of the visualization parameter.

Table 2: Turn-taking behavior according to experience

Session	1	2	3
Child 1	**Y=19 N=15**	Y=11 N=4	**Y=4 N=2**
2	**Y=26 N=6**	Y=0 N=13	**Y=4 N=5**
3	**Y=9 N=3**	Y=1 N=16	**Y=0 N=0**
OVERALL BOYS	**Y=54 N=24**	Y=12 N=33	**Y=8 N=7**
4	**Y=23 N=25**	Y=11 N=13	**Y=17 N=19**
5	**Y=29 N=21**	Y=10 N=16	**Y=13 N=17**
6	**Y=31 N=24**	Y=14 N=30	**Y=30 N=19**
OVERALL GIRLS	**Y=83 N=70**	Y=35 N=59	**Y=60 N=55**

Key: Y =with visualization, N=without visualization

As is evident in Table 2, the turn-taking behavior seems to decrease across sessions, regardless of whether the child plays with or without the visualization parameter. An interesting finding that arises when separating the levels of turn-taking in accordance to session is evident in the 1st session. While we reported in Table 1 that children's overall levels of turn-taking seemed similar with and without the visualization parameter, we see now in Table 2 that in Session 1 children's levels of turn-taking behaviours seems higher with the visualization than without. This might indicate that once the novelty of using the visualization wears off by the third session, the children interact less with the prototype. It might be interesting, however, to note that girls' turn-taking with the visualization seems to decrease by the 2nd session and then increase slightly again by the 3rd. Other parameters, such as non-intervention from adults, were kept constant across sessions.

B. Children's perspectives

In this second sub-section of the findings in this exploratory study we present children's talk about their interaction with MI. After each of the three sessions, the researcher discussed with children in an open-ended way their engagement with MIROR ('what happens when you play') and conducted more structured interviews after their final session ('what did you think of the music', 'is it same or different to what you play', 'can you remember what you played').

i. *Who follows who?* An important principle of MIROR Impro is that children are in control of the situation, and that they actually attempt to 'teach' the system their 'own' music. More than half the sample supports that it is MIROR who follows them and not the other way round. This is important as it may be an indication that children understand that they 'lead' MIROR or 'teach' it what they play: i.e. "I did not play what it played – it played what I played" (Child 5) *ii. The type of response*. Around half the sample – all girls - suggests that it preferred when the system responded with more variation than when the response was more similar to their own input melodies: "It responds differently to me so that the music is nicer" (Child 4). Child 6 tells us that the different response of MIROR Impro was pleasant to listen to and that it helped her do more with her playing, i.e. "I played more notes as it played more notes". So, while in initial discussions the child-machine interaction seems to be initiated by the MIROR Impro prototype, the development of the interaction is assisted by the nature of the machine's response to the child's playing.

Around half the sample preferred to play without the visualization for a number of reasons, i.e. they did not want to look ahead at the screen but rather at their hands (Child 1). Most children who said they preferred to play with the visualization said that they liked that they could see what there were playing. One to two children switched their preference from without visuals to having the screen in front of them when they played during the final interview, when, through discussion with the adult, they reached a better understanding of how their own playing was represented on the screen.

A further theme, which is not related to the visualization but arose from the data, was prominent in the analysis and could be linked back to the CSV results: children's perception of how they played.

iii. *Reflecting on how they played:* During discussions with children we asked them if they remembered how they played during interaction with the prototype. Their responses were not simply verbal but also indicated/played out the various gestures they had used during sessions rather than actually re-playing on the keyboard particular rhythmic patterns (1 child did do this) or humming any particular melodies/tunes (none of the children did this).

For example, Child 4 tells us "I don't remember which notes I played because I was looking at the screen". But later when asked again, she showed us the positioning of her hands on the keyboard throughout her playing saying "I remember this hand was here, the other was here and then I played also in the middle of these two hands", signifying the pitch or range of notes she used in her playing. She also says when asked where else she played that she made a movement with both hands from the notes further away towards the center of the keyboard (stepping movements with both hands). Child 1 too remembers what he played, through gestures and categorization (he shows hand movements on the keyboard all of which he used in his playing during his sessions: glissando/ using black-white notes, etc.). Children 5 and 6 similarly show they remember the stepping movement they enact in an upward movement on the keyboard when talking about what they played. It is interesting to note that those children that displayed more dense interaction with the machine (see Table 1) are also those that are able to re-enact for us a more embodied type of playing using whole body movements and gestures. This is of course noted in a small corpus of data from 6 children, yet it may indicate that MIROR Impro may in some children encourage particular ways of engaging with music, both musically and kinesthetically.

C. Comparison of Turn-Taking Behaviours with the Computational Music Analysis

Following the results extracted from this analysis, we then proceeded to compare some of these results with those from the Computational Music Analysis.

For this analysis we carried out two separate tasks: The first one was pattern discovery, where we looked for repeated patterns across the children's melodies, and the second one was to cluster all melodies into separate clusters, in order to see whether there exist clear categories.

Here we present part of the analysis of the clustering of the melodies, whereby we took the whole corpus and tried to computationally divide it into two or more classes. The idea behind it was to check whether the visualisation and no visualisation melodies could be automatically separated, and thus being different. For each segment of the children's melodies, we extracted a set of segmental viewpoints (Conklin and Anagnostopoulou, 2006), that is descriptors for the whole melody rather than note-by-note features such as successions of intervals. The viewpoints we chose for this were: number of notes per melody, duration of melody in milliseconds, melodic arch according to Huron (1996), notes that exist in simultaneities, notes that are single notes. The experiments used the Kmeans algorithm. We see that: The results of the clustering showed that there were two definite clusters in our data, which however do not coincide with the separation of V (visualization) and N (non-visualisation) melodies. The first cluster was much larger than the second one in terms of melody numbers, and contained the shorter melodies. This first cluster consisted of short melodies (31 notes), its average Huron shape was horizontal (which means it does not go up or down), and there were more notes in simultaneities than single. The second cluster consisted of much longer melodies, had a concave Huron shape, and again more notes in simultaneities than single notes.

While the results from the computational music analysis did not produce any significant differences between the visualization and non-visualisation corpus, we then compared these to the results of the levels of turn-taking as extracted from the .CSV files. The .CSV files provided us with the number of answers the system provided for each session (of each child). This indicated to us the density of turn-taking between the child and the MIROR prototype. For our analysis we compared the rates each cluster (1 and 2) appeared in each child's session with the levels of turn-taking (Table 3). We calculated the rates for the 1st cluster here, as this produced the most noteworthy results in comparison to the turn-taking behavior of the children.

In the first column of Table 3 we can see the number of answers (i.e. the output of the prototype) across each child's sessions while playing with the visualisation screen in front of them. The second column is the number of answers while the child plays without the visualisation screen. The third and fourth columns show the number of melodies across all sessions that belong to the 1st cluster only.

We found that these two clusters do not coincide with the V and N melodies at all. However, when comparing the results with the CSV file and specifically the number of answers for each child, we observe that the children whose levels of interaction with the prototype seem higher are also those whose midi files reveal more melodies belonging to the 1st cluster (i.e. shorter melodies, horizontal Huron shape, more notes in simultaneities than single).

Table 3: Comparison turn-taking overall & music analysis

Child	Turn-taking with V	Turn-taking without V	2nd Cluster with V	2nd Cluster without V
	CSV		Computational MA	
Child 1	34	21	41	67
2	30	24	30	99
3	10	19	18	17
OVER. BOYS	74	64	89	183
4	51	57	82	91
5	52	54	91	91
6	75	73	120	111
OVER. GIRLS	178	184	293	293

As we can see in Table 3, the number of times the 1st cluster appears in each of the children's sessions is not related to their playing with and without the visualisation screen. However, it does seem to be related to the levels of turn-taking, as children with higher levels of turn-taking are also those whose melodies are mostly categorised as belonging to the 1st cluster in this particular type of computational analysis. This makes sense as higher numbers of turn taking might result in shorter melodies. This seems to be the case particularly for girls, as they score consistently high across levels of turn-taking with and without visualisation, and across the number of melodies found that belong to the 1st cluster, again with and without visualisation. For Boys, this picture is less consistent. Both Child 1 & 2 for example did produce a medium level of turn-taking overall as we can see from their .CSV files (in comparison to girls' turn-taking), yet the clustering produced interesting results for the visualisation: A higher number of melodies overall was calculated for both boys when playing without the visualisation screen.

Again however, we must take into account the small sample and number of sessions. It is useful therefore to look at consistency and explore how experience (i.e. the development across sessions) influences the clustering, as the above result for the two boys shows us the overall number from all three sessions. In the final Table below in our analysis we compare as above the results from the .CSV files and the computational music analysis but now in each of the three children's sessions separately (Table 4).

Table 4: Comparison turn-taking across sessions & music analysis

Child	Turn taking with V	Turn taking without V	2nd Cluster with V	2nd Cluster without V
	CSV		Computational MA	
1	19-11-4	15-4-2	28-12-1	33-30-4
2	26-0-4	6-13-5	12-11-7	84-2-13
3	9-1-0	3-16-0	3-15-0	14-3-0
4	23-11-17	25-13-19	29-19-34	38-19-34
5	29-10-13	21-16-17	20-32-20	42-21-28
6	31-14-30	24-30-19	41-52-27	51-20-40

In each box therefore we place the value from the .CSV files and the music analysis for each of the three sessions. For example, in his turn-taking calculation with the visualisation screen, Child 1 scored 19 in his 1st session, 11 in his 2nd session and 4 in his 3rd session. We find that with the visualisation he played 28 melodies belonging to the 1st cluster in his 1st session, 12 in his 2nd and 1 in his 3rd session. Across his three sessions therefore, as his turn-taking decreases, so does the number of melodies belonging to the 1st cluster that he plays. Children 2 and 3 present us with a less clear picture of the relation between the density of turn-taking and the kind of melodies they create using MIROR Impro. A very high number of melodies that Child 2 produces for example in his 1st session without visualisation (84), does not seem related to his turn-taking behaviours as there are only 6 answers from his session without the visualisation as we can see from Table 4. Girls' .CSV files revealed consistently high turn-taking behavior across all three of their sessions. This seems to also coincide with the consistently high number of melodies belonging to the 1st cluster as extracted from the CMA. This result could guide us towards more focused analysis in the pedagogical experiments with regards to the relation between density of turn-taking and the type of melodies that children create with the MI prototype where this behaviour is evident.

IV. DISCUSSION

One of the underlining aims of a social (rather than deterministic) perspective of using music education technology in the classroom should be that children are placed at the center of the analysis, which is consistent with the constructivist learner centered accounts currently favoured in educational technology research (Oliver, 2012). In this exploratory study we sought to incorporate multiple modes of inquiry in investigating the *children's* experience of using the MIROR Impro technology, drawing on multiple methods of data analysis and cross-disciplinary work in order that we may gain a deeper understanding of the ways in which children engage with the technology on both a musical and behavioural level.

The data analysis indicates some connections between particular children's (a) turn-taking behavior and their embodied (gestural) understandings of how they played with the machine and (b) type of musical output and the density of their turn-taking behavior. It points also towards gender differences in the child-machine interaction.

A connection between density of turn-taking behaviours, higher rates in cluster 1 and children's gestural understanding of how they played merits particular attention here. The interviews revealed that the same children who displayed dense turn-taking behaviour either across all three sessions (all the female participants) or in particular sessions (Child 1) also used gesture (instead of only verbal accounts) in attempting to explain to us how they played.

The research findings also point towards gender differences in the ways children talk about their interaction with MIROR Impro as well as in their turn-taking behaviours. All girls in our sample displayed more dense turn-taking behavior (n=362) to boys (n=138) and talked about the interaction using gestural references. Again, in the girls' data set there is consistent density of turn-taking across all three of their sessions as well as higher rates of melodies belonging to the 1st cluster as indicated from the computational music analysis.

The interpersonal dimension that the MIROR technology introduces to children's music-making may in some children encourage particular ways of playing, both musically and kinaesthetically. The results, while coming from a cohort of 8 year-old children, seem related with findings from studies interpreting very young children's musical creativity as 'kinaesthetic gesture' (Cohen, 1980) and as a fusion between musical and social processes (Young, 2003). They signify that children's engagement with this new technology may provide the means for greater experimentation with forms of music-making that defy traditional Western-type models of music learning and introduce new forms of musical participation. In our next round of data collection, the development of a framework in which more systematic connections between turn-taking, musical output and gesture can be explored will be implemented from the initial stages of the research.

V. CONCLUSIONS

Although technology is increasingly being integrated in music education, the absence of pedagogical considerations in the design of the software continues to remain an issue for its practical applicability in the 'real world' of the classroom and with particular groups of users, such as young children. One of the underlining goals of the MIROR Platform is that it is eventually used in the context of early childhood education with teachers who may not be musically trained or with music teachers who may not be able to teach improvisation, now widely acknowledged as a valuable part of music education curricula (Azzara, 2002). Shorter-scale exploratory work by our team has so far been conducted in order that (a) the results are fed back into the development of the technology, and (b) an initial understanding of the issues involved in employing technology in early-childhood education is gained, before proceeding to test the technology in 'real' classroom settings.

Regarding this final point, technology, as a tool teachers have at their disposal, can only fulfill its promise as a powerful contributor to learning if used in developmentally appropriate ways. Employing interactive music systems, such as the MIROR Impro technology in the context of early childhood education brought up a range of issues on this point:

- the particular ways in which young children participate in, understand and engage with music-making require particular theoretical, research and analysis frameworks;
- young children's prior experiences with various technologies can range from near absent to quite high levels of competence, as we discovered in our preliminary work; this requires high degrees of flexibility when working with groups of children and more flexible time-spans of integrating the technology in existing learning and teaching practices;
- the new forms of musical participation that new music technologies often entail, suggests an emphasis towards more adaptive and open classroom environments; this also highlights the need for exploration of the degree to which teacher education programs prepare future generations of music teachers for the theoretical shift that new music technologies could bring about for children's music learning.

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Analysing Children's Improvisations During Child-Machine Interactions

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Introduction

- **The aim** of this ongoing exploratory study is to enrich our understanding of the variety of ways young children experience musical improvisation, as this is enabled through the MIROR platform -an innovative adaptive system for children's music improvisation and composition.We employ a computational music analysis method to do pattern discovery and bring out common aspects in children's improvisations.
- Improvisation is a common form of musical practice and yet remains the least studied or understood from a music analysis point of view. When populations with no musical background engage in musical improvisation (such as young children), the analysis of the musical aspects becomes more challenging: The possible lack of common learned musical schemata and related technical skills requires the introduction of methods of analysis which can deal with these peculiarities. In this work we propose a computational method for analysing such types of improvisations and apply it to the analysis of a small number of improvisation sessions. The analytical method is a type of semiotic analysis, where repetition, variation and transformation are brought forward..This study forms part of the European Project *Musical Interaction Relying on Reflexion (MIROR)* that uses novel software for the development of musical creativity (www.mirorproject.eu, see also Addessi & Volpe, 2011).

Research Procedure

The exploratory study was realized in November 2011 with 6 eight-year-old children, 3 girls and 3 boys in Athens. Each child engaged one-to-one with the prototype system for 3 sessions across 1 week in a quiet room, following a preliminary meeting to allow familiarization with the equipment and the researcher. The equipment comprised of a laptop with the newest version of the MIROR Impro prototype at the time of the study and a KORG synthesizer connected through USB MIDI with the laptop. In each session the child played with and without a visualization screen in front of them (simple representations of pitch, amplitude and tempo displayed on a laptop screen which was placed in front of /removed from children's visual span in each session). The data reported here comprises of (1) Musical data from 18 sessions in MIDI format and (2) Semi-structured interviews after one week of playing with MIROR Impro (n.6).

Computational Music Analysis Method

Knowledge Representation: We chose to represent the improvisations using the following musical parameters:

-*Pitch* (MIDI number)

-*Melodic Interval* (Number of semitones plus direction)

-*Contour Class* (0 when unison, 1 if small interval =< 5 semitones, 2 if big interval >5 semitones. Direction not taken into account).

-*Melodic Contour* (1 if rising, -1 if falling, 0 if static)

Algorithm: All repeated patterns within each viewpoint sequence are extracted. In order to identify common patterns, suffix arrays are employed. All common patterns of length less that 2 are ignored as trivialities. Patterns found are allowed to overlap.

Music Analysis: Discovery of repeated patterns in a corpus can be seen as a type of paradigmatic analysis (Nattiez, 1975): repetitions of specific patterns are made apparent. Added advantage: each musical parameter (viewpoint sequence) is processed separately, showing the exact repetition. We can thus observe repetitions at different levels of abstraction.

Results

The following tables show example pattern results with intervals and contour representations. Example patterns found, together with their frequency, number of sessions.

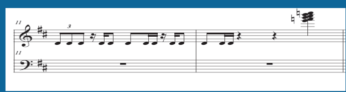
Pattern	Frequency	Number of sessions
[1,-1,1,-1,1,1,-1, -1,1,1]	152	25
[1,1,-1,1]	1402	ALL
[1,-1,1,-1,1,-1,1,-1,-1]	62	19
[1,1,1,1,1,1,1,1, -1]	37	9

Table 1: Patterns of Melodic Contour Representations

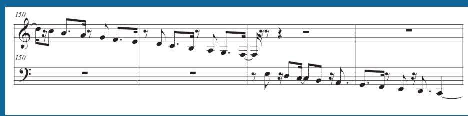
Pattern	Frequency	Number of sessions
[-3,-2,-0]	23	7
[-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1,-2,-2,-1,-2,-2,-2,-1]	16	6
[0,0,0,0,0,0,0,0,0]	376	7
[-2,2,-2,2]	266	29
[-27,27,-27,27]	16	1

Table 2: Patterns of Intervals (in semitones)

Example pattern: Repetition of same note [0,0,0,...]



Example pattern: Straight downward motion [-2,-2,-1,-2,-2,-2,-1,...]



Most of the discovered patterns tended to fall in one of the following categories

- straight upward motion,
- straight downward motion,
- oscillating motion between two pitches,
- repetitions of the same pitch,

All patterns are suggestive of gestures. During discussions with children we asked them if they remembered how they played during interaction with the prototype. Their responses were not simply verbal but also indicated/played out the various gestures they had used during sessions rather than actually re-playing on the keyboard particular rhythmic patterns (1 child did do this) or humming any particular melodies/tunes (none of the children did this). This is of course noted in a small corpus of data from 6 children, yet it may indicate that MIROR Impro may in some children encourage particular ways of engaging with music, both musically and kinesthetically.

Conclusion

The analysis of children's improvisations, although still at an initial phase, could assist in understanding better children's experiences of engaging with new technologies to improvise and compose and may provide developmentally better ways to pedagogically incoporate the teaching and learning of musical improvisation in primary education. Employing interactive music systems, such as the MIROR Impro technology in the context of early childhood education brought up a range of issues on this point:

- the particular ways in which young children participate in, understand and engage with music-making require particular theoretical, research and analysis frameworks;
- technologies can range from near absent to quite high levels of competence, as we discovered in our preliminary work; this requires high degrees of flexibility when working with groups of children and more flexible time-spans of integrating the technology in existing learning and teaching practices;
- the new forms of musical engagement that new music technologies often entail, suggests an emphasis towards more adaptive and open classroom environments; this also highlights the need for exploration of the degree to which teacher education programs appropriately prepare future generations of music teachers.

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A COMPUTATIONAL METHOD FOR EXPLORING MUSICAL CREATIVITY DEVELOPMENT

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ABSTRACT

The development of musical creativity using non-standard methods and techniques has been given considerable attention in the last years. The use of new technologies in teaching improvisation and thus development of creativity has received relatively little attention. The aim of this paper is two-fold: firstly to propose a way of formalising the measurement of creativity, and secondly to test whether the use of a particular interactive system built to support musical improvisational dialogues between the user and the computer (MIROR IMPRO), can develop creativity. First, based on previous research, we define a set of variables aiming at evaluating creativity, and we create a computational model to automatically calculate these variables in order to assess the development of creative abilities. Second, we assess the advancement of creativity in 8-10 year-old children, who spent six weeks interacting with MIROR-IMPRO. We used two groups of children in assessing this advancement: a group of children with no musical background (n=20) and a group of young pianists (n=10). We carried out a free improvisation test before the start and after the end of six sessions with the system. The results suggest a potential progress related to a number of these variables, which could be indicative of creativity advancement. The issue of measuring creativity is discussed in the light of these findings.

1. INTRODUCTION

Creativity is a fundamental human ability, and at the same time a particularly challenging concept to define. Various attempts exist to date, and its meaning tends to shift across the various disciplines. Yet however vague and slippery its definition may be, its core features are shared across domains, which makes it possible to model, and in general to become the subject of scientific investigation.

One of the first attempts to formally describe creativity is found in [26], where *Creativity Thinking* is modeled as a four-step process: *preparation* – information, specific knowledge and ideas about the case/problem under question are gathered, *incubation* – work proceeds unconsciously, *illumination* – suddenly the solution emerges, and *verification* – the solution is verified and elaborated. Another step-wise model suggested in [9] where a five-step approach is proposed in problem solving and creative thinking. The idea of problem solving is also closely related with the eminent contribution of J.P. Guilford in the field. Guilford in [11] introduced the idea of *convergent* and *divergent thinking* and associated the latter with creative thinking.

The above approaches to creativity focus mainly on the processes involved in creative thinking. Another aspect of creativity, closely related with attempts to measure or assess creativity, is focused mainly, but not solely, on the product. Creativity as 'product' is defined by Amabile in [5] as one whereby *"...appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated"*, hence introducing the idea of how a creative product is received and assessed by (as well as situated in) its environment.

But how can the creativity be assessed? Guilford in [10] created a test to measure creativity, by assessing divergent thinking. The subjects were given 180 ordinary life objects (e.g. a pencil, a spoon, a cap) that they were asked to score across four dimensions: originality, fluency, flexibility, and elaboration. Extending Guilford's ideas, Torrance developed the Torrance Tests of Creative Thinking (TTCT) [25], while Amabile proposed the Consensual Assessment Technique (CAT) for ranking the creativity of art objects [5]. CAT is based on the idea that expert judges within a field will have a valid opinion regarding the creativity values of an object of art. Gathering and examining such expert opinions may provide a good estimation of the creative worth of an object. A well described application of CAT can be found in [12].

In the field of music creativity, Webster's work [29] continues to be prominent among scholars. Webster built on Guilford's ideas and created a tool to evaluate the creative aptitude of children (ages 6-8), the *Measurement of Creative Thinking in Music (MCTM)* [27]. The MCTM evolved into MCTM-II in [30]. Children's creative thinking is evaluated through a ten-task session, of about 20-25 minutes. The qualities that are scored are musical expressiveness (ME), musical flexibility (MF), musical originality (MO) and musical syntax (MS) [29]. In the specific field of ethnomusicology, Lomax developed the *"cantometrics"* [14]. They are comprised of a set of 37 items measuring group organization, level of cohesiveness, rhythmic features, melodic features, dynamic features, ornamentation and vocal qualities. Later, McPherson in [15] developed measures to assess a musician's ability to perform music creatively. These new measures are pertained to evaluate music learner's performance from memory, by ear and through improvising.

Simonton in [21] performed computerized content analysis to assess the melodic originality of 15,618 themes of 479 classical composers, from Josquin des Pres to Shostakovich. Simonton defined a number of variables each of which pertain to different qualities of the case under investigation. Similarly in [22] he investigated 1919 compositions of 172 classical composers, spanning almost 500 years. A panel of experts manually scored several of the above variables, prior to the computer analysis.

Regardless of how well they approach the notion of creativity, the above measures require more or less the engagement of (often numerous) human experts in scoring. They also employ statistical averages in order to eliminate human errors and individual particularities.

At the same time, the broad introduction of computer technology in music educational processes created the possibility to computationally automate the whole process. Hence it becomes more and more pertinent to come up with proposals that require no human intervention, even if the range of the investigated qualities is decreased.

The introduction of new music technologies in the educational process involves also the introduction of new interaction paradigms between the user and the machine. An example of new interaction paradigms are Interactive Reflexive Music Systems (IRMS) [18], and in particular the MIROR IMPRO system [20], which was developed within the MIROR project [1] as the evolution of *The Continuator* [2][3][4][17][19]. The core concept in such a system is that basic musical elements can be taught and musical cognitive processes can be developed not only by the traditional teacher/learner dipole but also by the direct interaction of the learner with the system, without the involvement of a human instructor.

The application generates different kinds of output melodies based on the user's musical input, stimulating the reflexive interaction between the user and the application. This generation is based on a specific Markovian mechanism designed by Sony CSL Paris, allowing a meaningful musical output. Namely, the output is composed of what the user could have played herself, i.e. a constrained recombination of musical elements previously played by the user. In this way, each response of the system is composed of musical material close to the user's style, but at the same time proposes to the user to explore, as the next, step, new ways to express musical ideas.This study explores the use of MIROR IMPRO in developing young children's improvisational skills - recognised as a central component of musical creativity [29]. Therefore, it would seem important to develop a methodology of evaluating the creativity that arises as a result of engaging with such a system. This may later be integrated into the system in order to give real time information to the user and to record such information for a traditional trainer/learner session that may subsequently follow. The aim of the paper is to propose a way of measuring creativity in children playing the keyboard; and to use this model in order to assess creativity in children with and without musical background, comparing their pre and post tests (before and after an intervention of 6 improvisation sessions using the MIROR IMPRO system).

The paper is structured in the following way: in the **Methods** section, the technical description of the work is laid out, including the data collection process, the knowledge representation schemata, computational details and the description of the variables used to assess creativity. In the **Results** section, the results of the work are presented and subsequently discussed in the last section (**Discussion**).

2. METHODS

2.1 The Goal

In this section, a model and a computational method to measure creativity is introduced. Specifically, we describe the musical corpus we used, the knowledge representation schema, algorithmic details and particularities, and finally the creativity measuring model, realized as a set of measures/variables.

2.2 Data collection

Within the framework of the psychological experiments related to the MIROR project, a number of children's musical improvisations on a MIDI keyboard were performed. The keyboard was connected to MIROR IMPRO system. Each improvisation session is comprised of a dialogue of music phrases that are alternately human and machine generated. Each of these phrases is recorded onto a different MIDI channel and thus it becomes straight-forward to extract all human phrases.

The data we used comes from two experiments with MIROR IMPRO and young children - one with non-musicians and one where children had been studying the piano from between 1-4 years.

The reasoning behind this sampling is the following. In our initial work with non-musicians we found that the keyboard as an object (rather than the interaction with the system itself) seemed to draw the attention of the children. We then introduced a second sample of children who were already familiar with the keyboard, as a way to eliminate the effect the keyboard may have on the interaction and hence the musical output from this interaction. In this paper we present the analysis from both groups of children.

The study with the young pianists took place in a small music school and involved 10 children (six girls and four boys) playing alone with the MIROR IMPRO system for six weeks (that is six sessions of 15 to 20 minutes). The study with the non-musicians took place in a primary school and involved 20 children (sixteen boys and four girls) playing with MIROR IMPRO across six weeks, in similar conditions. In both studies we proceeded to conduct a pre- (before the six weeks) and post-test (after the six weeks) with the children. This consisted of asking each child individually to improvise a short tune (1-2 minutes long) on the keyboard.

We compare the pre-test sessions to the post-test sessions of both the young pianists' and the non-musicians' sessions, in order to find out if their creativity developed by their post-test session. In this way, we might begin to attribute such development to their in-between sessions where they interacted with the MIROR IMPRO system, in order to explore further the use of IRMS in the development of children's musical improvisations and creativity.

The young pianists pre-corpus consists of 5218 note events having duration of 2,359,916 msecs. The post-corpus consists of 2427 note events having duration of 662,627 msecs. The non-musicians pre-corpus consists of 8990 note events having duration of 2,022,753 msecs. The post-corpus consists of 6477 note having duration of 1,030,853 msecs.

2.3 Knowledge Representation

The concept of a symbolic musical corpus raises the issue of music knowledge representation. Having in mind the data manipulation task, the viewpoint representation formalism was chosen to be used [8], as it offers great flexibility in surfacing the attributes of the musical objects. It also offers a direct and straight forward representation on corresponding data structures. The concept of viewpoint is lately gaining popularity among researchers, due to its capability to capture in a well-defined representation set of symbols, a big variety of the musical features of musical data.

The musical object on which a viewpoint is defined can here be a single note or a sequence of notes, viz. a segment. Here the notion of a segment is used to describe the whole melody played by the child.

On the note level, several viewpoints were calculated: pitch (as MIDI number), pitch class, onset, duration, ioi (interon-set time interval), trail (time interval between a NOTE OFF event and the consecutive NOTE ON), fnitioid (time interval from first note in track), seqint (melodic interval – pitch distance from previous event), contour (rising: 1, static: 0, falling: -1) and several others.

Segmental viewpoints [7] are also constructed. For each segment a set of segmental viewpoints is calculated, such as the number of notes in the segment, the duration etc.

Segmental Viewpoint	Description
sd[seq]	Standard deviation of sequence seq
uniq_patt[seq]	Number of unique patterns in sequence seq
diff_patt[seq]	Number of different patterns in seq
tot_patt[seq]	Number of total patterns in seq
Avg_sise[seq]	Average size in number of note events of seq
Avg_dur[seq]	Average duration
Tot_size[seq]	Total size in number of note events of seq
Tot_dur[seq]	Total duration
Inteval (small,medium,large) [seq]	Percentages of interval divisions
Note (small,medium,large) [seq]	Percentages of pitch divisions
Rhythm (small,medium,large) [seq]	Percentages of rhythm divisions
velocity (small,medium,large) [seq]	Percentages of dynamic divisions
Texture[seq]	Measures how "thick" is the music
Cluster[seq]	Number of chords in seq

Table 1. Segmental viewpoints used.

2.4 Computational Processing

The computation proceeds by reading one by one all MIDI files in a directory (a directory with MIDI files is considered a corpus) and building from the corresponding MIDI events a sequence of viewpoints. Consecutively, repeated patterns within each viewpoint sequence are extracted.

Thus, the identification of patterns can be seen as a problem within the stringology domain. As such, in order to identify common patterns suffix arrays [16] are employed. Suffix arrays provide an easy to implement and fast way to locate each and every common substring within a string. In [24], suffix arrays technique proves its capability and its efficiency on a much larger corpus.

For constructing the suffix array, the well-known QuickSort comparison sort algorithm is used in this work. The suffix array can be scanned and common patterns can be reported, along with their frequency, their length and their locations within the corpus.

2.5 Creativity Variables

In order to assess creativity we used a set of variables that we calculated for each subject, for the improvisation tests that took place before and after the training. The idea of assessing creativity through a set of metrics (realised as variables) is drawn directly from the creativity literature, as most of the scholars are proposing to measure creativity based on a set of measures, scored by one or more experts. Our aim is to come up with a set of metrics that are scored automatically, eliminating thus the need of experts. As evidenced in the creativity literature, we assume that advancement in musical variation and diversity is an indicator of musical creativity.

The following variables were used:

V1 – Standard Deviation. Standard deviation is a metric on how much away from the average falls most of the values. A low standard deviation means that data tend to be close to the average. We calculate this for the sequence of three viewpoints – MIDI numbers, intervals and rhythmic values. It indicates the diversity of the musical vocabulary.

V2 – Number of patterns with frequency 1. We identify all sequences of the 3 viewpoints (notes, intervals, rhythmic values) that appear only once in the corpus. We borrowed this idea from the lexical analysis in [23], as it seems to indicate novelty and musical variety. Suffix arrays make straight forward the identification of those patterns, since we count the number of rows in the array that has no common with their next.

V3 – Average Size, Duration. The idea of this indicator is taken from Webster's MCTM [27][28]. We calculate two variants of this variable. First, we calculate the segmental viewpoints size (in number of notes) and duration (in msecs) for each subject. Then we calculate the average of all segments per subject. Second, we calculate the total size and total duration for each subject.

V4 – Ratio of different per total patterns. This variable is drawn by analogy from lexical content analysis in psychotherapy [13] and is used also in [23]. There are evidence that the greatest the ratio of different words per total words the greatest the lexical diversity [13]. So we assume that the greatest the above ratio the greatest the musical variability and hence the musical creativity. We identify all sequences of the 3 viewpoints (notes, intervals, rhythmic values)

V5 – Interval Variation. This is an indicator on musical intervals diversity. We calculated the segmental viewpoint `interval(small, medium, large)`. Then we calculate for each subject's music (viz. each MIDI file) the percentages of small, medium and large intervals. We assume that small intervals are less than 4 steps and large ones more than 8 steps – a step is a semitone.

We assume that the more evenly distributed the percentages are that more variation we have. This applies also to V6, V7 & V8

V6 – Pitch Variation. We calculated the segmental viewpoint `note(low, medium, high)`. Then we calculate for each subject's music the percentages of low, medium and high pitches. We assume that low pitches are below F3 (MIDI number 53) and high ones over C#5 (MIDI number 73).

V7 – Rhythm Variation. We calculated the segmental viewpoint `rhythm(slow, medium, fast)`. Then we calculate for each subject's piece of music the corresponding percentages. We assume that medium rhythmic values are with the notes that has more or less the quarter note duration; that is 500 msecs for our MIDI files. Hence we take +/- 10% of that for identifying the slow and fast rhythms.

V8 – Dynamics Variation. We calculated the segmental viewpoint `velocity(soft, normal, hard)`. For identifying the dynamics of notes we take into consideration the velocity recorded along with the notes within the MIDI file. The velocity takes values in [0, 127] range. We calculate for each subject's music the percentages, similar to the above variables. We assume the piano range lays below velocity value of 40 and the forte one above 60.

V9 – Texture Richness. For all notes in each subject's corpus we sum up their duration. Then we divide the duration of each piece of music with the total duration of all notes. The more notes we have (and the more lengthy they are) the less the value of V9 will be. It indicates how much populated with notes the music is.

V10 – Clusterness. For each segment we calculate the number of simultaneities. It is an indicator of the number of chords and consequently the richness of harmony produced. A simultaneity occurs when a `"note on"` MIDI event is transmitted while others `"note on"` events are still alive.

3. RESULTS

Table 2 reports the mean values on pre and post conditions for the two groups, non-musicians and musicians. The general trends indicate advancement in creativity when we compare mean values on pre and post sessions.

	Non-musicians		Musicians	
	Pre	Post	Pre	Post
V1 pitch SD	10.75	13.16	8.84	9.65
V1 interval SD	10.08	10.75	9.36	9.24
V1 rhythm SD	0.93	0.97	15.11	19.84
V2 unique pitch	23.90	30.00	20.3	17.8
V2 unique interval	39.70	40.3	27.5	24.9
V2 unique rhythm	23.85	24.15	46.4	40.0
V3 Nb notes / segmented	48.70	48.42	42.62	29.42
V3 duration /segmented	12324	7598	25299	9822
V3 Nb notes / total	449.5	323.85	521.8	242.7
V3 duration/ total	10113 8	51543	235992	66263
V4 different pitch	0.35	0.37	0.29	0.31
V4 different interval	0.32	0.35	0.25	0.35
V4 different rhythm	0.29	0.30	0.31	0.38
V5 variation interval small	57.87	59.00	50.45	49.92
V5 variation interval medium	15.30	18.13	25.05	25.09
V5 variation interval large	26.82	22.79	24.50	24.98
V6 variation pitch low	13.85	20.09	12.25	15.62
V6 variation pitch medium	58.30	50.71	55.35	55.00
V6 variation pitch high	27.84	29.20	32.40	29.37
V7 variation rhythm slow	12.22	11.60	69.99	53.60
V7 variation rhythm medium	4.42	3.52	7.13	10.35
V7 variation rhythm fast	83.36	84.90	22.88	36.05
V8 variation dynamics soft	37.26	15.59	14.76	8.11
V8 variation dynamics normal	27.30	14.93	31.13	26.89
V8 variation dynamics hard	35.44	69.49	54.10	64.99
V9 texture richness	0.89	0.70	1.35	0.66
V10 clusterness	17.43	21.60	19.56	26.39

Table 2. Variables mean values for non-musicians and musicians, on pre and post session.

However, due to a small sample size and limited number of treatment sessions, not all of shifts are statistically significant.

The pre – post treatment comparison was performed with asymptotic Wilcoxon signed rank test with Pratt zero handling (with *coin* package in *R* software [31]). The two groups were assessed in a separate manner, so that no direct statistical comparison between groups was made.

The tables below report only statistically significant differences between pre- and post-conditions, for the variables not reported below no significant difference was found. For variables V1, V2, V4, V5medium, V6 we predicted greater values in post session. i.e. greater values indicating the progress of creativity. For variables V5small and V5large we predicted smaller values in post session (see the explanation in the **Discussion** section). Accordingly, a one-tailed test was used for these variables. For variables V3, V7, V8, V9, V10 no directional hypothesis was made. Accordingly, a two-tailed test was used.

3.1 Non-musicians

	MEAN	STD DEV	MEDIAN
Pre	10.75	3.34	10.87
Post	13.16	2.88	13.72
Z = -2.65, p-value = 0.004 (one-tailed)			

Table 3. V1 – Standard Deviation on pre- and post-corpus.

As seen in Table 3, the average pitch SD was higher in the post-session than in the pre-session, indicating that greater variety in the notes used.

	MEAN	STD DEV	MEDIAN
Pre	101137.65	36301.93	96031.50
Post	51542.65	19238.46	49255.00
Z=3.40, p-value=0.001 (two-tailed)			

Table 4. V3 – Duration, total.

As it can be seen from Table 4, the average total duration was almost two times shorter in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	15.30	6.51	16.20
Post	18.13	6.00	18.45
Z = -1.75, p-value = 0.039 (one-tailed)			

Table 5. V5 – Percentages of medium intervals

As it can be seen from Table 5, the average medium intervals were more present in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	37.26	25.40	29.98
Post	15.59	12.32	11.93
Z = 2.65, p-value = 0.008 (two-tailed)			

Table 6. V8 – Dynamics Variation, soft.

As it can be seen from Table 6, on the average, “soft” dynamic was more than two times less present in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	27.31	9.11	28.06
Post	14.93	9.58	14.07
Z = 3.06, p-value = 0.002 (two-tailed)			

Table 7. V8 – Dynamics Variation, normal.

As it can be seen from Table 7, on the average, “normal” dynamic was more two times less present in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	35.44	24.67	34.40
Post	69.49	19.54	70.40
Z = -2.99, p-value = 0.003 (two-tailed)			

Table 8. V8 – Dynamics Variation, hard

As it can be seen from Table 8, on the average, “hard” dynamic was more than two times more present in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	0.89	0.26	0.86
Post	0.70	0.07	0.72
Z = 3.92, p-value = 0.001 (two-tailed)			

Table 9. V9 – Texture Richness

As it can be seen from Table 9, on the average, the musical excerpt played by the child is more “populated” in the post-session than in the pre-session (smaller values of this variable reflect more “populated” excerpt).

3.2 Musicians

	MEAN	STD DEV	MEDIAN
Pre	235991.60	111207.17	257527.50
Post	66262.70	31756.15	57980.50
Z= 2.60, p-value = 0.009 (two-tailed)			

Table 10. V3 – Duration, total

As it can be seen from Table 10 average total duration was more than three times shorter in the post-session than in the pre-session

	MEAN	STD DEV	MEDIAN
Pre	0.25	0.06	0.26
Post	0.35	0.07	0.38
Z = -2.29, p-value = 0.021 (two-tailed)			

Table 11. V4 – Ratio of different per total, intervals.

As it can be seen from Table 11, the average ratio of different intervals was higher in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	22.88	6.51	16.20
Post	36.05	22.17	31.60
Z = -2.09, p-value = 0.037 (two-tailed)			

Table 12. V7 – Rhythm variation, fast.

As it can be seen from Table 12, the average percentage of fast rhythm was almost twice higher in the post-session than in the pre-session.

	MEAN	STD DEV	MEDIAN
Pre	1.35	0.66	1.21
Post	0.66	0.04	0.68
Z = 2.80, p-value = 0.005 (two-tailed)			

Table 13. V9 – Texture Richness.

As it can be seen from Table 13, on average, the musical excerpt played by the child is almost twice more “populated” in the post-session than in the pre-session (smaller values of this variable reflect more “populated” excerpt).

4. DISCUSSION

Both musicians and non-musicians improvised on the keyboard. In general, it was observed that musicians, who were keyboard players, improvised by creating musical sequences based on their previously known pieces. Non-musicians, who were not familiar with the keyboard, played mostly in the form of gestures, such as upward and downward melodic movement, oscillation between two notes, continuous repetition of a pattern etc. (for more information see [6]).

The students' teachers were supportive of our sample's participation in the study, although their role in the process was not studied nor was the impact of children's participation measured in some way, when they returned to their 'normal' musical activities. A follow-up study may be able to explore this aspect, particularly teachers' perceptions of students' musical skills after having participated in such activities.

Webster in [29] suggests that certain divergent, imaginative skills among others, are also critical to creative thinking, such as musical extensiveness (the amount of time invested in creative imaging), flexibility (the range of musical expression in terms of dynamics, tempo, and pitch) and originality (the unusualness of expression). Our variables explored mostly variance in flexibility, between the pre and the post test.

4.1 Non-musicians

The pre tests and post tests for the players without any musical background show some differences, which could potentially be attributed to the use of the MIROR IMPRO system. More specifically, the standard deviation of the pitches used increases in the post test. This shows that the children start to be more adventurous and explorative in their choice of pitches, using a bigger range of the piano.

While the pitch standard deviation increases, the medium intervals also increase, compared to small and large intervals. This fact could indicate that children stop playing at random, in all the registers (i.e. they don't make huge intervals any more between high and low register), and they avoid repetitions of the same note (i.e. they don't use very small intervals any more). Instead they use intervals that are more or less typically used in music, of medium size.

Another interesting difference between pre and post test is that children play louder, which could indicate a stronger confidence in their playing, and at the same time use more notes in the same amount of time, to create a thicker texture. However, it is interesting that in the post test they also play for significantly less time. This could be seen in two ways: the first suggests that they play in a more focused way, given the above significant results, for less time, while the second proposes that they might be getting tired by the time they reach the post test, and decide to play less.

4.2 Musicians

Before discussing the results of the pianists, there is one fact that needs to be explained in order to better evaluate the results. Children with a background in piano playing, during the pre test, played mainly their known pieces from the piano lesson, and improvised less. Therefore, their pre test has a lot of features that we would normally find in known music. By the time the children reach the post test, all of the children leave the security of the known pieces and prefer to play more freely their own tunes. We believe that this can be attributed to the use of the MIROR IMPRO system, as there was scant interaction with the researcher throughout the study. The post test improvisation session is also significantly shorter. As they played more freely, it could be explained as more focused improvisational playing.

In the post test, their ratio of different per total intervals used is higher, which means that there is less repetition and more originality in their playing. At the same time, pianists play almost twice as fast as in the pre test, which could indicate more confident playing, especially as this is coupled with less soft and timid playing. Like the non-musicians, they also use more notes per unit of time, to create a thicker texture.

4.3 General discussion

The work described here is introducing a model for measuring creativity and creativity development. This model in essence defines and describes musical creativity via a set of attributes realised as distinct variables. While the utilization of a set of variables for describing creativity is something that most of the scholars in the field are employing (see section 1), the appropriateness of a particular variable can always be under question. For example, is it valid to hypothesise that different distribution in the (small, medium, large) range of intervals (that is variable V5) indicates musical creativity advancement? Of course in general, in the borderline cases this hypothesis holds true; for instance if a `interval(95, 3, 2)` tuple is becoming a `interval(40, 40, 20)`, the player is musically exploring a larger interval range and this seems to be consistent with musical creativity development in the literature. But in most in-between cases the extent to which changes in the variables indicates creativity development is open to discussion. In general the concept of creativity evades a clear definition and the issue of assessing creativity development is a challenging topic which can be dealt with in many ways. Future work will include fine tuning of variables, eventually defining significant limits on experimental basis.

5. CONCLUSION

This study firstly proposed a set of variables to measure creativity in music, based on existing literature on creativity assessment, and secondly investigated the development of creative music improvisations of young children, after playing an Interactive Reflexive Music System called the MIROR IMPRO. It drew on two examples, a group of 20 non-musicians and a group of 10 young pianists, and measured the development of their creativity in free improvisation before and after six sessions of using the system.

The non-musicians' post test free improvisations include higher diversity of musical vocabulary, more medium intervals and richer texture, indicating a sensible progress in improvisational creativity. At the same time, they include more intensity in dynamics, indicating more confident playing behaviour. Interestingly this seems also to be the case with the young pianists, as their post tests include similar features. In their post tests, however, there is more use of different intervals with less repetition and faster playing, even though they move away from the familiarity of their known piano pieces by this final session. It can be argued that the differences between pre and post tests observed in the musicians and non-musicians may be due to more than increased familiarity with the keyboard, that is the differences observed may be due to the use of the MIROR IMPRO system to develop creativity.

Further analysis of the in-between six sessions with MIROR IMPRO may provide more ideas regarding the precise variables that seem to shift across sessions in both groups of melodies. Future work also includes the direct comparison of the two groups, to investigate the differences between the young pianists and the children with no musical background, as well as the introduction of a control group to assess an eventual development of creativity without MIROR-IMPRO.

This would allow also fine tuning of the creativity assessment model and its testing in various new settings in order to improve the definition of the variables used, as well as the introduction of new related variables.

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